Insights into the
Problems, Progress, and Potential Solutions
for Sacramento River Basin Native Anadromous Fish Restoration

Spring-Run Chinook Salmon in Mill Creek, California (Photo by Dave Vogel)

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Prepared for:

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Executive Summary

Important native anadromous fish populations in the Sacramento River basin have experienced significant declines from historical levels. The reasons have been attributed to habitat degradation which usually encompasses a large variety of factors. **Despite enormous expenditures (*amounting to more than $1 billion*) in recent decades to reverse the decline in fishery resources through habitat restoration, increased flows, harvest restrictions, and other large-scale measures, significant upward trends in the fish population sizes have not been realized.** Even with considerable research on the topic, there remain major uncertainties on why reversals of those declines through many restoration actions are apparently not succeeding. **The key question is: Why are fisheries not recovering?**

Although many restoration plans attribute much of the decline in fish populations to habitat degradation and other "stressors", an adequate description of when the impacts have occurred on the fish populations is generally lacking. Examples include: dam construction, pollution, levee construction, diked wetlands, droughts and floods, unscreened diversions, south Delta diversions, general physical habitat degradation, predation, overharvest, and ocean conditions. This report examines many of these factors in time and space relative to the presence of each of the following life stages of the Sacramento Valley's anadromous fish: adult upstream migration, adult holding, spawning and incubation, fry and juvenile rearing, juvenile outmigration, and ocean conditions.

This report asserts that matching potential stressors on particular fish life phases in time and space should help to tease out the most important factors that have affected and continue to affect the fish populations. If definite stressors co-occur with the anticipated or known impact on specific fish life stages, it may indicate those stressors which are most important. Such an analysis could also suggest that some variables may have minimal importance. Based on analyses of readily-available reports, unpublished reports, gray literature, existing and new data, new study results, and the considerable professional experience of the author derived from working on fishery resource issues in the Central Valley over the past 30 years, numerous conclusions on those factors believed to be most important were developed. This report builds upon and integrates pertinent information to describe some of the more prominent problems for the fish populations and the corresponding progress toward alleviating those problems. Based on the resulting knowledge, this report poses potential solutions to the issues that have not yet been adequately addressed to achieve the ultimate goal of protecting and increasing the fish populations.

To prioritize the stressors currently impacting the Sacramento Valley's salmon, steelhead and green sturgeon populations and the actions that would most benefit those species, this report:

(1) examines the actions, projects, programs and conditions in the Sacramento River and tributaries upstream of the American River confluence and fish migration corridors in the Delta that have affected native anadromous fish resources;

(2) examines how recommended flow regimes in the State Water Resources Control Board's (SWRCB) recent Delta Flow Criteria report (SWRCB 2010) and the Department of Fish and Game's (DFG) Quantifiable Biological Objectives and Flow Criteria report for the Delta (DFG 2010) may be in conflict with and put at risk Sacramento River basin fishery resources; and

(3) provides recommendations for potential habitat restoration actions, water management projects, studies, or other measures that could be implemented in the near-term to provide additional benefits to fishery resources.

In most respects, and relative to other parts of the state, habitat conditions for anadromous fish in the Sacramento River and its tributaries have improved significantly over the past two decades as follows:

- Adult fish passage at many important upstream migration barriers has been significantly improved in recent decades and some major barriers have been completely eliminated, providing fish access to upstream areas essential for increased fish production.

- Thermal conditions in the rivers downstream of large dams have dramatically improved, yielding critically important protection of fish during highly temperature-sensitive periods in the life cycle.

- Remedial actions at an abandoned mine in the upper Sacramento River have largely eliminated a previous major source of fish mortality. Improved flow regimes in the rivers and streams have been implemented in recent decades allowing protection of fish during all the freshwater life phases.

- A massive program over the past two decades to screen unscreened or inadequately screened water diversions amounting to nearly $574,000,000 has resulted, or will soon result, in protection of fish at most diversion sites among which collectively divert a maximum of nearly 13,000 cfs.

- Watershed restoration programs to protect and enhance conditions on numerous tributaries have proliferated in recent times and are believed to have benefited fish habitats and overall watershed health.

Concurrently, freshwater and ocean harvest regulations have become increasingly restrictive over time, which has helped to protect depressed fish stocks. **Yet again, with all these expenditures and improvements, why are fisheries not recovering?**

While some opportunities remain in the Sacramento Valley (as described in this report) -- such as larger additions of gravel in important spawning reaches, juvenile fish rearing habitat improvements, and increased fish protection on smaller tributaries -- the available evidence indicates that conditions have become worse, not better, in the Delta during the most-recent decades. Despite the enormous, unprecedented actions to improve fish production in the upper

watersheds, there has been remarkable lack of focus or progress to fix the serious predation and habitat problems in the Delta, through which all Sacramento Valley anadromous fish must migrate. **Overall, predation is likely the highest source of mortality to anadromous fish in the Delta.** Despite well-known in-Delta problems of predation at a variety of locations for many years, very little progress -- in many instances, no progress -- has been made. Ironically, some measures implemented under the auspices of improving fish habitats have likely increased predation of anadromous fish in the Delta. The best available evidence indicates that in-Delta predation and habitat problems have gotten worse during recent decades.

Until significant progress is made on correcting the habitat problems and largely site-specific sources of native juvenile anadromous fish mortality in the Delta, it is likely that many of the benefits of upstream actions are, and will continue to be, negated. Although many studies over decades have demonstrated low survival of anadromous fish in the Delta, more such studies continue and are proposed, but are not oriented to determine site-specific in-Delta mortality sources. Re-focused study efforts in the Delta are sorely needed with the objective of locating and fixing fish mortality sites. Overall, until major predation problems in the Delta are corrected, difficulties for anadromous fish restoration will remain.

Other in-Delta and ocean-related actions also could significantly benefit the Sacramento Valley's salmonid populations. Appropriately-designed restoration of shallow-water rearing habitats in the Delta should be aggressively pursued because they would have a high probability of success. There may also be alternative ocean harvest methods that would increase salmonid populations by increasing the fecundity, or reproduction capacity, of the salmonids that spawn in the Sacramento Valley.

In addition, certain state agencies have recently recommended high reservoir releases (SWRCB 2010, DFG 2010) to attempt to ameliorate problems in the Delta. If implemented as proposed, without considering the risk of drastically reducing reservoir levels in some years, cold-water storage may be depleted, resulting in devastating impacts on anadromous fish egg incubation at critical times. Additionally, improperly timed high flows could provide unfavorable conditions for mainstem rearing fish. **Implementation of the flows described in the SWRCB and DFG reports would have a high potential of largely undoing recent decades' progress in restoring conditions for salmonids in the Sacramento Valley.** Clearly, careful examination of the impacts of large flow increases is warranted by thorough modeling studies to determine the effects on water supplies, thermal impacts to fish, and alteration of instream habitats. Unfortunately, little progress has been made on parsing out the various and most important factors related to flow that may influence fish survival. The causal effects of flow and fish survival relationships in the Sacramento River have been difficult to determine because of complex inter-relationships with numerous variables associated with flow. Focused studies to ascertain those relationships are needed. Furthermore, development of opportunities to reduce site-specific Delta stressors through non-flow measures is warranted and overdue.

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1.0 Introduction

Important native anadromous fish populations in the Sacramento River basin (Figure 1) have experienced significant declines from historical levels. This report examines: 1) the actions, projects, programs and conditions in the Sacramento River and tributaries upstream of the American River confluence and fish migration corridors in the Delta that have affected native anadromous fish resources; 2) how recommended flow regimes in the State Water Resources Control Board's (SWRCB) recent Delta Flow Criteria report (SWRCB 2010) and the Department of Fish and Game's (DFG) Quantifiable Biological Objectives and Flow Criteria report for the Delta (DFG 2010) may be in conflict with and put at risk Sacramento River basin fishery resources; and 3) recommends potential habitat restoration actions, water management projects, studies, or other actions that could be taken in the near term to provide additional benefits to fishery resources.

The most prominent anadromous fish declines have occurred with the winter-run Chinook salmon (*Oncorhynchus tshawytscha*) (a federally-listed endangered species), spring-run Chinook salmon (a federally-listed threatened species), steelhead trout (*O. mykiss*) (a federally-listed threatened species), green sturgeon (*Acipenser medirostris*) (a federally-listed threatened species), as well as late-fall-run and fall-run Chinook salmon (both Candidates for Endangered Species Act listings). Although other native fish species are also essential, this report focuses on the foregoing populations because of their threatened or endangered status, their potential importance to sport and commercial fisheries, and their overall intrinsic value to the ecosystem and society. Also, it can be argued that if many of the freshwater/riverine habitat needs for these species are met, the habitats for other important native fish will be satisfactory.

To counter the downward trend in California's Central Valley fishery resources, restoration has been a major focus for many State and federal agencies and stakeholder groups in recent decades. However, despite major, unprecedented efforts (***amounting to more than \$1 billion***)[1] to increase these fish populations through habitat restoration, increased flows, harvest restrictions, and other large-scale measures, significant upward progress in the fish population sizes have not been realized. This begs the question: "***Why not?***"

One might believe that an investigative answer to this question must be embodied within the crowded field of existing reports, study results, data, hypotheses, and opinions on the factors that have contributed to the declines in Sacramento River basin anadromous fish populations (many, but not all, of which are described in this report). Yet, despite considerable research on the topic, there remain major uncertainties on why reversal of those declines through many restoration actions are, based on the author's review of existing literature and personal experience,

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[1] The Central Valley Project Improvement Act program alone has amounted to nearly \$1 billion. Source: Cummins, K., C. Furey, A. Giorgi, S. Lindley, J. Nestler, and J. Shurts. 2008. Listen to the river: an independent review of the CVPIA Fisheries Program. Prepared for the U.S. Bureau of Reclamation and the U.S. Fish and Wildlife Service. December 2008. 51 p. plus appendices.

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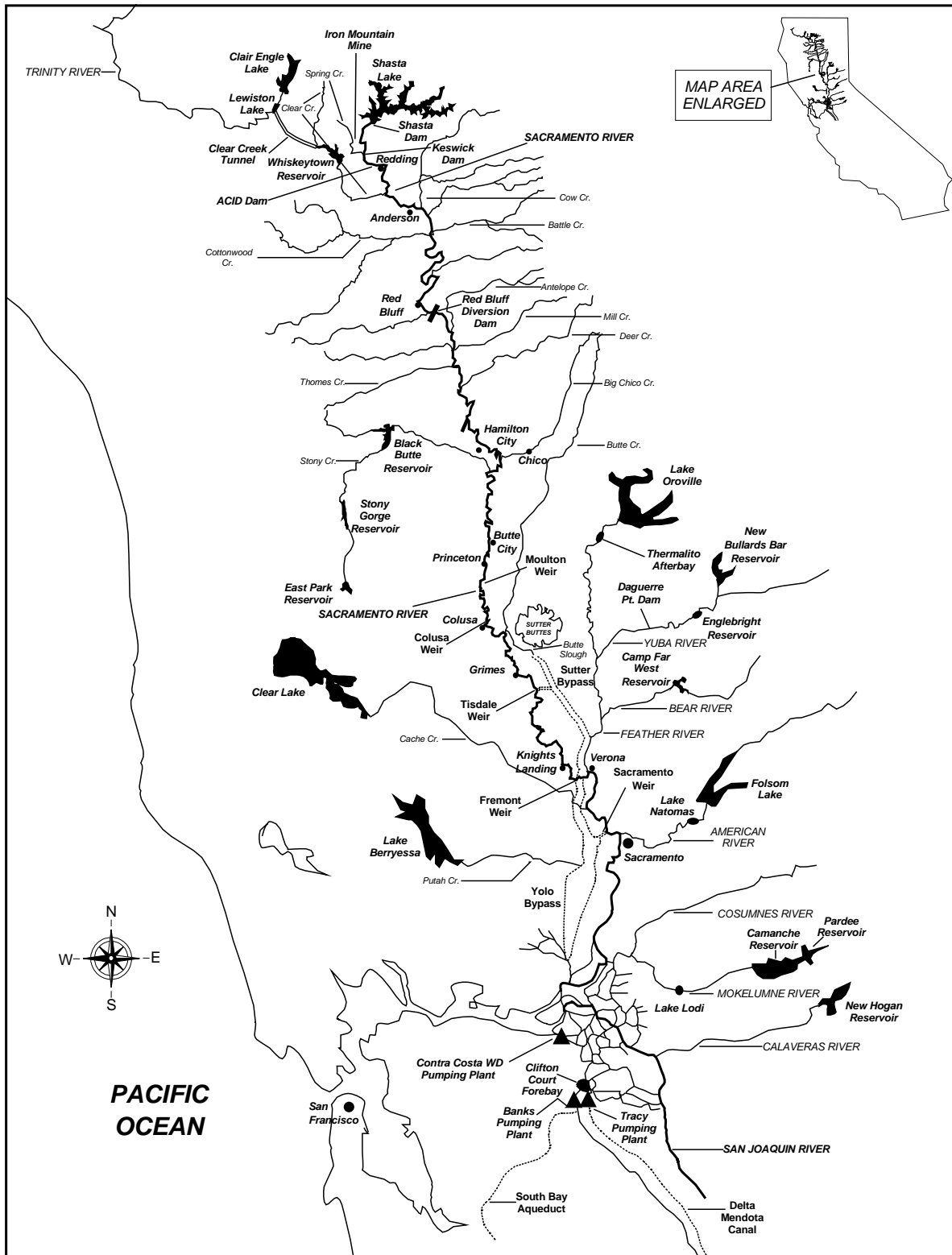
Figure 1. The Sacramento River basin, tributaries, and Delta with important features mentioned in this report.

apparently not succeeding. This report will focus on this issue, and provide recommendations on other actions to benefit anadromous fish populations in the Sacramento Valley watershed and in the Delta. Natural environmental factors (*e.g.*, drought, floods, ocean conditions) can and do play a major role in cyclical fish population declines, and those non-anthropogenic causes are also discussed here. Nevertheless, native fish populations have evolved to adapt to natural perturbations. As pointed out by the U.S. Fish and Wildlife Service (USFWS), "... *populations in healthy habitats typically recover within a few years after natural events. The decline of fish populations has continued through cycles of beneficial and adverse natural conditions, indicating the need to improve habitat.*" (USFWS 1997).

The term "habitat degradation" is a universal phrase used in many documents to describe a "stressor" or "limiting factor" contributing to the decline of fish populations. Habitat degradation usually encompasses a large variety of factors[2] and is often presented as all-encompassing lists of known or suspected causes of fishery resource declines. The following are example stressors which are commonly cited as contributing to the declines:

- Dam construction
- Pollution
- Levee construction
- Diked wetlands
- Droughts and floods
- Unscreened diversions
- General physical habitat degradation
- South Delta exports
- Predation
- Overharvest
- Ocean conditions

Notably, such lists are frequently out of context in terms of specifically **when** the impacts have occurred on fish populations; the habitat degradation discussion in many existing documents gets blended between eras. For example, in describing the reasons for the declines of Central Valley anadromous fish, the USFWS states:

> "*Habitat degradation is the primary cause of these declines.*" ... "*Habitat quality and quantity have declined due to construction of barriers to migration and levees, modification of natural hydrologic regimes by dams and water diversions, elevated water temperatures, and water pollution.*" (USFWS 1997).

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[2] E.g., Myers *et al.* (1998), citing Clark (1929), Needham *et al.* (1940), Reynolds *et al.* (1993), and Fisher (1994), state: "*Habitat degradation due to dams, water diversions, and placer mining, as well as past and present land-use practices have severely reduced the range and number of spring- and winter-run Chinook salmon and to a lesser extent fall and late-fall runs.*"

Another example, specific to winter-run Chinook salmon, is the 1997 National Marine Fisheries Service (NMFS) recovery plan for the species which states:

> "*The decline of the winter-run Chinook population resulted from the cumulative effects of degradation of spawning, rearing and migration habitats in the Sacramento River and Sacramento-San Joaquin Delta. Specifically, the population's decline was most likely precipitated by a combination of: 1) excessively warm water temperatures from releases at Shasta Dam, 2) hindering and blocking free passage of juveniles and adults at the Red Bluff Diversion Dam, 3) export of vast quantities of water from diversions in the south Delta, 4) heavy metal contamination from Iron Mountain Mine, and 5) entrainment to a large number of unscreened and poorly screened diversions.*" (NMFS 1997)

Yet another example is provided in the status review on the spring-run Chinook ESU (Evolutionarily Significant Unit), where NMFS concluded:

> "*Habitat problems were considered by the BRT [Biological Review Team] to be the most important source of ongoing risk to this ESU. Spring-run fish cannot access most of their historical spawning and rearing habitat in the Sacramento and San Joaquin River Basins (which is now above impassable dams), and current spawning is restricted to the mainstem and a few river tributaries in the Sacramento River. The remaining spawning habitat accessible to fish is severely degraded. Collectively, these habitat problems greatly reduce the resiliency of this ESU to respond to additional stresses in the future. The general degradation of conditions in the Sacramento River Basin (including elevated water temperatures, agricultural and municipal diversions and returns, restricted and regulated flows, entrainment of migrating fish into unscreened or poorly screened diversions, and the poor quality and quantity of remaining habitat) has severely impacted important juvenile rearing habitat and migration corridors.*" (Myers *et al.* 1998)

These foregoing generalizations are typical of most documents[3] describing anadromous fish declines. There is commonly a pattern evident where a particular premise regarding "stressors" on anadromous fish has been posed in early documents, and is subsequently propagated throughout later documents without recognition or acknowledgement that site-specific conditions have changed (for better or worse) during more-recent times. In addition, without a reasonable characterization of specific impacts to fish, fish restoration programs become complicated due to potential misallocation or misdirection of limited resources away from the most important problems.

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[3] An exception is the 2009 NMFS Draft Recovery Plan for winter- and spring-run Chinook and steelhead which will be discussed in this report.

In an attempt to avoid the pitfalls of earlier documents and to more-appropriately characterize when various stressors have exerted their impacts on fish, this report focuses on the recent decades, after large Central Valley dams had been constructed. The theme here is intended to provide insight and attempt to answer the question: *What has happened since large dam construction to increase or decrease the effects of stressors on native anadromous fish?*[4] Earlier periods are not discussed in any detail in this report because meaningful fish population data are lacking or irrelevant. Additionally, prior to major dam construction, there were key factors that adversely impacted fish, but are no longer applicable today. For example, it is known that railroad construction upstream of the present-day Shasta Dam site adversely impacted historical salmon runs and their habitats prior to dam construction (Hanson *et al*. 1940) and historical placer mining for gold in the Feather/Yuba basins caused enormous deleterious effects on fish habitats (HDR/SWRI 2007). Mining debris "totally obliterated" the Yuba River's former channel (Kelley 1989) and covered the Yuba River's salmon spawning beds, with debris covering the river's floodplain up to one and one-half miles from the river with sediments five to ten feet thick. (Yoshiyama *et al*. 1998.) Additionally, in 1919, it was recognized that severe overfishing on salmon stocks was depleting the fish runs and, for the six prior years, the numbers of spring-run Chinook reaching Baird Hatchery on the McCloud River upstream of the present-day Shasta Dam site were so few, egg take from those fish was not feasible (Scofield 1919). Clark (1929) reported that the salmon fisheries were "greatly depleted". Prior to Shasta Dam, Anderson-Cottonwood Irrigation District (ACID) dam in Redding was a partial or nearly complete barrier to upstream migrating spring-run Chinook for 10 years (1917 – 1927) (McGregor 1922, as cited by Moffett 1949) which was likely devastating to the population. Construction of large dams in the Central Valley resulted in loss of anadromous fish habitats in upstream areas that, arguably, cannot be easily remedied. However, as best as researchers could determine in 1949, it was estimated that because Shasta Dam created numerous beneficial effects for salmon in the river downstream of the dam (*e.g.*, temperatures), those improvements had compensated for the loss of spawning habitats above the dam (Moffett 1949). After large dam construction, there were periods when anadromous fish populations were large, indicating conditions for fish in downstream areas after dam construction were suitable to create large fish runs.

In an effort to investigate the reasons for fish population declines, this document analyzes readily-available reports, unpublished reports, "gray literature", existing and new data, new study results, and the considerable professional experience of the author derived from working on fishery resource issues in the Central Valley over the past 30 years (see Exhibit A). Some information presented in this report addresses issues affecting anadromous fish which have received insufficient or no attention (in the author's opinion). To determine the mechanistic causes of the dramatic declines in many fish populations in more-recent times, the major (but not all) anthropogenic changes that occurred during the post-large-dam construction period are evaluated in chronological context.

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[4] The topic of potential re-introduction of native anadromous fish upstream of major Central Valley dams is not discussed in this report. Examination of this issue is being pursued through a recent National Marine Fisheries Service Biological Opinion on the operations of the federal Central Valley Project.

This report examines the location, chronological and seasonal timing, and general magnitude of anthropogenic factors affecting fish species life stages. In particular, it is postulated here that matching potential stressors on particular fish life phases in time and space should help to tease out the most important factors affecting the fish populations. If there are specific stressors that co-occur with the anticipated or known impact on specific fish life stages in a spatiotemporal context (including a recognized time-lagged impact), it may indicate those stressors which are most important. Conversely, it could suggest some variables may have minimal importance. Because much of the relevant data for such analyses are often sparse or lacking, detailed comparisons are challenging. Additionally, environmental "noise" (or variation from random events) and autocorrelation (correlation between variables) adds to the difficulty in evaluation of cause-and-effects on fish (Lehman 1989) as do indirect effects of stressors.

Ultimately, the intent here is to build upon and integrate pertinent information to describe some of the more prominent problems for the fish populations, progress toward alleviating those problems, and, with that knowledge, to pose potential solutions to the issues that have not yet been adequately addressed to achieve the ultimate goal of protecting and increasing the fish populations.

2.0 Existing Fishery Resource Restoration Plans

There is no shortage of fishery resource restoration plans for the Sacramento River basin. The following is a short list of examples:

- **Fish and Wildlife Problems and Opportunities in Relation to Sacramento River Water Developments.** 1972. California Department of Fish and Game. (R. Haley, E.S. Smith, and W.F. Van Woert). 41 p.

- **The Upper Sacramento River – Its Problems and a Plan for its Protection.** 1975. California Department of Fish and Game. (J.W. Burns and others). 17 p.

- **Sacramento River System Salmon and Steelhead Problems and Enhancement Opportunities.** 1987. R.J. Hallock. Report to the California Advisory Committee on Salmon and Steelhead Trout. 92 p.

- **Upper Sacramento River Fisheries and Riparian Habitat Management Plan.** January 1989. California Resources Agency. 158 p.

- **Central Valley Salmon and Steelhead Restoration and Enhancement Plan.** April 1990. California Department of Fish and Game (F.L. Reynolds, R.L. Reavis, and J. Schuler). 115 p.

- **Restoring Central Valley Streams: A Plan for Action.** April 1993. California

Department of Fish Game (F.L. Reynolds, T.J. Mills, R. Benthin, and A. Low). 184 p.

- **Steelhead Restoration and Management Plan for California.** February 1996. California Department of Fish and Game (D. McEwan and T.A. Jackson). 234 p.

- **Sacramento-San Joaquin Delta Native Fishes Recovery Plan.** 1996. U.S. Fish and Wildlife Service.

- **Proposed Recovery Plan for the Sacramento River Winter-Run Chinook Salmon.** August 1997. National Marine Fisheries Service

- **Battle Creek Salmon and Steelhead Restoration Plan.** January 1999. Battle Creek Working Group. 118 p. plus appendices.

- **Final Restoration Plan for the Anadromous Fish Restoration Program: A Plan to Increase Natural Production of Anadromous Fish in the Central Valley of California.** January 9, 2001. U.S. Fish and Wildlife Service. 106 p. plus appendices.

- **Public Draft Recovery Plan for the evolutionarily significant units of Sacramento River winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the distinct population segment of Central Valley steelhead.** National Marine Fisheries Service. October 2009. 254 p. plus appendices.

- **Bay Delta Conservation Plan.** Working Draft. November 18, 2010. 1,148 p.

The relatively recent large-scale response and enthusiasm toward fish and fish habitat restoration have been dramatic in the Central Valley. For example, as recently as 1990, the California Department of Fish and Game (DFG) reported that its agency was the only fishery resource agency with a significant fisheries enhancement program (Reynolds *et al.* 1990). At that time, DFG was using special bond funds and annual appropriations to create anadromous salmonid spawning and nursery habitats. Today, the fish population/habitat restoration programs and funding sources among the various state and federal agencies and other groups probably number in the dozens. Universally, these existing plans focus on specific actions recommended under the assumption that implementation will improve habitats and, therefore, result in measureable increases in the fish populations. Although many of the early fish restoration plans are somewhat general in determining potential restoration actions, the recent draft NMFS recovery plan for winter- and spring-run Chinook and steelhead identifies hundreds of possible actions. The recovery plan also differs from many earlier plans by ranking the relative importance of fish population restoration actions. Unfortunately, most fish restoration plans problematically result in a "wish list" for numerous actions without characterization of how they will measurably affect fish. One of the problems of simply listing of all potential factors is that, often, the easiest actions to implement are the ones chosen, instead of the most important factors. Resources will always be limited and many existing plans do not characterize which actions, when

implemented, will result in the greatest benefits to fish or ignore the dilemma of limited resources and jurisdictional or legal impediments to their timely implementation.

This report, although not comprehensive, is intended to supplement, not supplant, these existing plans for native anadromous fish restoration.

3.0 Anadromous Salmonid and Green Sturgeon Biology

3.1 Selected Important Habitat Considerations for Anadromous Fish

Because of the importance in understanding how potential factors may have affected Sacramento River basin native anadromous fish populations, the following is a description of the relevant habitat attributes necessary to support their freshwater life phases. The seasonal presence or absence of specific life phases at specific locations is meaningful to determine the relative effects of the anthropogenic factors considered in this report.

The following discussion is organized by salmonid and green sturgeon life phases:

- Adult upstream migration
- Adult holding
- Spawning and incubation
- Fry and juvenile rearing
- Fry and juvenile outmigration
- Ocean rearing

These life phases are used in a conceptual model provided later to characterize how various factors may, or may not, affect the species.

3.1.1 Adult Upstream Migration

Sufficient instream flows and suitable water temperatures are necessary to attract salmonids into the Sacramento River and its tributaries prior to spawning activities. These required flow levels in the lower Sacramento River have never been quantified through scientific investigations but there is no evidence that this parameter has ever limited anadromous fish production in the Sacramento River and its largest tributaries. However, for the smaller tributaries, suitable conditions are usually present only from late fall to early spring when ambient air temperatures cool the tributary water down to acceptable levels for salmon. Tributary flows at the confluence with the Sacramento River or Feather/Yuba rivers and riffles in the stream must be high enough to allow fish physical access into the stream.[5] A general rule is that salmon require

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[5] This circumstance can occur either as a result of storm events, increased reservoir releases, reduction in riverine

approximately one-half foot of flowing water, at a minimum, for passage over riffles. An established run of anadromous fish into a stream explicitly requires that the returning spawning fish were originally hatched in the stream several years prior to their return. This fact is often overlooked when an intermittent, sporadic appearance of some fish in a traditionally non-anadromous stream occurs, which is a phenomenon more likely attributable to "strays" rather than progeny returning to their natal stream.

Green sturgeon have been documented throughout vast regions of the Pacific, from the Bering Sea to Ensenada, Mexico (Moyle, 2002), but can only be found in relatively condensed and specialized regions of the Pacific Northwest when they return to freshwater to spawn. Moyle *et al.* 1994 stated: "*They are known to spawn in three Pacific river drainage systems: The Rogue River in Oregon and the Sacramento and Klamath river systems in California.*" (as cited by Erickson *et al.* 2002). Although the exact details of environmental factors that draw green sturgeon to spawning grounds are not known, variables include, but are not limited to, water temperature, turbidity, availability of food, and topography of the river beds. As with anadromous salmonids, green sturgeon also require sufficient flow for upstream migration, but the appropriate flows have never been identified. However, this factor has not been assumed to limit green sturgeon migration.

3.1.2 Adult Holding Habitat

Adult anadromous fish require habitat where the fish can reside prior to and during spawning activities. These areas provide resting habitat for the fish during the final stages of gamete maturation. Holding generally takes place in the deeper areas of a river such as pools or behind instream structures; this also provides the fish some level of protection from predators (and poachers). The residency time for fish in these holding areas can vary from one or two weeks (exhibited by fall and late-fall Chinook salmon), to as long as several months, as demonstrated by winter-run and spring-run Chinook. Green sturgeon also require particular types of holding habitat prior to spawning. In particular, it appears that sturgeon prefer deep (*e.g.*, 30 feet) pools for holding habitat.

3.1.3 Spawning and Egg Incubation Habitat

The basic components of spawning behavior are similar for most salmonids. Salmonids select sites in the river or stream where suitable water velocities, depth, and substrate are present. Results of extensive research on Chinook salmon and steelhead spawning habitat requirements will not be detailed in this report but are readily available to accurately define substrate particle sizes for optimal redd construction and egg development conditions. Sufficiently high water velocities are necessary to provide inducement to spawning salmon and interstitial flow though salmon redds for egg incubation (Vogel 1983) (*e.g.*, 1.5 to 2.5 feet/second a half a foot above the riverbed).

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diversions, or a combination of these factors.

Incubating salmonid eggs cannot tolerate large quantities of fine particles (*i.e.*, sand and silt) within the redd. Once laid in the river gravels, eggs and larvae must receive oxygenated water of suitable temperature and free from toxic contaminants. The delivery rate of oxygen to the egg is a function of intragravel water velocity and the concentration of oxygen in the water. Heavy siltation on the eggs can reduce intragravel water flow to lethal levels (Wickett 1954). The principal benefits resulting from adequate water velocity to incubating salmonid embryos are the concurrent functions of transferring sufficient dissolved oxygen to the surface of the egg membrane and the removal of the egg's metabolic waste products (Brannon 1965). Lisle and Eads (1991) state that the threshold of concern for fine sediment content in salmonid spawning gravels varies between species and grain size of fine sediment, but most commonly is around 20 percent. The DFG's threshold of concern for fines in spawning gravel is 15 percent (Vogel 1993a).

Water temperature is a significant factor limiting salmon production within their natural range. The most water temperature-sensitive freshwater phase for salmonids occurs during egg incubation (Figure 2). The tolerances of steelhead eggs and larva are similar. The relatively narrow tolerance at increased water temperatures has been a high priority issue on many Central Valley rivers and streams for decades.
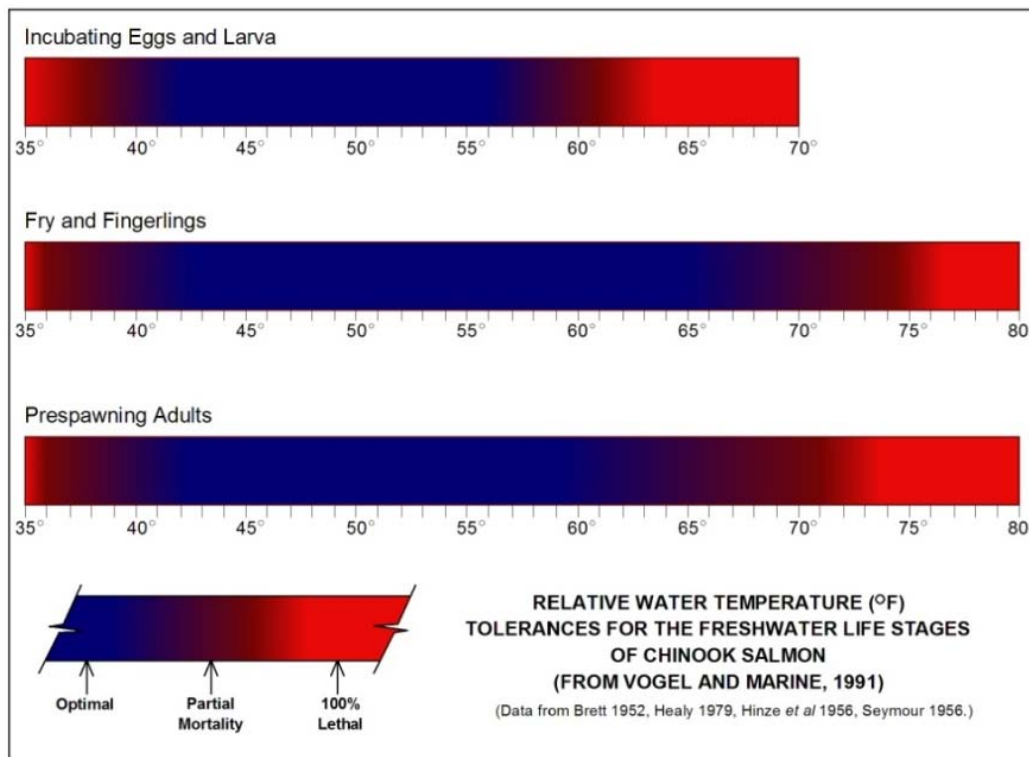
Figure 2. Relative water temperature (^{o}F) tolerances for the freshwater life stages of Chinook salmon (from Vogel and Marine 1991).

Peak green sturgeon spawning generally occurs between mid-April and mid-June (Moyle 2002) when temperatures are ideal. Based on similarities to white sturgeon, and through extensive artificial spawning and egg incubation of green sturgeon, it was determined that temperature of 17-18° C (63-64° F) may be the higher limit of favorable thermal conditions for green sturgeon embryos and that temperatures around 11° C (52° F) can result in a decreased hatch rate as well as smaller length of hatched embryos as compared to a water temperature of 14°C (57° F) (Van Eenennaam *et al.* 2005). However, sturgeon have been found spawning in temperatures as low as 8° C (47° F) (Moyle 2002). Along with temperature, it is generally believed that preferable spawning sites are found in depths of greater than 3 meters (9.75 feet) and in relatively fast water (Moyle 2002). After spawning, adult fish may remain in the river until late fall or early winter before returning to the ocean.

3.1.4 Fry and Juvenile Rearing

Anadromous salmonid fry are particularly vulnerable at emergence and the initiation of feeding because the fish leave the secure, low-energy environment in the interstices of streambed gravels and enter the high-energy environment of the river. Many researchers believe that in an "ideal" natural environment, the general behavioral tendency after emergence is for salmonids to select very quiet shallow water over a variety of substrates. When fish grow, they continually shift their distribution to deeper, faster water. When young salmonids move from spawning areas to rearing areas, complex factors may cause downstream or upstream movements (or both) which may be environmentally and genetically controlled. Many factors may interact to produce these complex instream movements (Vogel 1993b).

Rearing salmonids require a constant food supply from "drift" organisms. The food of young salmon is principally composed of a wide variety of terrestrial and aquatic insects (Moyle 1976). Based on an extensive field research project performed from January through June 1981 in the Sacramento River downstream of Red Bluff, it was concluded that young Chinook salmon: 1) were mainly insectivorous, 2) fed primarily on Chironomidae (a large group of insects), and 3) selected food items that were drifting or floating, not non-drifting benthic forms (Schaffter *et al.* 1982). An earlier study of the food habits of young Chinook salmon throughout the Sacramento River found that larval or adult insects were the principal diet items for salmon during all seasons and at all locations sampled (Rutter 1903). Young spring run in Deer and Mill creeks rear for 9 - 10 months feeding on drift insects (Moyle *et al.* 1989). Sasaki (1966) found that among those salmon he examined in the lower Sacramento River, lower San Joaquin River, and the Delta (which had food in their stomachs), 74 percent had insects in their diet. *Neomysis* (opossum shrimp) was of secondary importance in the lower Sacramento River and both *Neomysis* and *Corophium* (amphipod) were of secondary importance to insects in the lower San Joaquin River. Scofield (1913), as cited by Sasaki (1966) also found insects to be the most important food item for young Chinook salmon. Within the Delta, terrestrial insects are the most important food item for young Chinook salmon (Moyle 1976). Some recent information concerning the impacts of pollutants on salmonid food organisms will be briefly discussed in this report.

Young steelhead consume a diet similar in composition to that of young Chinook salmon. The fish primarily ingest insects during their freshwater life phase. Because steelhead rear for longer periods and grow to larger sizes than Chinook in freshwater, juvenile steelhead are more dependent on larger and more abundant food resources (USFWS 1995). Food organisms of steelhead include aquatic and terrestrial insects, crustaceans, chironomid larvae, *Neomysis mercedis*, amphipods, and larval fishes.

Instream habitat complexity is extremely important for fry and juvenile Chinook salmon and steelhead. Habitat complexity provided by instream structure such as large woody debris (*e.g.*, fallen trees and rootwads) and large rocks or boulders provide young salmonids areas to rear and protection from predatory fish. Proximity of a low-velocity area (for a fish's holding position) to a high velocity area (for feeding), or the proximity of predators and competitors can have overriding influences on how salmonids take up residency at particular locations in a river. The occupation of a sheltered location in the stream near high velocities (and consequently substantial food drift) minimizes the energy expenditure associated with the fish maintaining position in the currents while maximizing food availability. The fish must do so while avoiding predators (*e.g.*, bass, pikeminnow, or birds) and minimizing interactions with competitors. Cover habitat for rearing Chinook has been described as the characteristics associated with water depth, water turbulence, large-particle substrates, overhanging or undercut banks, overhanging riparian vegetation, woody debris, and aquatic vegetation. The needs of Chinook salmon for cover habitats vary diurnally, seasonally, and by size of the fish (Vogel 1993b); steelhead habitats have been similarly described.

Little is known about movements, habitat use, and feeding habits of young green sturgeon. After spawning, green sturgeon larvae average between 8-19 mm in length (Moyle 2002) depending on temperature and amount of nutrients provided to the eggs (Van Eenennaam *et al.* 2005). Juveniles and adults are reported to feed on benthic invertebrates, including shrimp and amphipods, and small fish (70 FR 17386). As with white sturgeon, juvenile green sturgeon in the Delta have been reported to have a diet principally composed of *Corophium* and *Neomysis* (Radtke 1966). *Corophium* was the only item found in the diet for young sturgeon in the size range of 19 - 39 cm in length during the fall. During the spring and summer, both food items were present in the diet. Juvenile and adults are generally considered to be benthic feeders, however it has been documented that juveniles eat small fish as well. In the San Francisco Estuary region they will feed on opossum shrimp and amphipods, (Moyle 2002).

3.1.5 Downstream Migration

Juvenile salmon downstream migrations tend to occur in groups and pulses; these pulses may correspond to increased flow events. For example, USFWS salmon research by Kjelson *et al.* (1982) and Vogel (1982, 1989) reported increased downstream movements of fry Chinook corresponding to increased river flows and turbidity, respectively. Young Chinook salmon may migrate downstream from Sacramento River tributaries and the mainstem river reaches into the Sacramento-San Joaquin Delta as pre-smolts (fry and parr) or as smolts. EPA (1994) describes a

smolt as "... *a salmon in the process of acclimating to a change from a fresh water environment to a salt water environment. This occurs when young salmon migrate downstream through the Delta to the ocean.*" Although this definition is accurate, it is simplistic because there are complex morphological, physiological, and behavioral changes associated with the transformation of parr salmon to smolt salmon.

The many variables and consequent interactions associated with the migratory behavior of young salmon are complex and not well understood (Kreeger and McNeil 1992). Abiotic factors which may have primary influence on young salmon migration include photoperiod/date, water temperature, and flow. Other abiotic or biotic factors which may affect migration include barometric pressure, turbidity, flooding, rainfall, wind, species, stock (*e.g.*, fall-run or spring-run), life history stage, degree of smoltification, parental origin (*e.g.*, hatchery or wild), size of juveniles, location (*e.g.*, distance from the ocean), food availability, etc. (Burgner 1991, as cited by Kreeger and McNeil 1992).

Little is known about freshwater movements of green sturgeon but the fish are believed to migrate out to sea before the end of the second year of life, although they may leave as young at one year. However, before reaching this stage, juvenile green sturgeon remain in estuaries and bays, but begin to travel greater distances the larger they become (Moyle 2002).

3.2 Chinook Salmon Life Stage Periodicity

The life span of Chinook salmon may range from two to seven years, but is generally two to four years for Central Valley salmon. Chinook salmon reside most of their life in the ocean (*e.g.*, one and a half to five years) where they rear before maturing and returning to their natal streams to spawn. Their life span and the timing of spawning migrations are primarily genetically controlled. Chinook salmon die upon completion of spawning (Vogel and Marine 1991).

Each of the freshwater life stages (*i.e.*, spawning adult, egg and larva, fry and juvenile) may be found in the upper Sacramento River every month of the year. The actual timing of each of the life stage events varies somewhat from year to year and is primarily a function of weather, river flows, and water temperature (Vogel and Marine 1991). This high degree of variation in life history exhibited by Central Valley Chinook salmon is a function of the differences among the four main seasonal races, fall, late-fall, winter, and spring runs. There is considerable variation within these races for traits such as spawn timing, juvenile riverine residency, and outmigration timing.

3.2.1 Fall-Run Chinook Salmon

Migration of adult fall-run Chinook salmon into the Sacramento River basin begins in July, peaks during October, and ends in December. Spawning occurs in October through December. After egg incubation, fry emergence from the river gravels occurs during January through February. Downstream movement of fry can begin as early as January during winter storm

events through the winter months and smolt emigration occurs during April through June.

3.2.2 Late-Fall-Run Chinook Salmon

The principal late-fall-run Chinook migration into the Sacramento River occurs during mid-October through mid-April. Spawning occurs from January through mid-April and egg incubation occurs from January through June. The principal spawning habitat for late-fall-run Chinook is found in the upper Sacramento River in river reaches downstream from Keswick Dam. Rearing and downstream migration or dispersal of juvenile fish from upstream to downstream areas can occur from April through December. The primary movement of smolts through the Delta is believed to occur during the winter months.

3.2.3 Winter-Run Chinook Salmon

Winter-run Chinook salmon spend 1–3 years in the ocean. Adult winter-run Chinook salmon leave the ocean and migrate through the Delta into the Sacramento River from December through July with peak migration in March (Moyle 2002). Many of the early-arriving fish hold for extended periods in the river prior to spawning. Spawning occurs from mid-April to early-August with egg incubation occurring from mid-April to September (Vogel and Marine 1991). The primary spawning habitat in the Sacramento River is above Red Bluff Diversion Dam (RBDD) at river mile (RM) 243, although spawning has been observed downstream as far as RM 218. Spawning success below RBDD may be limited primarily by warm water temperatures (Hallock and Fisher 1985).

Downstream movement of winter-run Chinook salmon fry begins in August, soon after emergence from the gravel. The abundance of juveniles moving downstream peaks at Red Bluff in September and October (Vogel and Marine 1991) but the lower river reaches are generally too warm for fish to enter the Delta at that time. Juvenile Chinook salmon move downstream from spawning areas in response to many factors, which may include inherited behavior, habitat availability, flow, competition for space and food, and water temperature. The numbers of juveniles that move and the subsequent timing are highly variable. Storm events and the resulting high flow and turbidity along with cooler water temperatures appear to trigger downstream movement of substantial numbers of juvenile Chinook salmon. In general, juvenile abundance in the Delta increases in response to increased Sacramento River flow (USFWS 1995). The peak movement of juvenile winter-run salmon into the Delta occurs during the winter months, but winter-run Chinook salmon smolts (*i.e.*, juveniles that are physiologically ready to enter seawater) may migrate through the Delta and bay to the ocean from November through May (Yoshiyama *et al.* 1998). The Sacramento River channel is the main migration route through the Delta. However, the Yolo Bypass also provides significant outmigration passage during higher flow events. During winter in the Sacramento Valley, juveniles rear on seasonally inundated floodplains. Sommer *et al.* (2001) found apparent higher growth and survival rates of juvenile Chinook salmon that reared in the Yolo Bypass floodplain than in the mainstem Sacramento River.

3.2.4 Spring-Run Chinook Salmon

Spring-run Chinook was believed historically to be the most numerous salmon stock in the Central Valley prior to construction of many Central Valley dams, which blocked access of the fish to their historical habitats. Only the main-stem Sacramento and some of its tributaries support remnant spawning runs. Adult spring-run Chinook salmon enter the mainstem Sacramento River from March through September, with the peak upstream migration occurring from May through June (Yoshiyama *et al.* 1998). Spring-run Chinook salmon are sexually immature during upstream migration, and adults hold in deep, cold pools near spawning habitat until spawning commences in late summer and fall. Spring-run Chinook salmon spawn in the upper reaches of the mainstem Sacramento River (downstream of Keswick Dam) and tributary streams (USFWS 1995), with the largest tributary runs occurring in Butte, Deer, and Mill creeks (Yoshiyama *et al.* 1998), the Feather River downstream of Oroville Dam, and the Yuba River downstream of Englebright Dam. Spawning typically begins in late August and may continue through October. Juveniles emerge in November and December in most locations, but may emerge later when water temperature is cooler. Newly emerged fry remain in shallow, low-velocity edgewater (DFG 1998).

Juvenile spring-run Chinook salmon typically spend up to one year rearing in fresh water before migrating to sea as yearlings, but some may migrate downstream as young-of-year juveniles. Rearing takes place in their natal streams, the mainstem of the Sacramento River, inundated floodplains (including the Sutter and Yolo bypasses), and the Delta. Based on observations in Butte Creek and the Sacramento River, young-of-year juveniles typically migrate from November through May. Yearling spring-run Chinook salmon migrate from October to March, with peak migration in November (S.P. Cramer and Associates 1997, Hill and Webber 1999). Downstream migration of yearlings typically coincides with the onset of the winter storm season (Moyle *et al.* 1989), and migration may continue through March (DFG 1998).

3.3 Steelhead Life Stage Periodicity

Steelhead/rainbow trout have one of the most complex life histories of any salmonid species, exhibiting both anadromous and freshwater resident life histories. Freshwater residents typically are referred to as rainbow trout, and those exhibiting an anadromous life history are called steelhead (NMFS 1998). The steelhead trout is an anadromous strain of rainbow trout exhibiting a general life cycle similar to Chinook salmon except that not all adults die after spawning and juveniles rear for longer periods in freshwater before migrating to the ocean. Viable naturally-produced runs of steelhead are found in the Sacramento River and some of its tributaries. Steelhead exhibit highly variable life history patterns throughout their range, but are broadly categorized into winter and summer reproductive ecotypes. Winter steelhead, the most widespread reproductive ecotype and the only type currently present in Central Valley streams (McEwan and Jackson 1996), become sexually mature in the ocean, enter spawning streams in summer, fall or winter, and spawn a few months later in winter or late spring (Meehan and Bjornn 1991, Behnke 1992).

In the Sacramento River, adult winter steelhead migrate upstream during most months of the year, beginning in July, peaking in September, and continuing through February or March (Hallock 1987). Spawning occurs primarily from January through March, but may begin as early as late December and may extend through April (Hallock 1987). Individual steelhead may spawn more than once, returning to the ocean between each spawning migration. Spawning, egg incubation, and fry emergence occurs in a manner similar to that previously described for Chinook salmon. Peak emergence of steelhead fry occurs in the late spring or early summer.

Juvenile steelhead rear a minimum of one and typically two or more years in fresh water before migrating to the ocean during smoltification. Juvenile migration to the ocean generally occurs from December through August. The peak months of juvenile migration are January to May (McEwan 2001), although downstream movements of young-of-the-year steelhead have been reported in the lower Yuba River from late-spring through summer (HDR/SWRI 2007). The importance of main channel and floodplain habitats to steelhead in the lower Sacramento River and upper Delta is not well understood. Steelhead smolts have been found in the Yolo Bypass during the period of winter and spring inundation, but the importance of this and other floodplain areas in the lower Sacramento River and upper Delta is not yet clear. The specific timing of steelhead migration through the Delta is not well defined. Most of the outmigration probably occurs during the wettest months. However, peak numbers of juvenile steelhead at the south Delta water export facilities (perhaps an indication of peak outmigration timing) occur during March and April (USFWS 1995).

3.4 Green Sturgeon Life Stage Periodicity

The green sturgeon is anadromous, but it is the most marine-oriented of the sturgeon species and has been found in near shore marine waters from Mexico to the Bering Sea (70 FR 17386). The northern distinct population segment (DPS) has known spawning populations in the Rogue, Klamath, and Eel rivers and the southern DPS has a single spawning population in the Sacramento River (NMFS 2005). The species is primarily marine and returns to freshwater mainly to spawn during March to July, peaking from mid-April to mid-June (Moyle 2002). Green sturgeon are believed to spawn every 3 to 5 years, although recent evidence indicates that spawning may be as frequent as every 2 years (70 FR 17386). Little is known about the specific spawning habitat preferences of green sturgeon. Spawning is generally associated with water temperatures from 46ºF to 57ºF. In the Central Valley, spawning occurs in the Sacramento River upstream of Hamilton City, perhaps as far upstream as Keswick Dam (Adams *et al.* 2002), and possibly in the lower Feather River (Moyle 2002). Prior to the listing of the species as threatened, a sport fishery existed on the lower Feather River (HDR/SWRI 2007) and Sacramento River. Capture of larval green sturgeon in salmon outmigrant traps indicates that the lower Feather River may be a principal spawning area (Moyle 2002). It is believed that adult green sturgeon broadcast their eggs in deep, fast water over large cobble substrate where the eggs settle into the interstitial spaces (Moyle 2002). Green sturgeon eggs hatch in approximately 8

days at 55ºF (Moyle 2002). Larvae begin feeding 10 days after hatching. Metamorphosis to the juvenile stage is complete within 45 days of hatching. Juveniles spend 1 to 4 years in fresh and estuarine waters and migrate to salt water at lengths of 300–750 mm (70 FR 17386). Green sturgeon have been salvaged at the state and federal fish collection facilities in every month, indicating that they are present in the Delta year-round. Historically, green sturgeon have been much less abundant than white sturgeon and were not as highly prized as a sport fish (Figure 3).

Figure 3. Green sturgeon in left picture (from Vogel 2008a) and a white sturgeon in the right picture held by the author (center) and two of his employees.

4.0 Anadromous Fish Population Status

4.1 Chinook Salmon

4.1.1 Fall-Run Chinook Salmon

Since construction of Shasta Dam, the fall-run Chinook has been the most abundant among the four salmon runs in the upper Sacramento River. Since 1950, when complete data on fall run became available, a peak of 408,000 spawners were observed in 1953 (Figure 4), the presumed largest annual run during the 1939 to 1969 period (Reynolds *et al.* 1990). However, for the period from 1956 to 1985, there was an approximate 50% decline in the mainstem (only) spawning population, mostly upstream of Red Bluff (Reynolds *et al.* 1990).
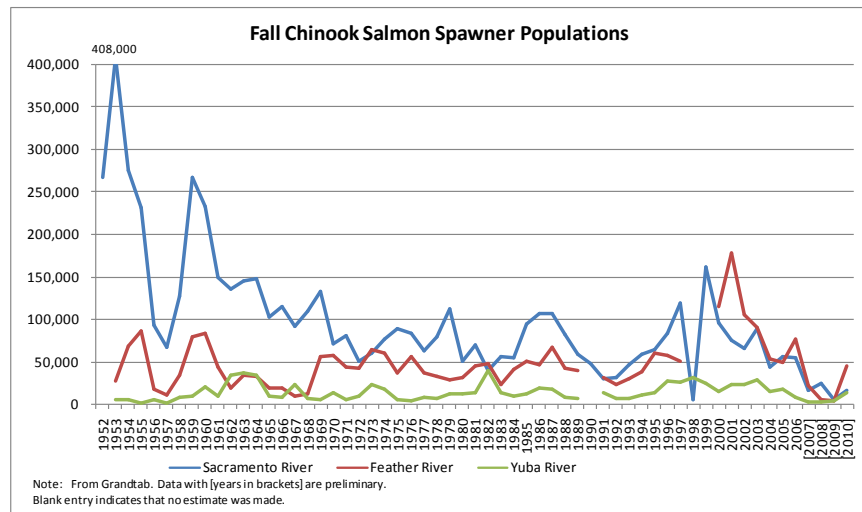
Figure 4. Estimated fall-run Chinook salmon run sizes in the Sacramento, Feather, and Yuba rivers. Source: DFG Grandtab.

Extensive mining, agriculture, urbanization, and commercial fishing substantially reduced Yuba River fall Chinook prior to the 1950s. Since then, natural production has been sustained, or in some years increased populations, even with out-of-basin stressors on the salmon runs. Unlike the Feather River, the Yuba River has no hatchery or long-term fish planting program and the run is primarily sustained by natural production (HDR/SWRI 2007).

4.1.2 Late-Fall-Run Chinook Salmon

Because enumeration of late-fall-run Chinook did not begin until Red Bluff Diversion Dam was constructed in the mid-1960s (Figure 5), there are no data available to indicate the population sizes from the construction of Shasta Dam in the 1940s until the mid-1960s.
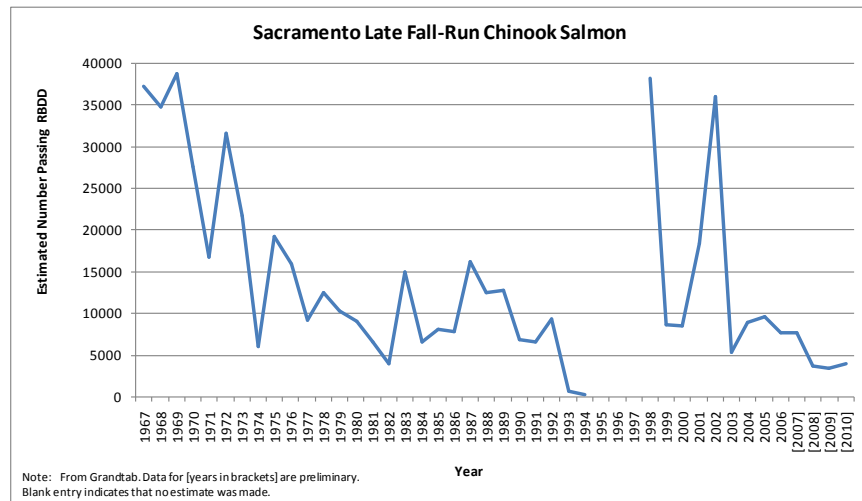
Figure 5. Annual run sizes of late-fall Chinook upstream of Red Bluff.

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4.1.3 Winter-Run Chinook Salmon

Historically, winter-run Chinook spawned upstream of the present sites of Shasta and Keswick dams. Despite recent popular belief, historically, the winter-run populations were not considered to be large prior to dam construction. As pointed out by Slater (1963), "*In any case, little evidence is extant that this run was distributed widely or that it ever was composed of large populations prior to Shasta Dam.*" However, because of cold-water dam releases during the period when winter-run Chinook spawn, the run size increased "dramatically" during the 1940s and 1950s (after dam construction), eventually surpassing the mainstem spring-run Chinook in significance (Reynolds *et al.* 1993). In 1989, winter-run Chinook salmon escapement was estimated at less than 550 adults. A precipitous decline in winter run since the mid-1960s (Figure 6) prompted the Federal government to list this run as threatened in 1989. Escapement continued to decline, diminishing to an estimated 450 fish in 1990 and 191 fish in 1991, prompting NMFS to reclassify it as endangered in 1994 (Myers *et al.* 1998).

Escapement in 1992 was estimated to be 1,180 fish, indicating good survival of the 1989 class. NMFS data indicate that the population has increased during the late 1990s through 2001. In 1996, returning spawners numbered about 1,000 fish and in 2001, returning adults were estimated to be 5,500 (Pacific Fisheries Management Council 2002). Despite increased efforts to maintain and enhance the population of winter-run Chinook salmon by various entities, in its final listing determination of June 28, 2005, NMFS again found that the Sacramento River winter-run Chinook ESU in-total was in danger of extinction throughout all or a significant portion of its range and concluded that the ESU warranted continued listing as an endangered species under the ESA (70 FR 37191).
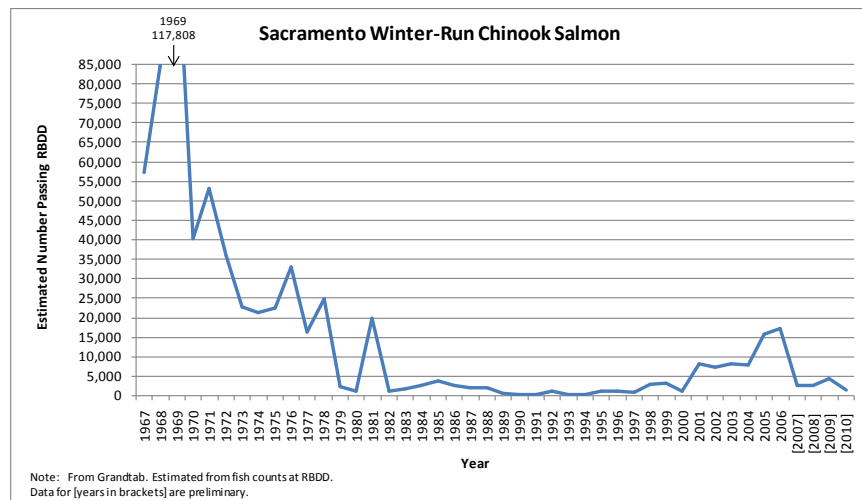
Figure 6. Annual run sizes of winter-run Chinook upstream of Red Bluff.

4.1.4 Spring-Run Chinook Salmon

Spring-run Chinook salmon may have once been the most abundant of Central Valley Chinook salmon (Mills and Fisher 1994). They occupied the upstream reaches of all major river systems in the Central Valley where there were no natural barriers. Central Valley spring-run Chinook salmon are now restricted to the upper Sacramento River downstream of Keswick Dam; the Feather River downstream of Oroville Dam; the Yuba River downstream of Englebright Dam; several perennial tributaries of the Sacramento River [*e.g*., Mill (Figure 7), Deer (Figure 8), and Butte creeks]; and the Delta.
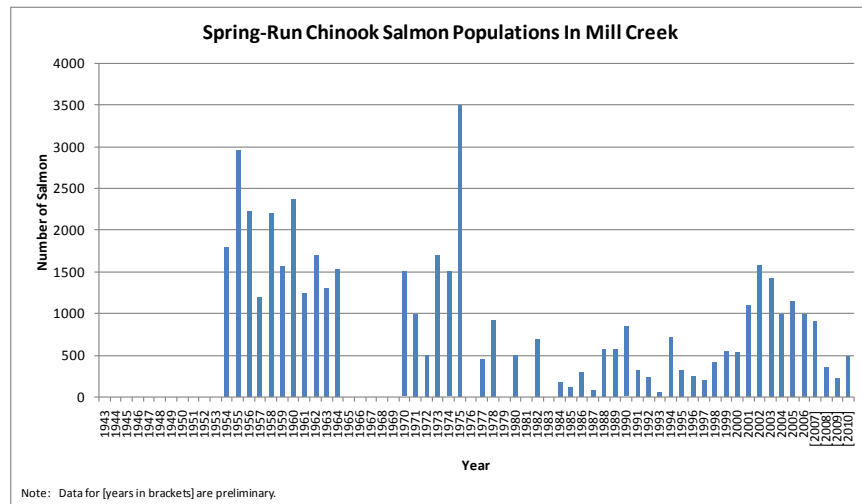
Figure 7. Annual run sizes of spring-run Chinook in Mill Creek.
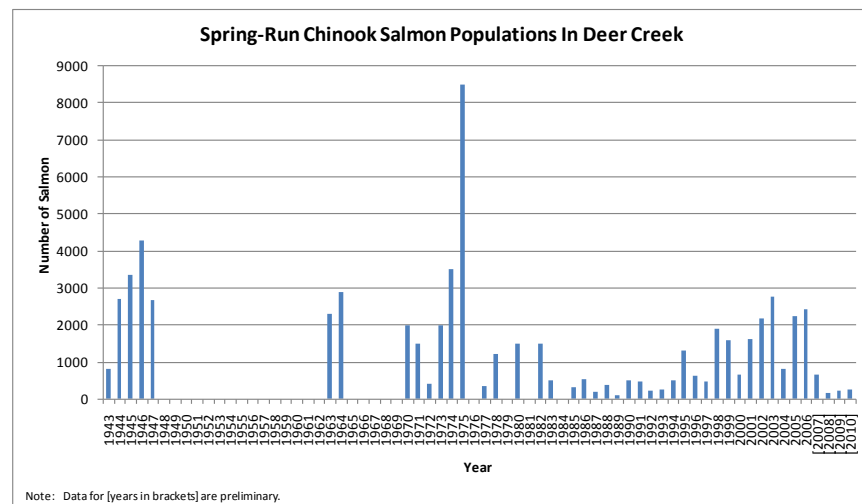
Figure 8. Annual runs sizes of spring-run Chinook in Deer Creek.

The abundance of Central Valley spring-run Chinook salmon, as measured by the number of adults returning to spawn, averages about 10,000 adults for natural spawners and another 1,000 to 2,000 adults returning to hatcheries (Mills and Fisher 1994). Spring-run Chinook salmon spawn in the early fall and the spawning periods may overlap with fall-run Chinook salmon if the fish are not geographically isolated. As a result, spring-run Chinook have interbred with fall-run Chinook salmon in the Sacramento and Feather Rivers (DFG 1998). Large dam construction on the Feather River has eliminated the previous spatial separation between the spring and fall runs of Chinook (HDR/SWRI 2007), as has also occurred in the mainstem Sacramento River. Genetically uncontaminated populations may exist in Deer Creek, Mill Creek, Butte Creek, and other eastside tributaries of the Sacramento River. In 1996, DFG believed there were at least eight runs of spring Chinook remaining in the Central Valley (Table 1). Naturally spawning spring run in the Feather and Yuba Rivers, as well as the hatchery stock from Feather River Hatchery, are considered the same Evolutionarily Significant Unit as spring run in the upper Sacramento River (HDR/SWRI 2007). The majority of the spring Chinook in the Sacramento River are the result of hatchery production at Feather River Hatchery. The most important remaining wild runs are in Deer and Mill creeks (Moyle *et al.* 1989); these runs have exhibited substantial declines (Figures 7 and 8). In 1990, Reynolds *et al.* (1990) reported that the spring Chinook runs in Mill and Deer creeks had undergone drastic declines (80-85%) in the prior two decades. The NMFS status review on this run concluded that the only streams considered having wild spring-run Chinook are Mill and Deer creeks, and possibly Butte Creek, and these are relatively small populations with sharply declining trends (Myers *et al.* 1998). DFG (1965), as cited by Myers *et al.* (1998), estimated total spawning escapement of spring-run Chinook in the mid-1960s to be 28,500, with the majority (15,000) spawning in the mainstem Sacramento River and the remainder scattered among tributaries. The mainstem Sacramento River spring runs have widely fluctuated in abundance since 1967 and this run is generally considered to be depressed. Mainstem spawners have declined substantially since the mid-1980s, from 5,000-15,000 to a few hundred fish (Myers *et al.* 1998). A petition to list all spring-run Chinook as endangered was submitted to the State of California in October 1995. On August 28, 1998, the California Fish and Game Commission determined that a state listing of spring-run Chinook as threatened was warranted. The spring-run Chinook was federally listed as a threatened species effective November 15, 1999 (64 FR 50394).

Table 1. Spring-run Chinook salmon stocks, 1996 status of populations and stock purity (DFG 1996).			
Spring-Run Chinook Stock	**Status of Population**		**Stock Purity**
	Present	**Sustaining**	
Deer Creek	Yes	Yes/Declining [1]	Yes
Mill Creek	Yes	Yes/Declining [1]	Yes
Butte Creek	Yes	Yes/Declining [1]	Questionable [3]
Battle Creek [2]	Sporadic	Sporadic	Questionable [3]
Big Chico Creek	Sporadic	No	Questionable [3]
Clear Creek	No	No	Questionable [3]
Sacramento River	Sporadic	Sporadic	No
Antelope Creek	Sporadic	No	Questionable [3]
Cottonwood Creek	Sporadic	No	Questionable [3]
Feather River	Yes	Yes	No
Yuba River	Sporadic	Sporadic	Questionable [3]
Cow Creek	No	No	No
Thomes Creek	No	No	No

[1] Population trend data for Deer, Mill, and Butte creeks indicate declining populations since the early 1970s. These three populations are sustaining, and Butte Creek recently had the highest return of spawners ever observed.

[2] The area of interest on Battle Creek is presently the 20-mile stream reach from the mouth upstream to Eagle Canyon Dam. Future consideration will be given to the 4-mile stream reach above Eagle Canyon.

[3] The purity of these stocks is listed as questionable due to either past introductions of hatchery produced spring-run Chinook salmon or a lack of genetic knowledge of the parentage of spawning fish.

4.2 Steelhead

Central Valley steelhead occur in the Sacramento River and some of its tributaries, including the Feather/Yuba rivers. Most wild, indigenous steelhead populations occur in the Sacramento River basin downstream of Red Bluff including the Yuba, Deer, Mill, and Antelope creeks with additional naturally spawning populations likely influenced by hatchery production in the Feather River and upper Sacramento River (HDR/SWRI 2007). Steelhead populations in the Sacramento River have declined substantially (Hallock 1989). Hallock (1987) estimated that upper Sacramento River steelhead populations decreased from more than 20,000 in the 1950s to less than 5,000 in the 1980s and that most of the decline has occurred since the mid-1960s. Since 1967, the decline of steelhead in the Sacramento Valley has been precipitous (Figures 9 and 10). Hallock *et al.* (1961), as cited by McEwan and Jackson (1996), reported that the composition of naturally produced steelhead in the population estimates during the 1950s averaged 88%. Wild populations in Mill and Deer creeks may be mostly native, but the populations are nearly extirpated. Annual steelhead counts on Mill Creek from 1953 to 1963 ranged from 417 to 2,269 adults; in 1964, 1,006 adult steelhead were counted in Deer Creek. The minimum estimate for steelhead during the 1993-1994 season was 28 in Mill Creek and 0 in Deer Creek (McEwan and Jackson 1996). Natural escapement in 1995 was estimated to be about 1,000 adults each for Mill and Deer creeks and the Yuba River (S. P. Cramer and Associates 1995). Hatchery returns have averaged around 10,000 adults (Mills and Fisher 1994). The most recent annual estimate of adults spawning upstream of RBDD was less than 2,000 fish (NOAA

2006).

Central Valley steelhead was federally listed as threatened on March 19, 1998 (63 FR 13347). The threatened status of Central Valley steelhead was reaffirmed in NMFS final listing determination on January 5, 2006 (NOAA 2006), at which time NMFS also adopted the term Distinct Population Segment (DPS), in place of ESU, to describe Central Valley steelhead and other population segments of this species. NMFS originally designated critical habitat for Central Valley steelhead on February 16, 2000 (65 FR 7764). However, following a lawsuit (*National Association of Home Builders et al.* v. *Donald L. Evans, Secretary of Commerce, et al.*), NMFS decided to rescind the listing and re-evaluate how to classify critical habitat for several ESUs (now DPSs) of steelhead. Critical habitat for Central Valley steelhead was redesignated by NMFS on September 2, 2005 (70 FR 52488).
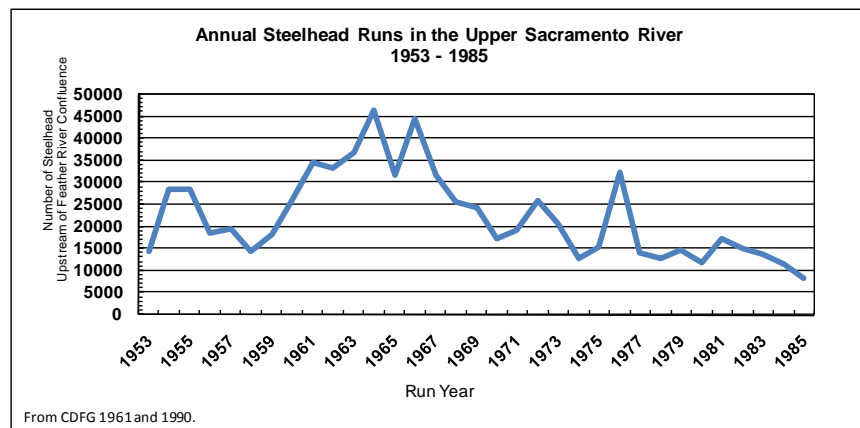
Figure 9. Annual runs of steelhead to areas upstream of the confluence with the Feather River.
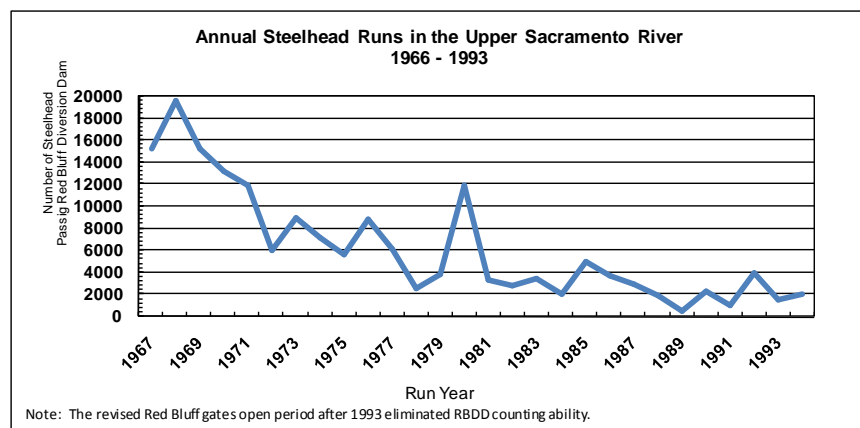
Figure 10. Annual runs of steelhead upstream of Red Bluff.

One of the primary problems with determining the population status of steelhead is the difficulty in distinguishing between the truly ocean-run fish and the resident rainbow trout. Although NMFS suggested that fish size can be used to differentiate between the two (70 FR 67130), that variable is not applicable to Central Valley steelhead/rainbow trout. This is attributable to the

fact that Sacramento River basin *O. mykiss* exhibit a large overlap in sizes of resident and ocean-run fish (*i.e.*, small steelhead and large resident trout are common sizes in Central Valley rivers). Historically, Sacramento River steelhead averaged about three pounds in weight and were generally smaller than steelhead found in other California watersheds (Hallock *et al.* 1961); resident rainbow trout of that size in the Sacramento River are common.

4.3 Green Sturgeon

The population status of green sturgeon has been the subject of considerable debate. Although white sturgeon is the most abundant sturgeon species in the Sacramento – San Joaquin drainage, green sturgeon have always been uncommon (Moyle 2002). In the estuary, white sturgeon is much more common than green sturgeon (Kogut 2002). DFG reported:

> "*Green sturgeon abundance estimates have varied substantially in the Sacramento-San Joaquin Estuary (Table 10). Aside from the high estimated abundance in 2001 of 3,580 fish (based on September and October catches only, to be comparable with estimates in earlier years), the largest estimate was 1,906 in 1979 and the lowest was 198 in 1954. Even without the low estimate in 1954 and the high estimate in 2001, there is no trend in these data ($F_{1,10} = 1.49$, p >0.25), so they provide no evidence for a green sturgeon population decline in the Sacramento-San Joaquin Estuary.*" DFG (2002)

DFG estimated the abundance of green sturgeon indirectly through large-scale tagging studies on white sturgeon which were initiated in 1954. The estimated green sturgeon abundance, which should be viewed with caution due to a variety of assumptions, is obtained by multiplying white sturgeon abundance by the ratio of green sturgeon to white sturgeon caught during the tagging studies (Kohlhorst 2001, Kogut 2002). Green sturgeon abundance has shown no apparent trends over the years, but 8,421 was the highest estimated number of fish (Kogut 2002).

Green sturgeon were classified as a Class 1 Species of Special Concern by DFG in 1995 (Moyle *et al.*1995). Class 1 Species of Special Concern are those that conform to the state definitions of threatened or endangered and could qualify for addition to the official list. However, DFG specifically responded to the proposed sturgeon petition to list the species as threatened by stating that there are no data to indicate a decline in green sturgeon populations over the past 30 to 50 years (DFG 2002). Moreover, in 2002 DFG believed green sturgeon populations were sufficiently abundant to allow angler harvest. At that time, the agency's regulations allowed sport harvest, permitting year-round take of one fish per day between 117 cm and 183 cm (3.8 feet to 6 feet long) total length and did not contemplate any changes in angling regulations (DFG 2002). However, on March 20, 2006, emergency green sturgeon regulations were put into effect by the DFG which required a year round zero (0) bag limit of green sturgeon in all areas of the state.

North American green sturgeon was determined to be comprised of two populations, a northern

and a southern distinct population segment (DPS) by NMFS on January 23, 2003 (NMFS 2003). The northern DPS includes populations extending from the Eel River northward, and the southern DPS includes populations south of the Eel River to the Sacramento River. The Sacramento River supports the southernmost spawning population of green sturgeon (Moyle 2002). The northern DPS was determined as not warranting listing under the ESA by the NMFS on April 6 2005, but remains on the Species of Concern List (70 FR 17386). The southern DPS of green sturgeon was listed as threatened under the federal Endangered Species Act (ESA) on April 7, 2006 (NMFS 2006).

Recently imposed regulations in Oregon and Washington have significantly reduced harvest of green sturgeon (BRT 2005). Although NMFS indicates that this management action primarily benefited the northern DPS of green sturgeon, it also undoubtedly benefited the southern DPS because of the highly migratory nature of the species up the west coast.

5.0 Problems, Progress, and Potential Solutions

This report sequentially focuses on individual anadromous fish life stages from the time of adult upstream migration through holding, spawning, egg incubation, fry and juvenile rearing, outmigration from the rivers and Delta, to ocean rearing. Most reports, and the resultant plans for improvement, instead focus on specific individual stressors to the species (*e.g.*, removing a dam) or specific locations (*e.g.*, a tributary) without necessarily articulating how proposed actions could meaningfully translate into overall effects on the species life cycle compared to other proposed actions. In this regard, it is helpful to have a basic conceptual model of the anadromous fish life cycle to better understand where in specific phases of the life cycles, potential stressors or limiting factors may affect the species (Figure 11). This conceptual model includes many of the primary factors that may limit anadromous fish but does not include every possible factor; life history characteristics are considerably more complex than depicted. For example, among others, it does not include minor factors, the potential deleterious effects of hatchery production on salmonids, and possible effects of disease on wild fish. In most cases, these latter topics and similar factors have only been hypothesized, not empirically demonstrated to have a measurable negative impact on Sacramento River basin anadromous fish. A notable exception is the lack of stock purity of spring-run Chinook caused by interbreeding with fall-run Chinook in the mainstem Sacramento River (Slater 1963) and in the Feather River (DFG 1996, DFG 1998). These latter circumstances place even greater importance on protecting and enhancing true spring-run Chinook in other tributaries discussed in this report.
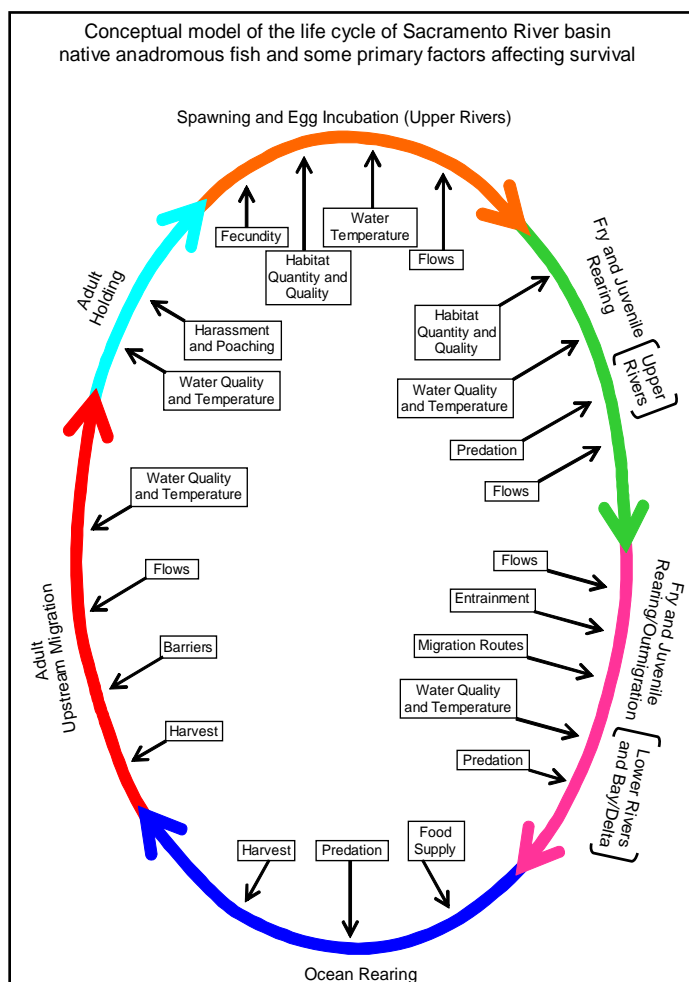
Figure 11. Conceptual model of the life cycle of Sacramento River basin native anadromous fish and some primary factors affecting survival.

The logic presented in this report relies upon a comparison of the seasonal presence of fish life phases with the co-occurrence of the most prominent, relevant anthropogenic factors believed to have adversely impacted anadromous fish. Specifically, the location, chronological and seasonal timing, magnitude, and duration of a particular factor are examined to determine poor or strong correspondence with the declines in anadromous fish populations. Past and present problems for Sacramento River anadromous fish are described relative to the chronological occurrence of those problems. For example, many existing plans discuss problems which no longer exist, or the problems have been diminished to far lesser importance as compared to decades ago.

The preceding is in recognition of the major caveat that, due to the complex nature of the life cycles and the interaction of environmental variables and effects on fish, determining causality of a particular variable translating to measurable effects on adult fish returns is nearly impossible (Cummins *et al*. 2008). Many factors may work in combination on long time scales (*e.g.*,

decades) to ultimately create adverse conditions for fish which would not be discernable on short time scales (*e.g.*, annual). For example, it is known that there has been a statistically significant trend toward earlier annual Sierra Nevada runoff and Delta outflow since the late 1940s which has been attributed to an increase in January-March warming in the Sierra Nevada of about 2° F (Dettinger *et al.* 1995). This phenomenon may simply be a function of long-term climate variability, but it could act synergistically with other stressors to create altered freshwater conditions for fish in a more-recent time scale.

The progress of some fish restoration and protection efforts is described herein. Many existing plans often do not describe progress either because the plans are outdated or specific restoration actions were overlooked. New information to benefit anadromous fish either not addressed or only partially addressed in existing plans for fish restoration is also presented here. As mentioned previously, this report is not comprehensive and is intended to supplement, not supplant, these existing plans for native anadromous fish restoration. It draws upon much of the past high quality efforts focused on fish and habitat restoration and is intended to enhance those existing plans.

5.1 Adult Fish Upstream Migration

Adult anadromous fish returning from the ocean and migrating upstream to spawning grounds face a variety of hazards. Protecting adult anadromous fish from time of entry into freshwater until successful reproduction in the upstream spawning habitats is critical. Those adults attaining the reproductive phase are the fewest in number among all the prior life stages. Fish reaching the spawning grounds are the oldest among all prior life stages and have already survived the vast majority of density-independent and density-dependent factors exerting the most influence on the population. Significant changes in the numbers of these adult fish can have resulting profound impacts on subsequent generations. Given the complexity of the anadromous fishes' life cycle, the upstream migrating adult fish should be the easiest to protect. Historically, this has not been the case, but major recent actions have enhanced the probability of successful migration to upstream areas where the fish reproduce.

5.1.1 Delta

5.1.1.1 *Barriers*

There are a number of barriers in or near the Delta believed to block or delay upstream migration of adult fish. The 2009 NMFS draft recovery plan for salmonids identifies the Suisun Bay Salinity Control Gates, the Sacramento Deep Water Shipping Channel, the Delta Cross Channel (DCC), and Fremont Weir as barriers (NMFS 2009). These same structures would also be barriers for sturgeon. Although the total counts of fish blocked in these areas are unknown, the problem remains important. Suisun Marsh, just west of the western Delta, has over 10 percent of California's remaining natural wetlands and is one of the largest contiguous brackish water tidal marshes in the United States (Guivetchi 1990). The Suisun Marsh Salinity Control Gates,

located nearly on the western legal boundary of the Delta, were constructed in 1988 and are used to protect the marsh through operations to tidally pump low salinity water into the interior marsh via Montezuma Slough (Brown 1990).   However, there is concern that upstream migrating salmon may be blocked or delayed by the control gates which prompted NMFS to investigate potential fish passage problems (Rooks 1998). From Suisun Bay, anadromous fish destined for the Sacramento River have a relatively straight-forward migration route through the Delta. Important exceptions occur if the fish, instead, migrate up the north or south forks of the Mokelumne River or move up into Cache Slough to the Yolo Bypass or Sacramento Deep Water Ship Channel (Figure 1). Once those fish enter the Mokelumne River system upstream of Georgiana Slough and the DCC gates are subsequently closed, those fish become "trapped" in that river system and can only re-enter the Sacramento River by migrating back downstream (uncharacteristic of upstream migrating anadromous fish) or when the DCC gates are reopened. Fish attracted into the Yolo Bypass during flood flows can become stranded or blocked at Fremont Weir when flows recede. This problem is likely to be severe, particularly for green sturgeon. Adult fish migrating into the Sacramento Deep Water Ship Channel can become blocked from upstream areas without flows to attract the fish back into the mainstem river. This is unlikely to be severe due to inadequate flows to divert fish up the channel off Cache Slough. Each of these regions could have structural measures implemented to eliminate the problem. Given the enormous expenditures which have been committed elsewhere in the watershed and Delta to benefit fish and the biological importance of returning adult spawners, it is surprising that more focus has not been given to this issue.

5.1.1.2 *Flows*

No information was found to indicate that the flow regime in the Delta currently adversely impacts Sacramento River basin anadromous fish migrating upstream through the Delta. Although freshwater outflow provides important cues for attracting adult fish to upstream areas (SWRCB 2010), Sacramento River flows have not been shown to be limiting for upstream migrating anadromous fish.

5.1.1.3 *Water Quality and Temperature*

No information was found to indicate that water quality currently significantly impacts Sacramento River basin adult anadromous fish in the Delta. Although pollution in the Delta is known to occur, those effects are largely believed to primarily impact smaller organisms more sensitive to pollution (discussed later). Recently, concern has been expressed over the influence of selenium on green sturgeon (EPA 2011), but no clear negative impacts have been shown. There are a multitude of water quality concerns with a large number of pesticides and other pollutants found in Delta water, but again no distinct effects on anadromous fish have been determined. However, given the numerical magnitude of pollutants in the Delta, this may possibly emerge as an important factor. Low dissolved oxygen in the San Joaquin River near Stockton at certain times of the year has been shown to adversely impact salmon, but Sacramento-origin fish have been unaffected. Water temperatures in the Delta are controlled by ambient conditions, and Central Valley reservoirs are too far upstream to influence Delta water

temperatures.

5.1.2 Mainstem Sacramento River

5.1.2.1 *Harvest*

The following discussion is applicable to the Delta, mainstem river, and the tributaries. Sport fishing for anadromous fish in the Sacramento River basin is highly regulated to protect fish returning to the spawning grounds. An extensive discussion on the topic is provided in DFG (1998). The intent of fishery managers is to allow harvest of surplus fish while ensuring sufficient numbers escape in order to reproduce and continue a healthy propagation of the species. Sport fishing regulations impose a variety of restrictions to limit overharvest, including in some instances, total prohibition on harvest. When endangered anadromous salmonids are intermingled with non-listed salmonids, it creates a dilemma for resource managers. For example, because of the overlap in the timing between salmon runs, some inadvertent harvest of listed species can occur even though anglers target non-listed species. NMFS believes the harvest of listed species in this circumstance is minimal, but nevertheless occurs. The fish are also subject to illegal harvest (*i.e.*, "poaching").

During the transition from salt water in San Francisco Bay to the Delta and upstream areas, the adult fish are subject to sport fishery harvest, depending on species, run, and the specific timing. Due to the threatened or endangered species status and recent poor returns of anadromous salmon, severe sport harvest restrictions imposed by the California Fish and Game Commission (CFGC) have been implemented in the Central Valley, including the Delta, to protect the adult life stage. Sport harvest of green sturgeon is now prohibited. To protect threatened steelhead from harvest, a complicated suite of regulations was imposed. Increased law enforcement activity to minimize illegal harvest has increased due to species listings and funding through Delta-related programs (*e.g*., Delta Bay Enhanced Enforcement Program) (DFG 1998).

Initially, during the 2010 – 2011 sport fishing regulatory period, salmon fishing in the Sacramento River (Keswick Dam to the Carquinez Bridge), the Feather River (below Oroville Dam to mouth), and all other anadromous tributaries was closed, except for the Sacramento mainstem stretch of river from just below Red Bluff to Knights Landing where one salmon was permitted from November 16 to December 31 (CFGCa). Subsequently, after predictions of the salmon runs improved, suggesting greater numbers of returning fish, a daily bag and possession limit of two salmon in the Sacramento River was allowed for three weeks in October from approximately Red Bluff to Anderson with the same limit in the Feather River primarily during August (CFGCb). Other tributaries remained closed to fishing. This management strategy was designed to provide sport fishing opportunities by mainly targeting the more abundant fall-run Chinook and, in particular, hatchery fish.

For the 2010 – 2011 season, regulations protecting steelhead (defined as any rainbow trout greater than 16 inches in total length) were more complicated. From just below Keswick Dam to

Anderson, one trout (up to 16 inches in total length) was allowed as the daily bag and possession limit all year. From Anderson to Red Bluff, two hatchery trout or hatchery steelhead (identified by adipose fin clips) was the daily bag limit and four hatchery trout or hatchery steelhead was the possession limit from January 1 through March 31 and August 31 through December 31. However, from April 1 through August 30, an additional one wild trout (no greater than 16 inches) could be in possession. From just below Red Bluff to the Carquinez Bridge, two hatchery trout or hatchery steelhead was the daily bag limit and four hatchery trout or hatchery steelhead was the possession limit all year long. In the Feather River, from the Fish Barrier Dam downstream of Lake Oroville to the city of Oroville no fish were allowed. From Oroville to the Highway 70 Bridge, one hatchery trout or one hatchery steelhead was the take and possession limit from January 1 through July 15. From the Highway 70 Bridge to the mouth, one hatchery trout or 1 hatchery steelhead was the take and possession limit all year. In the Yuba River from the mouth to the Highway 20 Bridge, two hatchery trout or hatchery steelhead was the bag limit and four hatchery trout or hatchery steelhead was the possession limit all year. From the Highway 20 Bridge to Englebright Dam, two hatchery trout or hatchery steelhead was the bag limit and four hatchery trout or hatchery steelhead was the possession limit from December 1 through August 31 only (CFGC 2010a).

During other times of the year, unlike in past decades, the rivers have been closed to sport harvest to protect steelhead, winter- and spring-run Chinook, and to some extent, late-fall-run Chinook (CFGC 2010a, 2010b). However, historically, sport harvest probably adversely impacted the steelhead populations; both juvenile and adult steelhead were caught. Because of generally favorable riverine conditions during the sport fishing season, the fish are particularly vulnerable to harvest. McEwan and Jackson (1996) suggested that over-harvest of steelhead in Sacramento River tributaries could have been a factor in their population declines. Although some inadvertent freshwater harvest of listed species undoubtedly still occurs, it is assumed to be minimal; no information was located to suggest otherwise. Harvest of non-listed anadromous salmonids (fall-run and late-fall-run) does occur but is maintained to ensure that sufficient numbers of fish return to spawn.

It is not possible to determine the effectiveness of DFG and NMFS law enforcement activities in terms of numbers of fish protected from overharvest. However, because much of the sport fishing activities for anadromous fish on the mainstem Sacramento River occurs by boat, access is largely limited to a relatively small number of boat launching facilities spread over a long distance of river. In some counties, the local county sheriff's boat patrols assist wardens in monitoring fishing activities. Additionally, daytime recreational boating activity is popular throughout the Sacramento River so poaching during daylight would be highly visible to the public. Undoubtedly, some nighttime illegal harvest (*e.g.*, exceeding the daily bag limit) occurs but there is no indication to suggest overharvest from in-river sport fishing has transpired in the recent past. The numbers of fish harvested are much less than the ocean harvest and, unlike the ocean fishery, inland sport harvest does not affect the age structure (discussed in Section 5.6.3) of the populations. Because of the heightened attention on protecting depleted fish stocks, listing of species as threatened or endangered, and increased regulatory oversight caused by these circumstances, it can be assumed that any potential problems caused by sport harvest have been

considerably reduced during recent years as compared to decades ago. As demonstrated by recent severe restrictions on sport harvest described above, fishery managers have been able to control and lessen this stressor to anadromous fish. These circumstances have increased, not decreased, protection for anadromous fish as compared to prior decades.

5.1.2.2 *Barriers*

The Red Bluff Diversion Dam (RBDD) on the upper Sacramento River near Red Bluff went into operation in August 1966. The purpose of the dam was to divert water off the Sacramento River into the Tehama-Colusa (T-C) Canal and Corning Canal. The Corning Canal is used only for agriculture whereas the T-C Canal was originally used to convey water for agriculture, wildlife refuges, and the T-C Fish Facilities (Vogel *et al.* 1988). The fact that the T-C Fish Facilities required fall, winter, and spring diversions of water into the T-C Canal is the circumstance that originally necessitated year-round diversions of water at RBDD (in contrast to only seasonal irrigation diversions). During the late 1980s, the T-C Fish Facilities were "mothballed" (*i.e.*, placed into a non-fish-production mode) (Vogel 1989) which eliminated the need for year-round diversions from the Sacramento River.

Fishery resource investigations conducted at RBDD during the 1970s and 1980s identified significant upstream anadromous salmonid passage problems at the dam (Vogel *et al.* 1988). Largely as a result of prior investigations, the USFWS began intensive studies (performed by this author) in the early 1980s to determine specific problems and potential solutions for anadromous salmonid upstream migration at the dam. Primarily, inadequate fish passage (ladders) at the site and fish attraction to heavy water flows under the 11 large dam gates were believed to cause the unusually high delay times and blockage of adult salmonids migration into the upper river. Experiments conducted by gate manipulation to increase fish attraction to the fish ladders met with mixed success. Many other problems with fish passage were uncovered during the studies. At one time, the operation of RBDD was considered one of the largest threat to anadromous fish in the Sacramento River. That has now changed. Numerous actions over the past several decades, most notably raising the dam gates during the fall, winter, and spring months, have significantly improved upstream fish passage (Tables 2 and 3).

Table 2. Improvements in fish passage at Red Bluff Diversion Dam (RBDD).		
Fish Protection Measure	**Effective Date**	**Fish Passage Improvement**
Eliminating Adult Salmon Delay and Mortality at the Louver Bypass Terminal Box	1985	Elimination of significant adult salmon mortality at the dam bypass
Improved RBDD Fish Ladder Maintenance	1985	Improved fish attraction into the fish ladders
Installation of the Training Wall at the Right-Bank Fish Ladder	1985	Improved fish attraction into the right-bank fish ladder
RBDD gates out 6 months/year	1987	Unimpeded upstream fish passage 6 months/year
Relocation of the Fish Screen Bypass Outfall	1990	Reduced delay of salmon downstream of the dam
RBDD gates out 8 months/year	1993	Unimpeded upstream fish passage 8 months/year

Table 3. Restoration actions[*] developed in June 1986 by Dave Vogel (U.S. Fish and Wildlife Service) and John Hayes (Department of Fish and Game) to benefit winter-run Chinook salmon ("10-Point Action Program").	
Restoration Action	**Status**
1) Raise the Red Bluff Diversion Dam gates from December 1 to April 1	Completed
2) Develop winter-run Chinook salmon propagation program at Coleman National Fish Hatchery	Completed
3) Restore spawning habitat in Redding area	Partially completed
4) Develop measures to control pikeminnow at Red Bluff Diversion Dam	Nearly completed
5) Restrict in-river fishery	Completed
6) Develop water temperature control for drought years	Completed
7) Correct Spring Creek pollution problem	Completed
8) Correct problems at Anderson-Cottonwood Irrigation District diversion dam	Completed
9) Correct stilling basin problem at Keswick Dam	Completed
10) Continue and expand studies on winter-run Chinook	Partially completed
[*] Many of these restoration actions are discussed later in this report.	

To assist in protecting the endangered winter-run Chinook salmon, the U.S. Bureau of Reclamation (USBR) raised the RBDD gates from November 1 through April 30 each year beginning in the late 1980s. This action was implemented to provide unimpeded upstream and downstream passage for anadromous fish. A NMFS Biological Opinion concerning USBR's operation of the Central Valley Project (CVP) required that the RBDD gates be raised for a longer period, from September 15 through May 14 of each year (USBR 1993) (Figure 12). That action is believed to have greatly diminished the problems of upstream fish passage previously evident from the late 1960s through the 1980s. However, a consequence of raising the dam gates occurred as adult anadromous fish became stranded in a side channel. For example, in 1993, 384 adult Chinook salmon were rescued and manually removed from isolated pools after the dam gates were raised (USFWS 1993). This problem can also develop when river flows naturally increase and decrease even when the dam gates are raised. Efforts to grade the side channel in an attempt to prevent the formation of isolated pools were temporarily successful, but the channel configuration periodically changes and close monitoring of conditions to prevent fish stranding is required along with fish salvage as necessary.

Figure 12. Red Bluff Diversion Dam with all 11 dam gates raised to provide unimpeded upstream and downstream fish passage. Photo by Dave Vogel.

Several years ago, 10 adult green sturgeon were found dead just downstream of the dam (or impinged under the dam gates). It was determined that dam operations killed the fish. Early that year, prior to irrigation operations, the gates were completely opened to allow unimpeded fish passage to upstream areas. The dam gates were subsequently lowered for seasonal irrigation operations but some gate openings were set with only a six-inch gap to pass water to downstream reaches. The dam operators were not informed that the very large green sturgeon required more than a six-inch opening when the fish migrated back downstream and the fish were subsequently killed. Because the adult fish can pass under the gates with at least a one-foot opening, that measure was later implemented but the circumstance, nevertheless, was one of the rationales used by NMFS as a justification to list the species as threatened with extinction.

Ultimately, for a variety of reasons, and to provide unimpeded passage of adult green sturgeon during the summer months, raising all the dam gates during the remaining four months was deemed the best solution for fish passage at RBDD. With ESA listing of the green sturgeon, the RBDD gates will be permanently raised 12 months/year beginning in 2012 upon completion of a new 2,500 cfs pumping plant located just upstream of the present dam site.

The Anderson-Cottonwood Irrigation District (ACID) diversion in Redding (Figure 1), approximately three miles downstream of Keswick Dam, utilizes a gravity-flow diversion off a 450-foot-wide flashboard dam which was originally constructed in 1917 (USBR 1992). Much of the original concern over fishery resource impacts caused by ACID operations was oriented toward severe upstream migrant fish passage problems. It was believed that in the early years of ACID operations (prior to the installation of a fishway), the dam blocked nearly all upstream migrating salmon en route to their spawning grounds (McGregor 1922). The flashboards on the dam are generally in place from April to October (RAC 1989). DFG previously constructed and maintained a fish ladder at the dam (Reynolds *et al.* 1990). Since installation of this fishway,

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concern was expressed that the fish passage facilities were inefficient (Reynolds *et al.* 1990) and were subsequently replaced in 2001.

Keswick Dam, located approximately 302 river miles upstream of San Francisco Bay, is the upstream terminus of anadromous fish migration in the mainstem Sacramento River. When flows are high and exceed the hydroelectric power plant capacity, water flows over the spillway where adult fish can be attracted. Historically, these fish became stranded and entrapped in the stilling basin below the spillway (Figure 13). However, recent structural measures were implemented by the USBR to provide for fish reentry back into the river which is believed to have resolved the problem.

Figure 13. Keswick Dam located at river mile 302 on the upper Sacramento River. The stilling basin on the right side of the picture used to trap adult anadromous salmonids. Aerial photo by Dave Vogel.

5.1.2.3 *Flows*

No information was located to indicate that flows in the mainstem Sacramento River impede or limit upstream migration of anadromous fish. Every day of the year, since large dam construction, instream flows have been sufficiently high to provide physical passage of fish to upstream areas.

5.1.2.4 *Water Quality and Temperature*

Although water temperatures at some times of the year are sub-optimal for adult fish, no information was located to indicate that water temperature or quality measurably adversely impact anadromous fish migrating up the Sacramento River. To the contrary, because of the release of cold water and increased flows during summer months to downstream areas (*i.e.*, conveyance to the Delta), upstream migrating conditions for anadromous fish are more favorable now as compared to the era prior to large dam construction. For example, City of Redding residents use to swim in the Sacramento River during the summer prior to dam construction and considered it like "bath water" (Clair Hill, pers. comm.); in the present era it is frigid for swimming and more than suitable for anadromous fish.

5.1.3 Sacramento River Tributaries

The principal tributaries in the Sacramento River supporting anadromous fish include the Feather River, Yuba River, Butte Creek, Big Chico Creek, Deer Creek, Mill Creek, Antelope Creek, Cottonwood Creek, Battle Creek, Cow Creek, and Clear Creek. There are other tributaries where anadromous fish may have historically been present, but never observed in large numbers. Some streams such as Stony Creek and the Bear River[6] are hostile to anadromous fish spawning and incubation because of silted riverbed substrates, high water temperatures, and unsuitable rearing habitats due to river channels formed by very high and frequent winter-time flows (SWRCB 2000, Vogel 1998, Vogel 2003a).

5.1.3.1 *Barriers*

Many of the Sacramento River tributaries possess diversion dams for agriculture, and some possess dams created to control extremely high sediment loads created by hydraulic mining upstream. Such dams can be, and are historically known to be, detrimental for anadromous fish attempting to migrate to spawning and rearing habitats. The construction of Englebright Dam was completed in 1941 by the California Debris Commission to retain hydraulic mining debris in the Yuba River. Currently, the U.S. Army Corps of Engineers (USACE) administers the operation and maintenance of Englebright Dam which, located approximately 24 miles upstream of the confluence with the lower Feather River and 280 feet high, presents an impassible barrier for anadromous fish in the river in the Yuba River system (HDR/SWRI 2007). Daguerre Point Dam is located farther downstream (at approximately river mile 11.5) on the lower Yuba River. Construction of the dam was completed in May of 1906 by the California Debris Commission to retain hydraulic mining debris. Following the floods of 1963 and 1964, the dam was entirely reconstructed except for a short section of the right abutment. Reconstruction of the dam, including the extension and rehabilitation of both fish ladders, was completed in October 1965 (Corps 2001) using the best available science and the engineering technology that was available at that time. However, design of the fish ladders is considered suboptimal in relation to present-day engineering technology (NMFS 2009). Also, it is believed that adult sturgeon are unable to ascend the fish ladders at Daguerre Point Dam (HDR/SWRI 2007).

With early recognition of the problems with fish passage at dams in tributaries, DFG installed fish ladders to accommodate upstream passage. All diversion dams on Mill, Deer, and Antelope creeks had fish ladders installed to benefit the upstream migration of anadromous salmonids (Reynolds *et al.* 1990) (spring-run Chinook, fall-run Chinook, and steelhead) with no evidence that the structures provide undue adult fish mortality (DFG 1998). Additionally, fish ladders had been installed at two natural falls on Deer Creek (Reynolds *et al.* 1990) to expand the habitats available for salmon (primarily for spring-run Chinook) (*e.g.*, Figure 14). Clough Dam on Mill Creek was breached during high flow conditions in 1997 providing unimpeded fish passage.

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[6] Clark (1929) reported that the Bear River "*has never been known to be a salmon stream as only occasional salmon have been observed there.*"

Using approximately $1.25 million in USBR/CalFed funds, the California Department of Water Resources (DWR) permanently removed Clough Dam and improved the fish ladder, fish screen, and canal capacity at the next upstream dam and changed the point of diversion from the original Clough Dam to the upper dam (Curtis Anderson, DWR Northern District Chief, pers. comm.). Stanford-Vina Dam on Deer Creek has fishways believed to be adequate for salmon passage. In 1998, DFG reported that a new high efficiency fish ladder was completed at the Parrott-Phelan Diversion on Butte Creek (DFG 1998). Many other examples exist.

Figure 14. A DFG biologist maintaining a fish ladder in upper Deer Creek for passage of spring-run Chinook salmon. Photo by Dave Vogel.

During the 1990s and 2000s, several dams believed to delay or block anadromous salmonids were removed. Saeltzer Dam on Clear Creek was removed which provided unimpeded access of fall-run Chinook, spring-run Chinook, and steelhead to upstream reaches and is believed to provide improved holding, spawning, and rearing habitat conditions. Altering Western Canal's structure on Butte Creek into a siphon under the creek, as well as constructing new conveyance facilities, eliminated four dams believed to delay or block salmon, particularly spring-run Chinook. This opened 25 miles of unimpeded access for salmon.

New fish ladders were recently constructed on some tributaries to improve anadromous fish passage. The Coleman National Fish Hatchery diversion dam on Battle Creek was redesigned and constructed to facilitate fish passage into upper Battle Creek, allowing access into more than 40 additional river miles (Cummins *et al*. 2008). A large-scale program is currently underway in Battle Creek to restore fish access to upper reaches (discussed later). As part of a Federal Energy Regulatory Commission (FERC) relicense condition, by 1990, PG&E had constructed a new fish ladder at the power company's diversion on South Cow Creek (Reynolds *et al.* 1990). New fish ladders were recently constructed on several dams (*e.g.*, Parrott-Phelan, Gorrill, and Adams) in Butte Creek to improve fish passage, particularly for spring-run Chinook (Figure 15).

Figure 15. New fish ladder constructed on Butte Creek. Photo by Dave Vogel.

5.1.3.2 *Flows*

Flows in the Feather/Yuba rivers have not been identified as a problem limiting upstream migration of anadromous fish. The Fisheries Agreement of the Lower Yuba River Accord provides for new minimum instream flows in the lower Yuba River that are intended to maintain or increase fishery resource protection (HDR/SWRI 2007).   Measures to be implemented through the FERC re-licensing of the Oroville Project can also be expected to benefit anadromous fish. In Butte Creek, removal of passage barriers, construction of screens and ladders on diversions, and increased instream flows through diversion changes have recently benefitted anadromous salmonids (Cummins *et al*. 2008). However, historically, low flows in the spring in some smaller tributaries where spring-run Chinook are present (*e.g.*, Mill, Deer, and Antelope creeks) have made it difficult for late-arriving fish to migrate upstream either due to insufficient flows or warm water temperatures (DFG 1998). For example, in the mid- to late-1940s, hundreds of adult spring-run Chinook perished in Deer Creek because of the low-flow/high-temperature problem (Moffett 1949). This has persisted in some years, prompting actions to provide water exchanges with tributary diverters to improve spring-run upstream migration (RAC 1989). DFG and conservancies on some spring-run tributaries (*e.g.*, Mill and Deer creeks) have recently worked cooperatively to ensure adequate instream flows for upstream migrating salmon (DFG 1998). Flows to benefit spring-run Chinook migration in Butte Creek have also been implemented (DFG 1998).

5.1.4 Conclusions on Adult Fish Upstream Migration

- Previously, sport harvest of anadromous fish was far more liberal than regulations imposed in recent years. Much of the present-day sport harvest is so restrictive that current regulations, depending on the species and run, range from very low daily bag and possession limits and very narrow windows of allowable fishing, to total harvest prohibitions. Law enforcement activities to minimize illegal harvest have increased

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during recent years. The available evidence indicates that freshwater sport fishing mortality cannot explain the historical decline of anadromous fish. Furthermore, this "stressor" has become less, not worse, over time.

- There are some partial and total barriers to adult anadromous fish in the Delta that have unknown severity of impacts to the species. Under certain flow conditions, adult fish can be totally blocked during their upstream migrations at the DCC (when the gates are closed), the Sacramento Deep Water Ship Channel, and Fremont Weir.

- Previously, the most severe problem for upstream migrating anadromous fish was empirically established at the RBDD but, in the past 15 years, significant structural and operational improvements at the dam incrementally improved passage success, including seasonal removal of the dam gates during the primary migration season. By 2012, the dam gates will be removed year-round and upstream passage problems will be totally resolved. The available evidence demonstrates that this stressor to anadromous fish has become much less, not greater, during the past two decades.

- The precipitous declines and depressed populations of spring-run Chinook in tributaries downstream of RBDD (where fish have been unaffected by the dam) suggest that there are factors other than RBDD causing major impacts on some fish populations.

- Historically, the ACID dam in Redding was known to be problematic for upstream fish passage but, in recent years, modern-day fish ladders were installed which are believed to have improved migration success to important spawning areas been ACID and Keswick dams. The negative impact on adult anadromous salmonids at the site has become less over time.

- Many dams in the tributaries pre-date construction of the large mainstem dams and were historically known to create problems for upstream migrating fish. However, incrementally over the years, new and improved fishways have been installed on many of the dams, lessening the adverse conditions.

- No information was found to indicate the flow and thermal regimes in the Delta, Sacramento, Feather, and Yuba rivers, although not optimal at all times of the year, limits the upstream migration of adult anadromous fish. To the contrary, the available evidence demonstrates that these conditions have improved in areas downstream of the dams and have benefitted the fish populations in recent years.

5.2 Adult Fish Holding Habitat

5.2.1 Mainstem Sacramento River

5.2.1.1 *Water Quality and Temperature*

The mainstem Sacramento River has an abundance of deep, cold-water pools for holding adult anadromous fish all months of the year. There is no information to suggest that the quantity and quality of these habitats in the mainstem Sacramento River have been limiting to anadromous fish. Both winter-run and spring-run Chinook can hold in the upper river for several months prior to spawning. Because of the natural channel morphology and cold hypolimnetic water released from Shasta Reservoir, salmon have many deep pools where the fish can hold between Keswick Dam and Red Bluff and mature prior to spawning. Green sturgeon also appear to prefer deep pools for holding habitat but have a higher tolerance for warmer water temperatures than salmon and can therefore hold in further-downstream habitats. Large numbers of adult green sturgeon have been observed holding over summer in deep pools in the middle Sacramento River near Hamilton City. New sonar and underwater video camera footage, including channel measurements, in the Sacramento River near Hamilton City shows the type of riverbed substrate and habitat characteristics preferred by sturgeon at that location (Figures 16 and 17). The footage also showed more than 100 adult green sturgeon at the location, suggesting that the species may be substantially more abundant than previously believed: Sonar Camera Footage of Green Sturgeon[7]
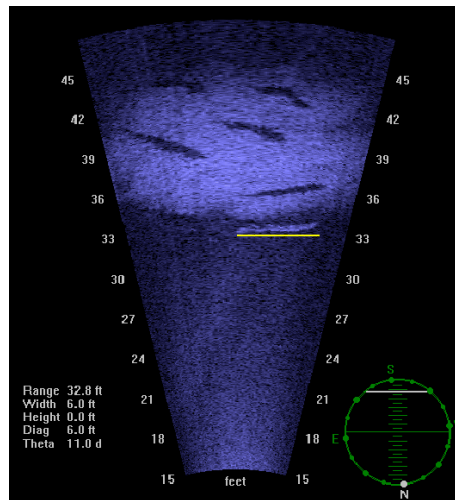
Figure 16. Sonar camera image of five adult sturgeon in the Sacramento River near Hamilton City. A sturgeon located 33 feet from the camera lens is approximately 6-feet long (shown by horizontal yellow bar) and positioned a short distance off the bottom as evidenced by its acoustic shadow 36 feet from the camera lens. The other four sturgeon are positioned on the sand riverbed. Water depth is 27 feet. (from Vogel 2008a).

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[7] A variety of videos are provided in this report which can be viewed by clicking on the underlined hyperlink and accessing to the Internet.

Figure 17. Acoustic Doppler Current Profiler cross section of water velocity distribution in the Sacramento River channel near Hamilton City where abundant green sturgeon were found. Black oval shows location where most sturgeon were observed. Transect was measured on August 28, 2007 during a river flow of approximately 9,450 cfs. (from Vogel 2008a)

These types of habitats are prevalent throughout the mainstem Sacramento River. Additionally, recent acoustic tagging of adult green sturgeon revealed that some fish utilize deep, bedrock pools a short distance upstream of Red Bluff (UC Davis, unpublished data). With the RBDD gates raised, green sturgeon have unimpeded access to upstream reaches as far as ACID dam in Redding, although it appears the fish favor areas much further downstream. At the time green sturgeon spawn, Sacramento River flows are generally high due to conveyance of water from upstream reservoirs to downstream areas. Additionally, the water is favorably cold because of a combination of release of hypolimnetic water from Shasta Reservoir, use of the new water temperature control device on Shasta Dam, the trans-basin diversion of cold water from the Trinity River to the Sacramento River, and the Whiskeytown temperature control curtain. It can be concluded that these conditions have improved in recent years compared to earlier times.

Historically, there were instances where adult salmon were exposed to lethal levels of metals originating from Iron Mountain Mine (IMM) and other abandoned mines near Keswick Dam. For example, in 1944 heavy mortalities of adult fish occurred when toxic runoff was not diluted in the reach several miles downstream of Shasta Dam (Moffett 1949). However, since the EPA cleanup of this IMM Superfund site, the problem has been resolved.

5.2.2. Sacramento River Tributaries

5.2.2.1. *Water Temperature*

Water temperature conditions generally are favorable for anadromous fish in the Feather and Yuba rivers due to the influence of upstream reservoirs. New Bullards Bar Dam and Reservoir, constructed by the Yuba County Water Agency (YCWA) on the North Yuba River in the late 1960s, has provided favorable conditions for over-summering spring-run Chinook in the lower Yuba River (in areas that were previously upstream migration corridors) due to higher, colder flows (HDR/SWRI 2007). Releases of cold water from Oroville Dam, which has structural facilities for selective withdrawal from vertical water layers in the reservoir to benefit fish (Reynolds *et al.* 1990), have improved holding habitat conditions for anadromous species in downstream reaches.

Holding areas on some smaller tributaries may be more problematic, primarily for spring-run Chinook. Although water temperatures are suitable for oversummering periods in upper Mill and Deer creeks, very high mortalities of spring run have been observed in Butte Creek, supposedly attributed to warm water. Butte Creek is likely on the marginal edge of suitable conditions for spring run because of the naturally restricted access for fish to low-elevation reaches. Removal of Saeltzer Dam on Clear Creek has provided spring-run Chinook access to cold-water upstream reaches but, for unknown reasons, the fish do not necessarily migrate far enough upstream early in the season to avoid undesirable later-season temperature problems. The latter issue may be caused by interbreeding between spring-run and fall-run due to a lack of sufficient spatiotemporal separation in the runs. Ironically, prior to the removal of Saelzer Dam, DFG recommended that a fish ladder be installed and operated there to provide separation between the two runs: "*To optimize benefits for all anadromous species, only spring-run Chinook salmon and steelhead should be allowed access to the upper reach above Saeltzer Dam.*" "*This segregation is essential to successful restoration of spring-run Chinook salmon to Clear Creek.*" (Reynolds *et al.* 1990). A recent peer review of Central Valley Project Improvement Act (CVPIA) restoration actions was highly critical of the Clear Creek plan which was termed "*.. a largely unprecedented experiment with little or no scientific merit.*" (Cummins *et al.* 2008). In Big Chico Creek, access of spring run to cold holding habitats in upstream reaches is dependent on fish passage at barriers at Iron Canyon Dam. Planning efforts to improve fish passage in Big Chico Creek have been completed but, apparently, funds are lacking for implementation (D. Coulon, DFG, pers. comm.). Both Butte and Big Chico creek spring run are highly prone to human disturbance during the summer months (discussed below) which undoubtedly results in stress in marginal water temperatures and could lead to significant pre-spawning mortality. Large-scale habitat and fish passage improvements underway in the Battle Creek watershed (discussed later) are expected to result in major improvements for anadromous fish which may establish winter-run and spring-run Chinook through fish access to upstream cold-water areas during the spring and summer.

5.2.2.2. *Harassment and Poaching*

As compared to the mainstem, anadromous fish in the tributaries are much more prone to human disturbance from harassment and poaching. In particular, because adult spring-run Chinook hold over summer in clear-water pools in some tributaries (Figure 18) ([Spring Chinook](#)), the fish are highly vulnerable to disturbance by human activities. This circumstance is particularly true in Mill, Deer, Big Chico, and Butte creeks where the public has ready access to important spring-run Chinook holding areas and swimming in the cold pools is popular during the hot northern California summers (Figure 19). Another form of human disturbance of oversummering spring run occurs during research and monitoring activities. Due to heightened concern over the population status of spring run, annual surveys of the streams are conducted. Adult fish are easily counted via snorkeling in the clear-water pools (Figure 20). Ironically, these efforts likely stress, or at the least harass, adult spring run and could inadvertently cause pre-spawning mortalities. There have also been anecdotal reports of poaching in lower tributary reaches. During the 1980s, DFG trained their wardens to increase focus on fish; prior to that time, most attention was on deer poaching. In an effort to increase public awareness and response to illegal activities, DFG launched a confidential secret witness program (CalTip) in 1981 to encourage the public to report poachers and polluters. The benefits of these law enforcement efforts are difficult to discern.

Figure 18. Adult spring-run Chinook salmon in Butte Creek. Photo by John Icanberry, USFWS.

Figure 19. Swimmers in Big Chico Creek in holding habitat for adult spring-run Chinook. Photo by Dave Vogel.

Figure 20. Adult spring-run Chinook in Deer Creek. Underwater photo by Dave Vogel.

5.2.3 Conclusions on Adult Fish Holding Habitat

- With a few exceptions, adult fish holding habitats for anadromous fish in the Sacramento River and its tributaries are good to excellent.

- There is an abundance of deep, cold pools for anadromous fish in the mainstem Sacramento River. Access of adult fish to areas upstream of Red Bluff where water temperatures are cooler has been incrementally improved since the 1980s with fish passage improvements at RBDD.

- Over the past one to two decades, remedial actions to eliminate the discharge of acid mine drainage historically known to have killed adult salmon in the upper river have essentially solved that problem.

- Recently, structural measures implemented at the Keswick Dam spilling basin have also eliminated that source of mortality to adult fish holding in the upper river.

- The thermal regime for mainstem holding habitats has improved since installation of the water temperature control device on Shasta Dam and structures on the Trinity River trans-basin diversion into the Sacramento River.

- The available evidence shows that mainstem holding habitats for anadromous fish have consistently and significantly improved in recent decades.

- Spring-run surveys have become common in all tributaries possessing sustained or remnant populations, but these surveys likely adversely impact adult fish during periods when they are most susceptible to stress and marginal water temperatures.

5.3 Spawning and Incubation

5.3.1. Mainstem Sacramento River

5.3.1.1. *Fecundity*

Changes in the fecundity of anadromous fish can have profound effects on the reproductive capabilities and resilience of the populations. As discussed later in a subsequent section of this report pertaining to "Ocean Rearing" (Section 5.6.3), the available evidence indicates that the greatest change in salmon fecundity is attributable to the effects of how the fish are harvested in the ocean through the sport and commercial fisheries.

5.3.1.2. *Habitat Quantity and Quality*

Based on early surveys prior to the construction of Shasta and Keswick dams, it was estimated that 187 miles of habitat for Chinook salmon were available upstream of the present dam sites (Hanson *et al.* 1940). Because these dams blocked salmon passage, a large amount of habitat in the Sacramento River basin was eliminated, resulting in large-scale reductions in physical habitats for all runs and for all freshwater life stages. However, significant declines in both spring-run and fall-run Chinook were noted by 1929, prior to the construction of Shasta Dam, which were attributed to overharvest, blockage by irrigation dams (*e.g.*, ACID dam during 1917 – 1927), and habitat degradation caused by railroad construction and hydraulic mining (Reynolds *et al.* 1990). Although Shasta Dam eliminated the majority of spring-run and winter-run Chinook spawning and rearing habitats in the Sacramento River basin, the runs' present-day

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migration and spawning timing still reflects the historical migration and spawning timing (Myers *et al.* 1998).

Additionally, construction of Shasta and Keswick dams eliminated the recruitment of spawning gravel to the main-stem river immediately below the dams and resulted in "armoring" of the riverbed making much of the substrate unsuitable for spawning (Buer *et al*. 1984, Buer 1985). Prior to construction, about 100,000 tons of spawning gravels per year were recruited to downstream areas (Buer *et al*. 1984). Based on underwater surveys, the Sacramento River downstream of Keswick Dam has become scoured to bedrock in many areas and armored with large cobbles (Vogel and Taylor 1987). Most spawning gravel recruitment in the upper Sacramento River is presently derived from bank erosion and tributaries, but controlled dam releases are limiting the amount of gravel recruitment from riverbanks (Buer 1985). Gravel mining on some tributaries has also reduced the recruitment of spawning gravels into the mainstem channel (Reynolds *et al.* 1990). Overall, the elimination of gravel recruitment from sources upstream of the dams and gradual armoring of riverbed substrates downstream of the dams has resulted in a chronic, but nevertheless important, adverse impact to salmonids by reducing the quantity and quality of spawning areas. Synoptic spawning substrate surveys elsewhere in the mainstem Sacramento River indicate that the substrates are sub-optimal for spawning. Potential spawning gravels possess considerable fines (sand and silt) near the threshold of concern for egg and alevin incubation and many of the spawning riffles are composed of sub-optimally-sized large cobbles instead of smaller gravels (D. Vogel, pers. observations). The Resources Agency of California believed that the loss of spawning gravel downstream of Keswick Dam and gravel mining in some tributaries partially caused the decline in upper Sacramento River Chinook salmon (RAC 1989).

In 1987, the USFWS mapped the entire riverbed (bank-to-bank) from ACID dam to Keswick Dam (Figure 21). Findings from those surveys demonstrated that some spawning habitat for salmon was still present in this three-mile reach and salmon (particularly winter-run Chinook) were utilizing those areas, but the riverbed had been scoured in many areas to bedrock or coarse, armored substrate (*e.g.*, large cobbles) too large for salmon spawning (Vogel and Taylor 1987). In that year, approximately 10 percent of the entire winter run utilized this reach for spawning (Vogel and Taylor 1987), empirically emphasizing the importance of the reach. As a result of those surveys, this author and DFG initiated a plan during the 1980s to infuse large quantities of spawning gravels downstream of Keswick Dam to increase salmon spawning habitats (Table 3). With partial funding by USBR, approximately 30,000 cubic yards of gravel were dumped in this area of the river by DFG during 1988 and 1989 (Reynolds *et al.* 1990). Additionally, to partially compensate for the historical loss of spawning gravel in the upper river, DFG and DWR have been involved in Chinook salmon spawning gravel replenishment projects in the upper reaches of the Sacramento River since 1978. Since then, spawning gravel replenishment has periodically occurred in this reach and other areas further downstream once prior gravel additions are mobilized during high flows. In 1990, eight sites were chosen for gravel replenishment (USFWS 1993). Flows as high as 50,000 cfs mobilized and dispersed the spawning gravels and have increased spawning substrates for fish, particularly for winter-run Chinook (USFWS 1993). Anadromous fish spawning is not uniform, and in most instances is more concentrated in

upstream areas closer to dams. It has therefore been recognized that replenishment of good spawning gravel in the uppermost reaches immediately downstream of the dam sites will likely enhance population recovery efforts.
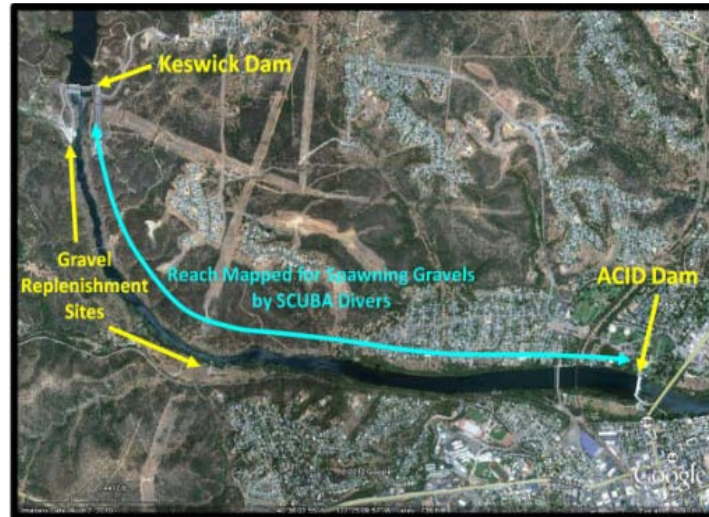
Figure 21. Location of spawning habitat surveys by the USFWS in 1987 (Vogel and Taylor 1987).

Because of the concern over impacts to winter-run Chinook salmon spawning and egg incubation, recent bridge retrofit construction projects in the upper Sacramento River where salmon may spawn prompted new restrictions on in-river construction activities. Generally, any bridge project in the upper Sacramento River has required pre-construction spawning gravel surveys in the vicinity of the bridge and, based on those findings, required restrictions on any in-river work which may adversely impact spawning or egg incubation. Recent examples include Diestelhorst Bridge (Vogel 1994), South Bonnyview Bridge (Vogel 1995a), Deschutes Road Bridge (Vogel 2000), North Street Bridge (Vogel 2003b), Jellys Ferry Bridge (Vogel 2007a), I-5 Bridge in Anderson, and Cypress Street Bridge. None of these projects are believed to have harmed anadromous fish.

5.3.1.3. *Water Temperatures*

Good Chinook salmon spawning success in the Sacramento River is determined by the length of the river reach that possesses cold water. In most years, the area of suitable spawning habitat with respect to water temperature is located in the 60 river miles between Keswick Dam and Red Bluff. Water temperatures between Keswick Dam and Red Bluff are affected by the following factors (RAC 1989):

- Ambient air temperature
- Tributary inflows
- Volume of water released from Keswick Dam
- Ratio of Spring Creek Power Plant to Lake Shasta releases
- Total storage at Shasta and Clair Engle (Trinity) Lakes

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- Depth of water released from Shasta Lake

Historically, in some instances, warm water temperatures in the Sacramento River downstream from Shasta Dam have caused egg mortalities. The problem has impacted mainstem-spawning spring-run Chinook and the earliest-spawning fall-run Chinook in the early-fall during dry years when low flows of relatively warm water were further influenced by high ambient air temperatures (SWRCB 1995). The adverse impacts of warmer water were most evident for winter run and mainstem spring run because their egg incubation timing encompasses seasonally warm months. For example, during the droughts of 1976 and 1977, warm water temperatures undoubtedly adversely impacted winter-run Chinook egg incubation. Hallock and Fisher (1985) found that water temperatures suitable for winter-run Chinook salmon egg incubation were present downstream of Red Bluff in only 4 of the 18 years for the period of 1967 through 1984. This indicates that optimal spawning and incubating temperatures for winter run below Red Bluff were historically highly unlikely during any given year. This circumstance was exacerbated after the construction and operation of Red Bluff Diversion Dam which impeded and blocked some upstream migrating salmon.

The change in the thermal regime also affected the rate of incubation and subsequent emergence timing of salmonids. Earlier emerging fish may have an advantage over later emerging fish because they may occupy "optimum" habitats and cause displacement (dispersal) of later fish to downstream areas. Additionally, water temperature has a strong influence on salmonid growth rates during fry and juvenile rearing. Temperature could influence seasonal shifts in micro-habitat use or become an overriding factor in establishing the longitudinal distribution of fishes in a river. A thermal advantage to salmon was provided by relatively warmer water (but still suitable) releases during the winter months which accelerated incubation of salmon eggs and subsequent growth and emigration from the river (Moffett 1949). *O. mykiss* also have benefited from the warmer winter water temperatures that resulted from the construction and operation of Shasta Dam and Reservoir. As early as the late-1940s, greatly accelerated rainbow trout production below the dam and excellent trout fishing was enhanced in downstream reaches (Moffett 1949). In the present day, trout fishing in the upper Sacramento River downstream of Keswick Dam is considered excellent.

The periodic summer water temperature problems associated with Shasta Reservoir during lower water elevations were largely eliminated following the installation of the $84 million water temperature control device on the face of the dam and the installation of a water temperature curtain in Whiskeytown Reservoir which maintained cooler water introduced into the upper Sacramento River via the Trinity River trans-basin water diversion. Releases of hypolimnetic water deep in the reservoir provides for suitable water temperatures during critical salmon egg incubation periods while concurrently providing for power generation (Vogel 1990).

The thermal regime resulting from construction of Shasta Dam also has benefited green sturgeon. The range of green sturgeon in the mainstem Sacramento River is now likely greater than it was historically because of an improved and expanded thermal regime in the river at times important for sturgeon. There are no records of green sturgeon from Lake Shasta or Lake Oroville

(USFWS 1995) and no evidence that green sturgeon were ever present upstream of Shasta Dam. Prior to construction of Shasta Dam, the Sacramento River downstream of the site was characterized by low, warm flows during the late-spring and summer months when green sturgeon spawn. Water temperatures could exceed the thermal tolerances of sturgeon eggs and become sub-optimal or lethal[8]. After dam construction, the seasonal thermal regime changed dramatically such that the river became much colder providing consistently optimal temperatures during the entire sturgeon spawning and egg incubation season (Figure 22). This greatly improved thermal regime extended far downstream of the dam site (Figure 23)[9] and is now recognized to continue past the Red Bluff Diversion Dam. This circumstance is attributable to three principal factors: 1) release of cold, hypolimnetic water from the deep reservoir, 2) the trans-basin diversion of Trinity River water to the Sacramento River, and 3) increased releases of reservoir water and conveyance of water in the river for downstream beneficial uses during the spring and summer months. The mid-Sacramento River mainstem flow regime during the late spring and summer months (when green sturgeon spawn and larvae and fry rear) is higher and cooler than it was historically. The biological significance of this phenomenon is that post-Shasta Dam operations undoubtedly improved and expanded the range of suitable green sturgeon habitats in the mainstem Sacramento River as compared to pre-Shasta Dam conditions. The installation of the water temperature control device on Shasta Dam has further enhanced the thermal regime for anadromous fish in the mainstem.
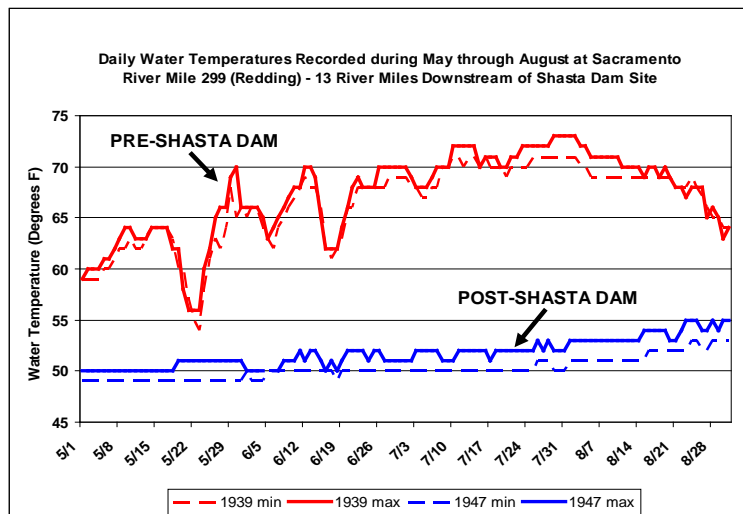
Figure 22. Daily water temperatures measured in the Sacramento River at river mile 299 during May through August, 1939 (pre-Shasta Dam) and 1947 (post-Shasta Dam) (constructed using data from Turek 1990).

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[8] Lethal to eggs above 68°F.

[9] Comparable data were only available for August. However, these data provide an indication of how the thermal regime improved because of characteristic temperatures during the spring and summer months (reference back to Figure 22).
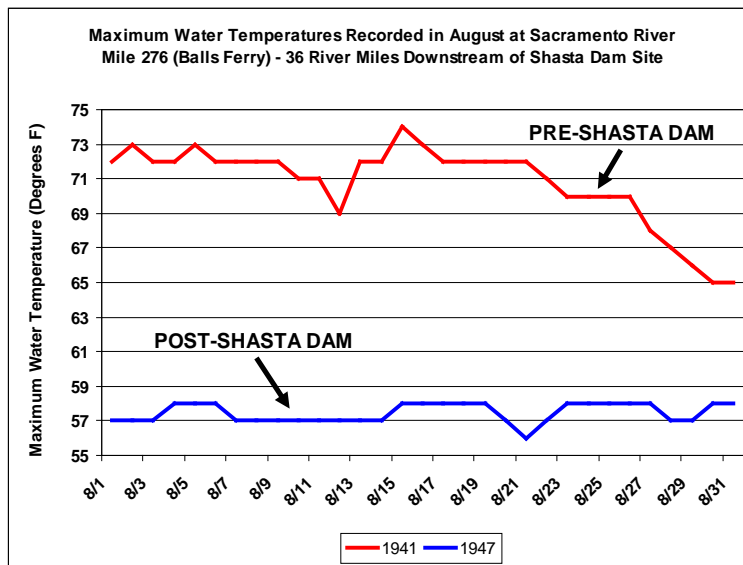
Figure 23. Daily maximum water temperatures measured in the Sacramento River at river mile 276 during August, 1941 (pre-Shasta Dam) and 1947 (post-Shasta Dam) (constructed using data from Turek 1990).

However, the large-scale changes in the reservoir operations that would result from proposed new Delta flow criteria (*e.g.*, SWRCB 2010, DFG 2010) could seriously jeopardize spawning and egg incubation conditions for some species at critical times of the year. These draft reports by the SWRCB and DFG have suggested that high flows should be released from upstream reservoirs in an attempt to alleviate mortality problems in the Delta. If implemented, those flow measures would result in frequent, major drawdowns on Shasta Reservoir, even to dead pool MBK (2010). Large drawdowns on the reservoir would severely deplete the cold-water pool available for fish in downstream reaches and would have devastating impacts on anadromous fish and largely undo the major progress made on upstream fishery restoration in recent years. As appropriately described by SWRCB (2010) and DFG (2010), "*temperature and water supply modeling analyses should be conducted...*" prior to implementation of such dramatically increased flows.

5.3.1.4. *Flows*

Changes in the flow regime after Shasta Dam and Keswick Dam construction also altered spawning and incubation habitat for salmonids on the mainstem Sacramento River. The minimum flow for spawning salmon downstream of Keswick Dam immediately after construction was specified at 2,500 cfs for protection of eggs and fry (Moffett 1949). There were sporadic instances of redd dewatering that occurred in the years shortly following dam construction. As recently as 1990, DFG believed that the existing flow requirements downstream of Keswick Dam (Table 4) were inadequate for salmon with a primary concern focused on stranding of salmon redds along with a lack of a specified down-ramping rate to protect for the stranding of juvenile fish (Reynolds *et al.* 1990). The latter problem has been largely eliminated by appropriate ramping of reservoir releases. The CVPIA has resulted in

improved flow management by avoiding inadequate or fluctuating flows that could cause fish losses (DFG 1998). During the 1980s, DFG and USBR negotiated a new instream flow schedule to eliminate the deleterious effects of redd dewatering from a flow of 3,900 cfs during the fall to 2,600 cfs in the winter (Table 4). There is no evidence that this modern-day flow regime has been detrimental to anadromous fish spawning and incubation. During many years, the actual flows are much higher than the minimum specified flow levels because of reservoir operations, downstream flow needs, and tributary accretions.

Table 4. Required minimum instream flows (cfs) downstream of Keswick Dam.		
	Pre-1981 flow regime	Post-1981 flow regime
January 1 – February 28	2,600 cfs	3,250
March 1 – August 31	2,300 cfs	3,250
September 1 – November 30	3,900 cfs	3,250
December 1 – December 31	2,600 cfs	3,250

5.3.2 Sacramento River Tributaries

5.3.2.1. *Habitat Quantity and Quality*

There are two reaches in the Feather River where both fall-run and spring-run Chinook spawn: the low-flow channel from Oroville to Thermalito Afterbay outlet, and the lower reach from Thermalito Afterbay outlet to Honcut Creek, near the town of Live Oak (Sommer and McEwan 1995). Approximately 75% of Feather River natural fall-run Chinook spawning occurs in the eight-mile reach between the Fish Barrier Dam (RM 67) and the Thermalito Afterbay outlet (RM 59) which is regulated at 600 cfs, (except during flood flows) with the remainder of the spawning activity occurring in the 15-mile reach between the Afterbay outlet and Honcut Creek (RM 44) (Sommer *et al.* 2001, as cited by HDR/SWRI 2007). The Feather River downstream of Oroville Dam in the low-flow channel has an armored cobble bed due to lack of gravel recruitment and periodic high flows in the reach where most salmon spawn and has become progressively more armored over the past 16 years (Sommer *et al.* 2001). There has been a significant increase in the proportion of spawning salmon using the low-flow channel in recent years which may be partially attributable to increased flows, but hatchery operations and introgression between fall and spring runs may also play a role (Sommer *et al.* 2001). The lower reaches contain more gravel and less armoring partly due to actively eroding riverbanks (HDR/SWRI 2007). Some limited steelhead spawning occurs in small secondary reaches in the low-flow channel which possesses smaller-sized substrate and more cover habitat, but is less than 1% of the available habitat in the low-flow channel (DWR 2000, as cited by HDR/SWRI 2007). Water temperatures in the low-flow channel typically average about 47°F in the winter to about 65°F in the summer (HDR/SWRI 2007), the latter of which can limit any salmon production during the warmest months of the year. However, cold water releases from Oroville Reservoir generally provide suitable temperatures for spawning later in the season (DWR 2001, as cited by HDR/SWRI 2007).

Construction of New Bullards Bar Dam and Reservoir on the North Yuba River has improved

conditions for anadromous fish in the lower Yuba River due to a better thermal regime and higher flows in downstream reaches (HDR/SWRI 2007). A 1965 DFG and YCWA agreement and the 1966 Federal Power Act license placed limits on flow reductions and fluctuations, which have generally been effective in protecting fall- and spring-run Chinook redds (SWRCB 1994, as cited by HDR/SWRI 2007). Additionally, a 2005 FERC order provided even further protection of salmonid redds and juvenile stranding from flow reductions and fluctuations (FERC No. 2246, as cited by HDR/SWRI 2007). More recently, the Lower Yuba River Accord was negotiated and now provides instream flows at an equivalent or higher level of protection for spring-run, fall-run, steelhead, and green sturgeon compared to previous conditions (HDR/SWRI 2007). Although the present-day instream flows on Sacramento River basin rivers downstream of the major dams may or may not be optimal, the flow regime and physical effects on spawning and incubation habitats are probably not a major limiting factor to the salmonid runs. As previously mentioned, the Fisheries Agreement of the Yuba River Accord provides for new minimum instream flows in the lower Yuba River that are intended to maintain or increase fishery resource protection. This Agreement was developed by State, federal, and consulting fisheries biologists, fisheries advocates and policy representatives, and establishes higher minimum instream flows during most months of most water years (HDR/SWRI 2007).

Historically, flows and habitat conditions on some of the smaller tributaries important for anadromous fish production were believed to be insufficient. For example, Fry (1960) reported that Battle Creek, beginning a short distance upstream of Coleman National Fish Hatchery, was badly degraded by low flows caused by upstream power diversions and Mill and Deer creeks suffered from low flows due to irrigation diversions. Although some other important tributaries for anadromous salmonids do not have large dams blocking gravel recruitment, gravel mining has impacted the supply for spawning fish (Buer *et al*. 1984). Gravel replenishment projects in important spawning areas lacking natural gravel recruitment would undoubtedly benefit anadromous fish. Many of the important anadromous fish tributaries currently have restoration programs underway (discussed later) which are assumed to also benefit spawning habitats during recent years.

Physical habitat conditions for spawning and incubation in Mill and Deer Creek are believed to be highly favorable for spring-run Chinook and these two tributaries are considered as the best habitats currently available (NMFS 2009). However, the runs are currently depressed indicating the primary problems affecting the species are elsewhere. The USFWS has recently proposed extracting fertilized spring-run Chinook eggs from these tributaries as a potential source for a proposed program to re-introduce salmon into the upper San Joaquin River downstream from Friant Dam. However, doing so is premature and has a high probability of adverse impacts to Mill or Deer creek populations because of the currently depressed populations. Furthermore, the likelihood of success for San Joaquin spring-run restoration is very low due to a multitude of factors (*e.g.*, probable inter-breeding with fall-run Chinook[10] and extremely poor juvenile fish outmigration survival in the San Joaquin River and Delta).

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[10] Such as has already occurred on the mainstem Sacramento River downstream of Keswick Dam and the Feather River downstream of Oroville Dam.

5.3.3 Conclusions on Spawning and Incubation

- Construction of dams has resulted in the lack of gravel recruitment to some downstream anadromous fish spawning areas, a problem that is particularly acute downstream of Keswick Dam.

- Although Englebright Dam has halted recruitment of gravels from upstream areas, spawning gravel for salmonids is abundant and is not limiting in the lower Yuba River (with the exception of the Englebright Dam reach, for which the Corps has embarked on a gravel reintroduction project).

- The flows and thermal regimes resulting from the reservoirs associated with these dams have significantly improved spawning and incubation habitats, particularly during recent years.

- Recent recommended high reservoir releases (SWRCB 2010) to ameliorate problems in the Delta (*e.g.*, predation) could drastically reduce reservoir levels in some years and deplete cold-water storage; if implemented as proposed, such measures could have devastating impacts on anadromous fish egg incubation at critical times in some years.

- Watershed restoration programs on numerous tributaries are believed to have benefited habitat conditions and those collective efforts are expected to continually improve habitats for fish.

5.4 Fry and Juvenile Rearing

5.4.1 Mainstem Sacramento River

5.4.1.1 *Habitat Quantity and Quality*

In addition to the major reduction in reproductive habitat, a large amount of rearing habitat for young salmonids was lost in upstream areas when the large Sacramento River basin dams were built. Following construction, fish produced within the main-stem reaches downstream of the present dams were forced to rear in large river channels formed by historical high flows because of the change in the species geographic distribution. The instream habitat attributes of complexity and diversity previously available upstream of large dams cannot be re-created in the large river channels downstream of dams through flow alone and cannot serve as a surrogate for the lost habitats upstream of the dams. The biological significance of this circumstance is that the dam construction did more than simply reduce the amount of habitat. Juvenile salmonids originating from present-day main-stem spawning (unlike previously available habitats in smaller stream channels upstream of the dams) have to contend with the rigors of a larger riverine channel. It is generally acknowledged that the biological quality for fry and juvenile

rearing of past available reaches upstream of the dams was superior to the habitats downstream of the dams and the reduction in physical habitat (*i.e.*, quantity) was absolute. Thus, the resultant effects on the fish populations would be expected to appear shortly following dam construction, but was not realized.

The Sacramento River below Keswick provides a diversity of aquatic habitats, ranging from fast water riffles (relatively shallow, turbulent water flowing over cobbles) and glides (deeper, slower-moving water) in the upper reaches, to slow-water pool and glide habitats under tidal influence in the lower reaches. It is presently not known if the main-stem Sacramento River instream habitats provide sufficient amounts of the micro-habitat diversity and complexity required for juvenile salmonid rearing. Each life stage of riverine fishes demonstrates a marked "preference" for different velocities in a river or stream. In all cases, their documented utilization with higher velocities declines precipitously. Higher releases from dams result in increased velocities within the spawning and rearing habitats downstream of the dams and, if too high, are detrimental to fish habitats. Certain increases in reservoir releases can substantially reduce the number and areas of low water velocity which could displace fry from optimal to suboptimal habitats and induce premature downstream movement. Such circumstances could result in non-uniform dispersal to inferior rearing habitats or may cause density-dependent problems (*e.g.*, 90 percent of the fish using 10 percent of the rearing habitat). High flow regimes recommended by SWRCB (2010) could result in premature displacement of fry to unfavorable rearing habitats.

There are indications that the mainstem river channel may not provide adequate rearing areas for anadromous fish, as evidenced by rapid displacement of fry from upstream to downstream areas and into non-natal tributaries (Vogel 1993b) during increased flow events. Underwater observations of salmon fry in the mainstem Sacramento River suggest that optimal habitats may be limited. As discussed previously, recently emerged fry prefer different habitats for rearing than larger-sized juvenile fish which can reside in the higher velocity regions of the mainstem channel. Much of the main river channel is devoid of structural complexity necessary for fry rearing and, due to the channel morphology and relatively high flows released from Shasta Dam during the primary rearing period, the best habitats are on the channel fringes (*e.g.*, Winter-Run Chinook Fry Rearing on the Sacramento River near the Riverbank). Underwater observations near artificial structures in the main channel have shown fry rearing activity, but may suggest the fish are utilizing those areas because insufficient other natural structures are limited or lacking. The following are examples:

Winter-Run Chinook Salmon Rearing Behind a Trashrack in the Sacramento River at Redding, California

Winter-Run Chinook Fry Rearing in Front of a Fish Screen at Redding, California

Winter-Run Chinook Fry Rearing near a Bridge Pier in the Sacramento River at Redding, California

As the fish grow larger, they are better able to rear in the mainstem away from structures, often shoaling (schooling) and using much deeper water areas as demonstrated below:

The benefits of riparian habitat for native anadromous fish within the primary rearing areas are undisputed. Riparian habitat provides for recruitment of large and small woody debris into the rivers which can be used by fish for protective rearing habitat. Terrestrial insect input from overhanging or streambank vegetation has been shown to be an important source of food for juvenile fish. Cover, in the form of shade, is often sought by young fish for preferred rearing areas. Additionally, the shade provides some cooling effects from reduced insolation. The mainstem Sacramento River has been characterized as a relatively natural, well-defined channel between Keswick Dam and Red Bluff, meandering "somewhat freely" from Red Bluff to Colusa, but virtually canalized by flood control and reclamation levees downstream of Colusa (Boles and Turek 1986). DWR (1979), as cited by Boles and Turek (1986), estimated that native vegetation in the Sacramento River riparian zone from Redding to Colusa between 1952 and 1977 had decreased 14 percent, while agricultural use and urban use in the same reach increased 12 percent and 3 percent, respectively.

DWR indicated that bank stabilization on the mainstem Sacramento River downstream of Red Bluff has reduced bank erosion, which was believed to have impeded salmonid rearing habitats as affected by riparian vegetation (Buer *et al.* 1989). The great majority of these bank stabilization projects were constructed decades ago. Very little spawning habitats for most anadromous fish are present in this river reach (primarily because of seasonally warm water temperatures) and the principal rearing habitats for these species are in upstream reaches and some tributaries. Although this mainstem reach is a migratory corridor for anadromous fish and obviously serves as rearing area for at least some portion of their freshwater life phase, its relative importance is not known. An exception to the foregoing is the transitional reach between Red Bluff and those downstream areas that have been leveed and stabilized, generally within the reach from Red Bluff to Chico Landing. This area possesses the most significant area of remaining riparian habitat; it is "generally un-leveed and contains significant and substantial remnants of the Sacramento Valley's riparian forest" (RAC 1989), and it should be a primary focus of efforts to improve rearing habitat on the mainstem.

There have been recent attempts to improve potential rearing habitats in downstream reaches by adding in-channel woody debris near the stream banks. However, downstream warmer reaches possess a higher abundance of native and non-native predatory fish, many of which prefer and

use submerged woody debris as velocity refugia and favorable habitat for ambushing prey. The interaction of rearing salmonids with woody debris in their primary upstream, cold-water rearing areas where the predatory fish are less abundant is well accepted as beneficial. However, those same benefits in downstream areas, depending on specific locations, are debatable and could, in some instances, be detrimental by favoring plentiful predatory fish over juvenile native anadromous fish. Any in-channel structures, natural or artificial, in the lower-most river and Delta could be detrimental (discussed in Section 5.5.3.6).

In recent decades, there have been major programs to increase the riparian forests along the upper and transitional reaches of the Sacramento River where colder temperatures will be less favorable to predatory fish. In 1989, the Resources Agency of California completed a comprehensive riparian management plan. Within that plan, it was postulated that reestablishment of a viable riparian ecosystem along the upper Sacramento River would help reverse the decline in Sacramento River fishery resources (RAC 1989). By 1990, the DFG and DWR had become extensively involved in a stream and riparian habitat restoration program (Reynolds *et al.* 1990). Additionally, the Sacramento River National Wildlife Refuge within the Sacramento National Wildlife Refuge complex was recently established among 27 property units along a 77-mile reach of the Sacramento River between Red Bluff and Princeton (Figure 24) (source: USFWS). Presumably, efforts such as these to reverse the historical loss of riparian habitats have improved the instream environment for anadromous fish in recent years. Although quantification of those fishery resource benefits is difficult, it is reasonable to conclude that this factor has improved, rather than worsened, conditions for anadromous fish during the past decade or so.
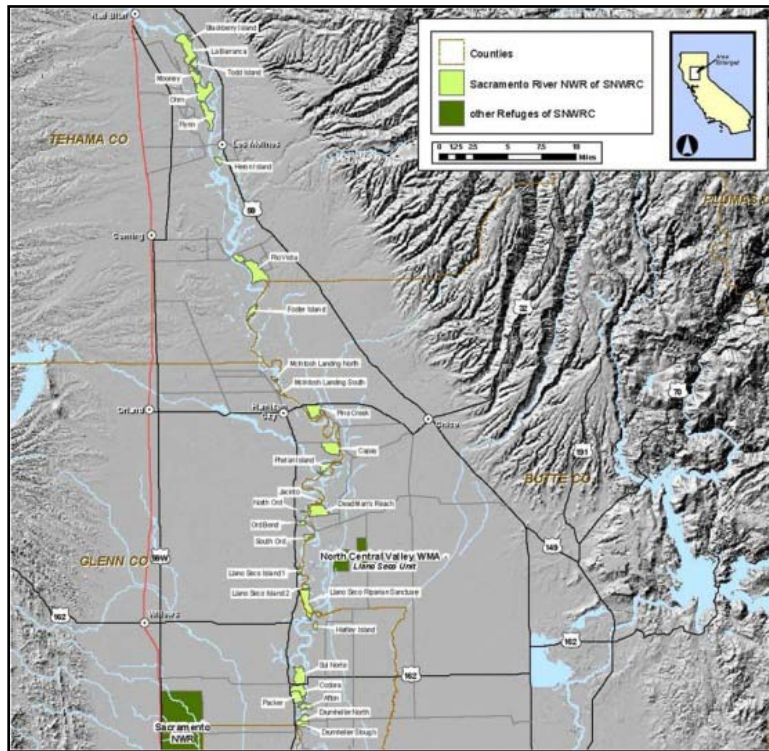
Figure 24. Locations of parcels of the Sacramento River National Wildlife Refuge along the Sacramento River (source: USFWS).

In recent years, large numbers of juvenile fish stranded upstream of RBDD have been documented shortly after the gates were raised at the end of the irrigation season. The stranding occurs in a large side channel just upstream of the dam. Some attempts to reduce this problem were implemented by partial configuration of the channel to improve drainage of isolated pools. This dilemma for rearing fish needs to be continually monitored and avoided. The situation will persist even after the RBDD gates are raised year-round because the river bed elevation is on the cusp of providing unfavorable conditions during the winter months when the high presence of juvenile fish and the frequent, naturally occurring fluctuating river flows can strand fish in pools as flows recede.

The CVPIA fish restoration program has not addressed the topic of invertebrate prey base for rearing juvenile salmonids (Cummins *et al*. 2008). Invertebrate food supply in the Sacramento River is apparently highly abundant for resident *O. mykiss* indicating that this factor would not be limiting for juvenile salmonids, which consume the same or similar organisms. Following construction of Shasta Dam, the salmonid food base in the river below the dam was believed to improve and the population of *O. mykiss* expanded significantly (Moffett 1949). The same can be assumed in the Feather and Yuba rivers where healthy populations of *O. mykiss* are present. Mitchell (2010) found consistently high average freshwater growth rates of yearly and older *O. mykiss* in the lower Yuba River.

Adverse impacts of poor water quality on rearing salmonids resulting from historical pollution in the upper Sacramento River have been well documented. It appears that the most significant past pollution impacts occurred from Iron Mountain Mine (IMM) acid mine drainage (AMD). AMD from the mine entered Spring Creek which flows into the Sacramento River between Shasta and Keswick dams (Figure 1). Iron Mountain Mine was periodically mined for copper, gold, iron, pyrite, silver and zinc from the 1860's until 1963. The site has been associated with water quality degradation and impacts on aquatic resources in nearby drainages during much of its history. Impacts include numerous fish kills in the upper Sacramento River that have been attributed primarily to the contamination of surface waters with IMM AMD that has a low pH and high concentrations of cadmium, copper and zinc. A recent EPA Environmental Endangerment Assessment of Iron Mountain Mine made the following conclusions: The primary species and populations of concern because of IMM AMD contamination are the Sacramento River's four runs of Chinook salmon, a run of steelhead trout, and resident rainbow trout. Of particular concern are the potential effects of the IMM AMD on the endangered winter-run Chinook salmon and steelhead. The early life stages of these fish (particularly swim-up fry) are highly susceptible to the toxicity of and suffocation from aqueous and sediment-borne metals and their resulting effects. (CH2M Hill 1992)

Previously, contamination from AMD released from IMM has been a major risk to Sacramento River fishery resources because of the presence of various freshwater life phases within the zone of impact of IMM AMD and the high dependence of these fish on this area for reproduction and rearing. It is evident that juvenile anadromous salmonids have been at particular risk from IMM AMD because these fish have been present in the upper Sacramento River when uncontrolled spills from Spring Creek Reservoir[11] have occurred (Table 5). The presence of some of the fish species' most susceptible life stages within the zone of potential impact has been documented to occur at the time of year when the risks to their populations are the greatest (*i.e.*, the rainy season). Adverse impacts to one salmon year class can be accentuated over time because there is little age-group overlap between year classes (discussed later). The specific magnitude and long-term effect on Sacramento River fishery resources were largely unknown because the duration and magnitude of exposure of the various fish life stages to the contaminants have not been thoroughly documented. (CH2M Hill 1992)

Table 5. Uncontrolled Spills from Spring Creek Reservoir		
Start of Spill (date)	**Length of Spill (days)**	**Volume of Spill (acre-feet)**
12/22/64	7	5,159
1/13/69	10	5,195
1/9/78	14	15,248
2/6/78	2	355
3/28/79	2	22
2/19/80	2	496

---

[11] Spring Creek Reservoir was constructed in 1963.

1/30/81	4	194
3/22/82	3	1,065
11/24/81	3	30
1/26/83	4	1,662
3/1/83	4	5,177
2/15/86	4	3,457
3/25/89	43	2,535
Note: Information obtained from U.S. Bureau of Reclamation, Central Valley Operations- Report of Operations, 1967-1990.		

As mentioned earlier, a large-scale cleanup of IMM through the EPA Superfund has essentially resolved this previously major problem for rearing salmonids. There are no documented occurrences of other pollutants having a significant adverse impact on juvenile anadromous fish rearing in the upper river. It was therefore assumed that the degree of pollution and its potential attendant immediate effects on anadromous fish were probably greater during the 1945 to mid-1960s era than the mid-1960s to present era, primarily because of more recent environmental reforms and regulatory actions, and would not have adversely impacted recent fish populations.

5.4.2 Sacramento River Tributaries

5.4.2.1. *Habitat Quantity and Quality*

It has been commonly stated that Sacramento River tributary habitats for salmonids are degraded (*e.g.*, Reynolds *et al.* 1993). The negative salmonid habitat alterations are often attributed to water diversions causing reduced stream flows and land use practices, including hydraulic mining and gold dredging, which radically changed the sediment structure and bed profile of rivers and sometimes altered stream channel courses. Because most of the diversions have been in place for a long period (with some exceptions), it is presumed that the total volume of water diverted has not changed appreciably over time. The continuing effects of gold mining operations have also been present since the late nineteenth century, and thus the timing of their effects are not well correlated with the more recent rapid decline of anadromous fish runs.

A comprehensive, stream-by-stream assessment to ascertain historic habitat alterations in the tributaries supporting anadromous salmonids is outside the scope of this report. However, based on the author's familiarity with many of these streams over approximately the past 30 years, on discussions with landowners in some of the watersheds, and based on review of dozens of related documents since the early 1980s, it can be reasonably concluded that the most significant adverse salmonid habitat alterations in these tributaries occurred decades ago, but that significant habitat improvements have been realized in recent years. For example, all the diversion dams constructed in Mill and Deer creeks on the valley floor took place prior to 1945. Another example is Battle Creek, where the primary impacts to fish occurred prior to the mid-1940s because of hydroelectric development and the construction of Coleman Hatchery (RAC 1989).

Hanson *et al.* (1940) provide accounts of the relative condition of habitats in the primary and

secondary salmon-producing tributaries between Redding and the mouth of the Feather River shortly prior to the completion of Shasta Dam. In comparison to the present day, those prior surveys on these streams indicate that these habitats for salmon, in many instances, are in better condition now than they were just prior to construction of Shasta Dam. It can be reasonable concluded that major habitat alterations in the tributaries supporting anadromous fish have not occurred during the most recent decades and, therefore, measureable changes in tributary habitat conditions during recent years cannot account for the recent precipitous declines in some salmonid populations. An exception to the general lack of major habitat alterations in recent decades is the construction of Whiskeytown Dam on Clear Creek, an important fall-run Chinook (and possibly late-fall-run Chinook) stream, in the mid-1960s. Notwithstanding its construction, that does not appear to have had a significant effect because Saeltzer Dam was constructed in 1903 downstream of the Whiskeytown Dam site and its ineffective fish ladder blocked upstream movement of salmon (Hallock 1987), indicating that the most significant habitat loss in Clear Creek occurred prior to Whiskeytown Dam construction. Black Butte Dam was constructed on Stony Creek in the mid-1960s, but this tributary has never been considered a major salmon-producing stream and historically probably supported only small runs of salmonids upstream of the present dam.

The available evidence therefore indicates that habitat conditions in the tributaries have improved over time in recent decades. The following are a few examples. Significant habitat improvements on Mill, Deer, and Butte creeks have been implemented which are believed to have benefitted spring-run Chinook (DFG 1998). Major actions implemented or soon to be implemented on Battle Creek (Figure 25) are also believed to improve conditions for rearing anadromous salmonids. The Battle Creek Salmon and Steelhead Restoration Project, scheduled for completion in 2014, will restore 48 miles of salmonid habitat. During implementation of the federal Anadromous Fish Restoration Program and the CALFED Ecosystem Restoration Program, there were significant efforts to establish local watershed groups to promote public education on the values of fish restoration through improved land and water management practices. Watershed groups have proliferated (Figure 26) and have been and are used as a channel to obtain grants to study and improve watershed conditions in important native anadromous fish tributaries in the Sacramento River basin.

Figure 25. The Battle Creek Restoration Project (from the Greater Battle Creek Watershed Working Group).

Sacramento River Watershed Partners

Goose Lake Watershed Council

Pit River Watershed Alliance

McCloud River CRMP

Upper Sacramento River Exchange

Lower Clear Creek Watershed Group

Shasta West Watershed Group

French Gulch Upper Clear Creek Resource Mgt. Group

Western Shasta RCD

Cottonwood Creek Watershed Group

Mill Creek Watershed Conservancy

Tehama County RCD

Sacramento River Conservation Area Forum

Deer Creek Watershed Conservancy

Big Chico Creek Watershed Alliance

Friends of Butte Creek

Little Chico Watershed Group

Sacramento River Preservation Trust

Butte Creek Watershed Conservancy

Butte County RCD

Upper Stony Creek CRMP

Glenn County RCD

South Yuba River Citizens League

Yuba Watershed Council

Nevada County RCD

Yuba County RCD

Colusa County RCD

Middle Creek CRMP

West Lake RCD

Scotts Creek Watershed Council

Lower Lake Watershed Council

East Lake RCD

Upper Cache Creek CRMP

Upper Putah Creek Stewardship

Cache Creek Watershed Stakeholders Group

Cache Creek Conservancy

Yolo County RCD

Lower Putah Creek Coordinating Committee

Putah Creek Council

Solano County RCD

Central Modoc RCD

Pit River RCD

Fall River RCD

Stillwater-Churn Creek Watershed Alliance

Cow Creek Watershed Group

Bear Creek Watershed Group

Battle Creek Watershed Conservancy

Cherokee Watershed Alliance

Feather River RCD

Feather River CRMP

Sierra Valley RCD

Lower Feather River/Honcut Creek Watershed Group

Friends of Deer Creek

Wolf Creek Community Alliance

Sutter County RCD

Dry Creek Conservancy

Georgetown Divide RCD

El Dorado County RCD

South Fork American River Watershed Group

American River Watershed Group

Placer County RCD

American Basin Council of Watersheds

Dixon RCD

SACRAMENTO RIVER watershed PROGRAM

www.sacriver.org

0 3.75 7.5   15   22.5   30 Miles

By Peter Tittmann of LocusCor_GIS and Chris Ericksen of Larry Walker Associates June 2006

Copyright of the Sacramento River Watershed Program, 2006

Figure 26. Map of Sacramento River basin watershed groups. Source: www.sacriver.org.

Operations of New Bullards Dam and Reservoir on the North Yuba River have led to significantly improved flow and thermal regimes in the lower Yuba River. Spring-run Chinook juvenile rearing extends year-round in the lower Yuba River (HDR/SWRI 2007) indicating habitats are suitable for anadromous fish. Higher densities of juvenile spring run are evident in areas upstream of Daguerre Point Dam, which may be attributable to a higher number of spawning salmon in this reach, more complex high-quality cover, or lower numbers of predatory fish (HDR/SWRI 2007). Higher densities of juvenile steelhead are also found upstream of Daguerre Point Dam and larger juveniles and resident trout have been commonly observed both upstream and downstream of the dam (SWRI *et al.* 2000, as cited by HDR/SWRI 2007). Implementation of the Lower Yuba River Accord has improved conditions for rearing anadromous fish. Instream flows through the Accord provide an equivalent or higher level of protection for spring-run, fall-run, steelhead, and green sturgeon compared to previous conditions (HDR/SWRI 2007). Release of cold, hypolimnetic water from Oroville Reservoir has improved the thermal regime for rearing salmonids in downstream reaches. Additionally, the FERC re-licensing process associated with Oroville Dam is assumed to result in improved rearing habitats for anadromous fish in the Feather River.

It is, therefore, reasonable to conclude that the foregoing collective efforts have improved habitat conditions for anadromous fish on many tributaries.

5.4.3. Conclusions on Fry and Juvenile Rearing

- Unprecedented, large-scale fish habitat restoration actions have been implemented in most Sacramento River basin tributaries important for native anadromous fish production; many of these measures have been recently completed, are underway, or will soon be accomplished.

- Dam construction in the Feather and Yuba rivers led to cooler water and more-reliable instream flows in downstream reaches, benefiting fish rearing in the lower rivers through dam operations over recent years.

- Incremental improvements on many tributaries have been achieved through a variety of regulatory and voluntary actions.

- Smaller, but extremely important tributaries such as Battle, Clear, and Butte creeks are expected to have greatly expanded and improved anadromous fish rearing habitats through dam removals, improved flow regimes and other actions.

- Due to heightened awareness of the importance of anadromous fish, there has been a proliferation of watershed groups in most tributaries which have focused on improving overall watershed health.

- There are no indications that the quality and quantity of fry and juvenile rearing in the

tributaries have declined in recent decades. To the contrary, based on restoration activities in the tributaries, it is reasonable to conclude that fish habitats in the tributaries are considerably better than what existed decades ago.

- Relative changes in the quantity and quality of mainstem Sacramento River rearing habitats since the construction of Shasta and Keswick dams are difficult to discern, largely due to lack of site-specific data.

- In the many decades since large dam construction, there has undoubtedly been a chronic, slow decline in the physical/structural attributes for optimal rearing habitats. Substrates and in-channel structures important for complex, high-quality rearing habitats have declined because of lack of replacement due to a downturn in riparian habitats which provide woody debris input into the river and lack of any significant ongoing gravel recruitment from areas upstream of the dams.

- The location and timing of the source of Iron Mountain Mine pollution corresponded with the presence of the important anadromous fish in the potential zone of impact. The magnitude of impacts is sufficient to have caused substantial fish kills in some years. The water quality in juvenile rearing habitats have vastly improved due to enormous Super Fund expenditures to remediate acid mine drainage (metal pollution) from Iron Mountain Mine in the upper portion of the river.

- In many cases, dams now prevent access to former rearing areas but over the decades following dam construction, the instream flow regimes in areas below the dams have improved for rearing fish.

- Carefully controlled timing and magnitude of flows from Shasta and Keswick dams and dams in the Feather and Yuba river watersheds have reduced fish losses caused by stranding; this fish mortality factor has been reduced over the years.

- The benefits of large storage reservoirs which convey large quantities of high quality water to downstream areas have improved water temperatures for rearing.

- The mainstem Sacramento River is not flow-limited for fish rearing habitats.

- The existing flows in the mainstem Sacramento River at important times of the year may actually be too high to maximize the quantity and quality of rearing habitats for fry and juvenile life stages of salmonids.

- The significant changes to the flow regime that would result from the proposed new Delta flow criteria in SWRCB (2010) and DFG (2010) could jeopardize conditions for anadromous fish in the upper reaches. Among these potential detrimental changes is an alteration in the thermal regime which could be unfavorable for rearing fish during

portions of the year.

5.5 Fry and Juvenile Outmigration

5.5.1. Sacramento River Tributaries

5.5.1.1. *Entrainment*

The importance of screening water diversions on Sacramento River basin tributaries has been widely recognized for many years. In recent decades, there have been an increase in the number and quality of fish screens; the following are a small sample of numerous examples. As of 1987, there were 13 satisfactorily working fish screens on tributary streams supporting anadromous salmonids. Most of these were installed from the 1950s through the 1970s (Hallock 1987). Since then, DFG has continually upgraded and improved the agency's screens in anadromous fish tributaries. In 1990, DFG reported that all water diversions on Mill, Deer, and Antelope creeks had been adequately screened for fish protection (Reynolds *et al.* 1990). By 1990, as part of a FERC relicense condition, PG&E had constructed a new fish screen at the power company's diversion on South Cow Creek (Reynolds *et al.* 1990). USFWS recently upgraded the fish screens on Coleman National Fish Hatchery water supply intakes in Battle Creek. Several new fish screens were installed on Butte Creek, an important spring-run tributary, at Adams Ranch, Gorrill Land Company, and Parrott-Phelan Dam (Figure 27). A water diversion facility on lower Big Chico Creek was relocated to the mainstem Sacramento River with new fish screens in 1997 (DFG 1998). Browns Valley Irrigation District completed a fish screen on the Yuba River approximately one mile upstream of Daguerre Point Dam in 1999 and completed a major rebuild of the 65 cfs capacity facility in 2005. There are numerous additional examples, but it can be reasonably assumed that irrigation operations on the tributaries have resulted in far less fish entrainment during recent years as compared to decades ago. A significantly expanded discussion on this topic is provided later in Section 5.5.2.1.

Figure 27. New fish screens constructed on Butte Creek. Photo by Dave Vogel.

5.5.1.2 *Flows*

No information was found to indicate that flows during the outmigration of salmonids on tributaries have decreased in recent years. To the contrary, it appears that outmigration conditions have become more favorable. The following describe several examples of these flow improvements. Instream flows under the recently executed Lower Yuba River Accord provide an equivalent or higher level of protection for spring-run, fall-run, steelhead, and green sturgeon compared to previous requirements (HDR/SWRI 2007). Measures to be implemented through the FERC relicensing process for Oroville Dam are anticipated to benefit anadromous fish. However, DFG has expressed concerns that flows over Daguerre Point Dam on the Yuba River can disorient outmigrating juvenile salmonids and increase their vulnerability to predation (DFG 1996). Numerous, unprecedented fish habitat restoration actions have been executed or are underway on many anadromous fish tributaries (*e.g.*, Battle Creek). Implementation of measures resulting from federal Biological Opinions has resulted in improved instream flows in Clear Creek. In 1989, the Resources Agency of California formally recognized the importance of outmigration flows for juvenile salmonids on some tributaries which resulted, in part, in planning and application of improvements in Mill and Deer creeks. Heightened public awareness and the potential for law enforcement actions to ensure significant adverse impacts to threatened or endangered fish do not occur are assumed to have benefitted fish during recent years, but this is difficult to determine. It is reasonable to conclude that this factor affecting anadromous fish has not been shown to have appreciably changed in recent years to the detriment of anadromous fish as compared to decades ago. Nevertheless, due to the overlap of early irrigation and late outmigration of salmonids on some tributaries (*e.g.*, Mill and Deer creeks), this problem remains for part of the outmigration period in the spring, particularly during drought years, and solutions should be developed to minimize or eliminate deleterious effects on fish (*e.g.*, structural facilities or other measures to provide water exchanges to improve the timing and magnitude of outmigration flows for fish).

5.5.2 Mainstem Sacramento River

5.5.2.1. *Entrainment*

Loss of young anadromous fish in unscreened riverine diversions is almost universally cited as a significant contributing cause for declines in fish populations. Even prior to large dam construction, unscreened water diversions were considered a serious hazard for salmon (Moffett 1949). Nearly all anadromous fish restoration plans call for screening these diversions. For this reason, a substantial amount of discussion on the topic is provided in this report.

In 1989, the Resources Agency of California (RAC) reported that there were more than 300 unscreened diversions on the Sacramento River between Redding and the Feather River confluence (RAC 1989). It was estimated that approximately 1.2 million acre feet of water is diverted annually through these diversions. It was previously hypothesized that most fish losses

may occur between Ord Ferry and Knights Landing (Figure 1) based on the following estimated annual diversions by river reach during April through October (Hallock 1987):

Redding to Red Bluff	0.3 %
Red Bluff to Ord Ferry	1.6 %
Ord Ferry to Knight's Landing	56.0 %
Knight's Landing to Sacramento	42.0 %

The first largest empirical evaluation of anadromous salmonid losses entrained into unscreened irrigation diversions from the Sacramento River was conducted by DFG during 1953 and 1954. At that time, DFG estimated there were more than 900 irrigation, industrial, and municipal water supply diversions upstream of the Sacramento-San Joaquin River Delta from stream sections used by anadromous salmonids within the entire Central Valley (Hallock and Van Woert 1959). DFG reported that most of these diversions were for irrigation purposes and very few were screened to prevent fish losses. During their investigation, the ACID diversion at Redding was the only gravity-flow diversion found; all others were pumped diversions. [Since their study, the RBDD became a large-scale gravity diversion on the main-stem Sacramento River beginning in August 1966 (Vogel *et al.* 1988)]. The 1953-1954 DFG investigations did not include sampling at the large diversions at Glenn-Colusa Irrigation District (GCID) or ACID. In 1953 there were 335 separate diversions (utilizing 448 pumps) along the 246-mile reach of the Sacramento River between Redding and Sacramento. Hallock and Van Woert (1959) concluded from intermittent sampling at 23 diversions in the Sacramento River during the 1953 irrigation season that no diversion was found to be taking young Chinook salmon or steelhead in significant quantities. Results of their sampling during the entire 1954 irrigation season at nine selected diversions in the vicinity of Colusa showed that losses at individual pumps were small. The greatest seasonal loss found in 1954 was 2,116 fingerling salmon and 110 yearling steelhead in a 24-inch centrifugal pump (Hallock and Van Woert 1959). DFG concluded:

> "*Individually, most of the small irrigation diversions do not destroy many young salmon and steelhead. Collectively, however, they take considerable numbers.*"

> "*In view of the migration time of fingerling salmon, which results in the bulk of the fish moving out of the upper river and reaching the delta by late March, and an irrigation season which does not get into full swing until late April and early May, the small losses encountered in the diversions are not surprising.*" (Hallock and Van Woert 1959) (Figure 28).
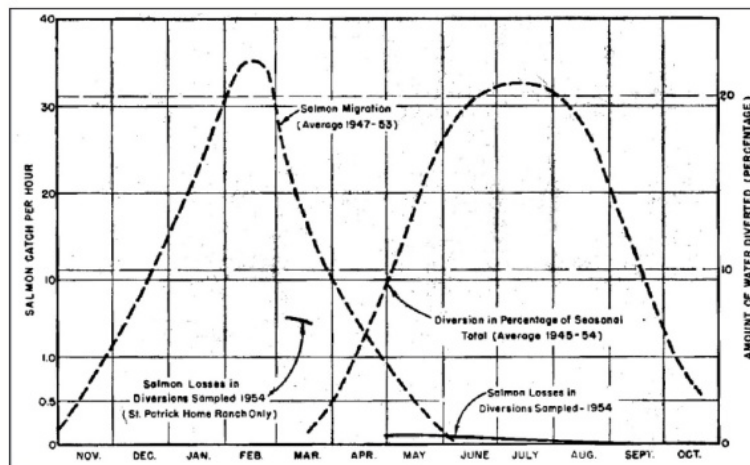
Figure 28. Comparison between times of the seaward migration of Sacramento River juvenile Chinook salmon, their losses in irrigation diversions, and the diversion of water for irrigation. (from Hallock and Van Woert 1959)

In examining the topic of potential effects of diversions on young anadromous salmonids, there are numerous aspects which should be considered. A particular element that may have an overriding influence at one diversion site could have a negligible influence at another diversion site. The following factors (from Vogel 1995b) are not listed by priority because each diversion has site-specific characteristics which influence the diversion's effects on fish.

- Seasonal timing and magnitude of the water diversion
- Proximity of the diversion to salmonid rearing habitat
- Longitudinal location of the water diversion in the river relative to the proportion of juvenile salmon which would ultimately migrate past the diversion
- Hydrologic conditions preceding the principal downstream migration (*e.g.*, wet or dry water year type)
- Specific life phase of the downstream migrants passing the diversion (*e.g.*, fry versus smolt)
- Physical configuration of the diversion intake and associated facilities
- Location of the diversion intake in the water column
- Concentration of the downstream migrants at various location in the water column and across the river channel
- Day-to-night changes in fish distribution and behavior
- Day-to-night changes in water diversion rate
- Hydraulic conditions near the diversion intake
- Water temperature in the vicinity of the diversion intake
- Location of the diversion intake in the river channel (*e.g.*, oxbow, inside or outside bend, set back or on the river, etc.)
- Absence or presence and concentration of predatory fish at the diversion site

Among these factors, the specific location, timing, and magnitude of the diversion relative to the

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seasonal presence of fish at the site are likely the primary considerations in determining potential effects on fish.

Although there are obviously differences among Sacramento River diversion operations depending on the number and types of crops irrigated, climate, and numerous other factors, most diversions generally begin operations in April. The greatest magnitude of irrigation diversions occur during the late spring and summer months. Sharp reductions in these diversions occur in the fall, and little or no diversions occur during the late fall and winter months. As previously noted, the greatest proportion of water diverted from the Sacramento River occurs downstream of the principal rearing areas for anadromous salmonids. If the diversions occurred within the principal salmonid rearing habitats, the magnitude of impacts would be expected to be significant; however, that is not the case with the Sacramento River in the areas where many irrigation diversions occur. There are no empirical data to demonstrate that this region is an important rearing area for anadromous salmonids during the time the majority of irrigation diversions occur (Figures 29-32). However, these fish migrate and undoubtedly rear in the mid- and lower Sacramento River but during a time when minimal or no irrigation diversions occur. A significant exception to this occurs during the fall and winter period when water is diverted through a small number of these facilities for wetlands/waterfowl and rice stalk decomposition purposes. An ongoing study of fish entrainment (discussed below) will help determine the relative differences in the timing of diversions and potential effects on juvenile anadromous fish (Vogel 2011).
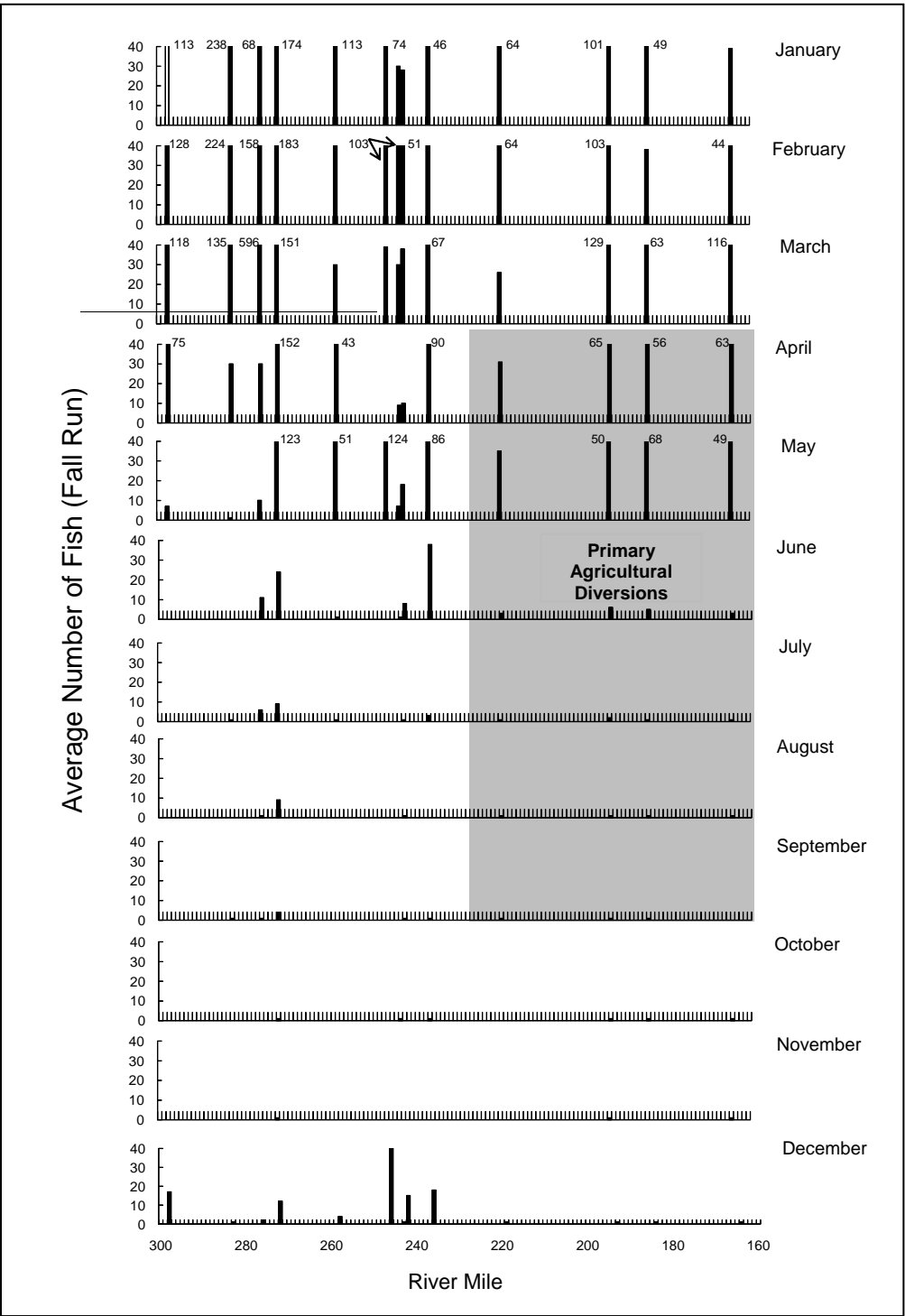
Figure 29. Spatial and temporal distribution of fall-run Chinook captured by the USFWS during year-round monthly beach seining at 13 sites in the Sacramento River, 1981 – 1991 [(N = 60,728) from Johnson *et al.* 1992].
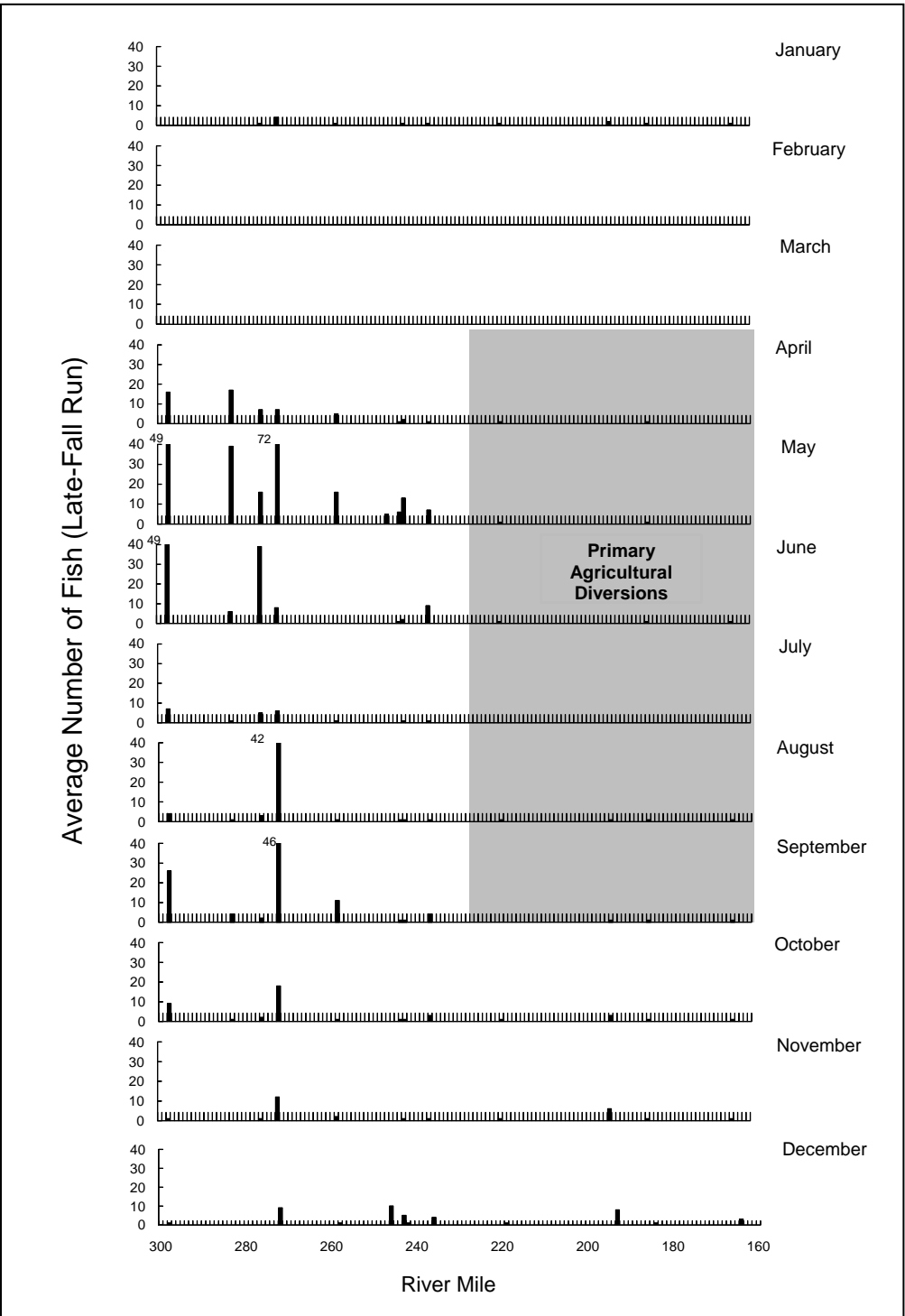
Figure 30. Spatial and temporal distribution of late-fall-run Chinook captured by the USFWS during year-round monthly beach seining at 13 sites in the Sacramento River, 1981 – 1991 [(N = 6,284) from Johnson *et al.* 1992].

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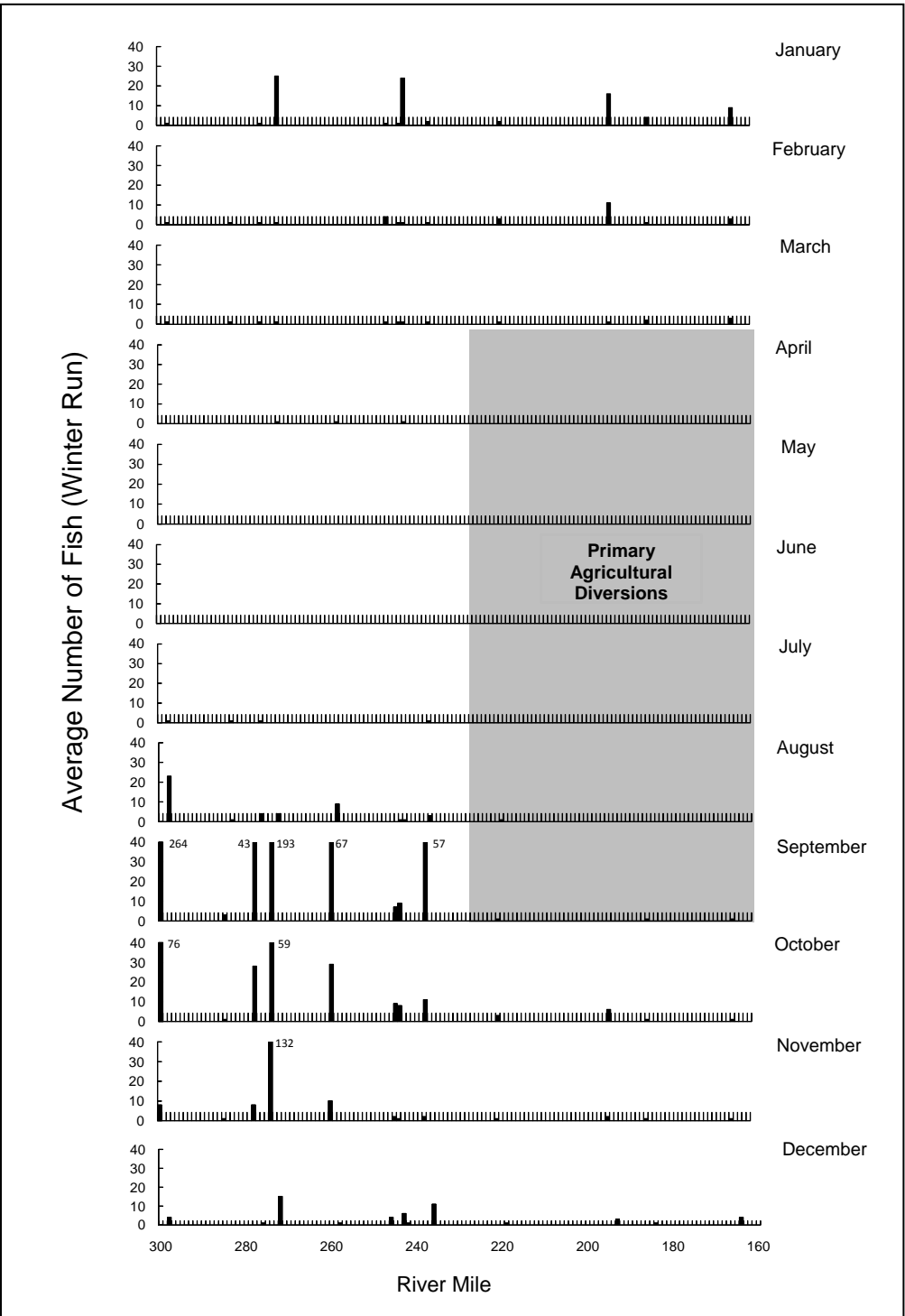
Figure 31. Spatial and temporal distribution of winter-run Chinook captured by the USFWS during year-round monthly beach seining at 13 sites in the Sacramento River, 1981 – 1991 [(N = 10,778) from Johnson *et al.* 1992].
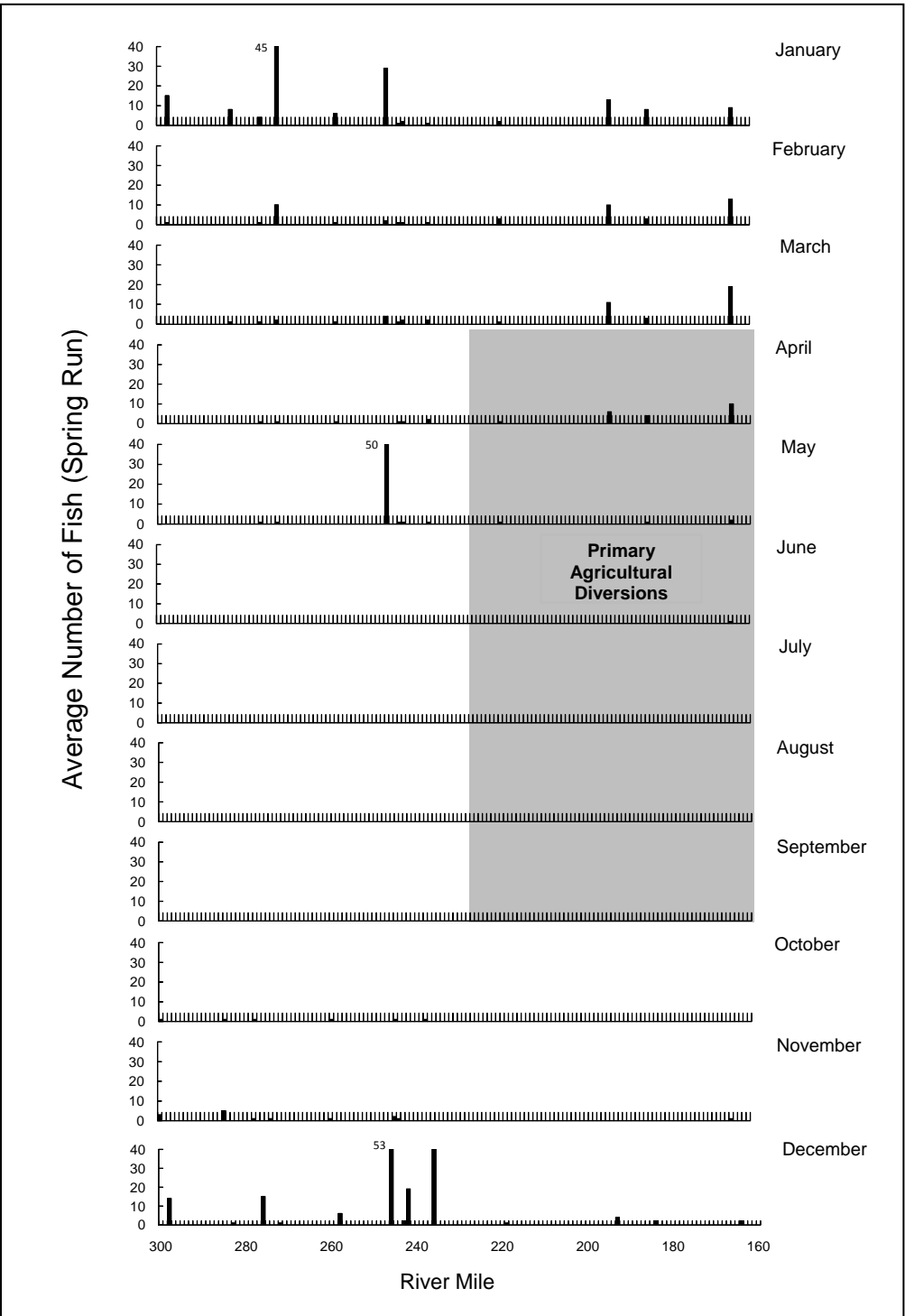
Figure 32. Spatial and temporal distribution of spring-run Chinook captured by the USFWS during year-round monthly beach seining at 13 sites in the Sacramento River, 1981 – 1991 [(N = 4,768) from Johnson *et al.* 1992].

The majority of the salmon emigration during wet winter conditions occurs during January through March (Vogel and Marine 1991) and is demonstrated by the DFG fish sampling program which, among other purposes, is conducted to determine the timing and relative abundance of juvenile anadromous salmonids emigrating from the upper Sacramento River system (Vincik and Bajjaliya 2008) (Figures 33 and 34). The DFG monitoring program ceases during the summer months, due to minimal or no juvenile salmon presence. Storm events increase river flow and turbidity which causes many salmon to either volitionally or non-volitionally move from the upper river to the Delta. If the fish have not already emigrated from the primary rearing grounds in the upper river, a later emigration of juvenile salmon occurs during April and May as smolts (Vogel 2011); this is particularly true during dry hydrologic conditions (Vogel and Marine 1991). In this latter instance, there is greater overlap between the onset of irrigation and the presence of outmigrating salmon.
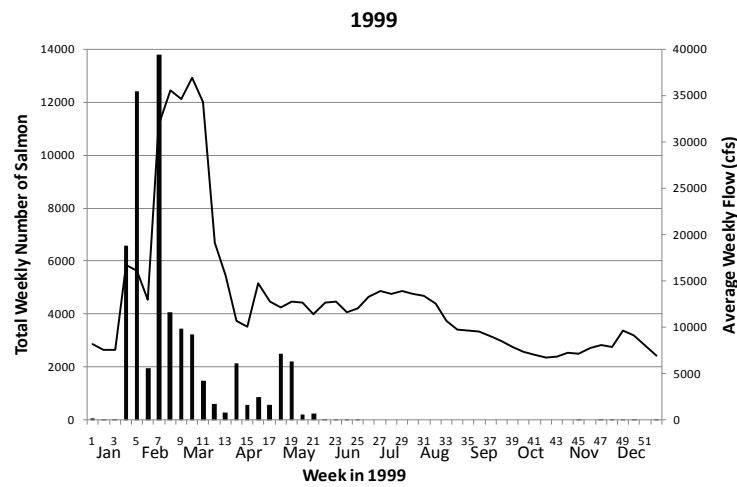
Figure 33. Total weekly numbers of juvenile Chinook salmon (all runs combined) captured with two rotary screw traps near Knights Landing during 1999 compared to average weekly flow (cfs) at Bend Bridge. Monitoring is not conducted during the summer months. (from Vogel 2011)
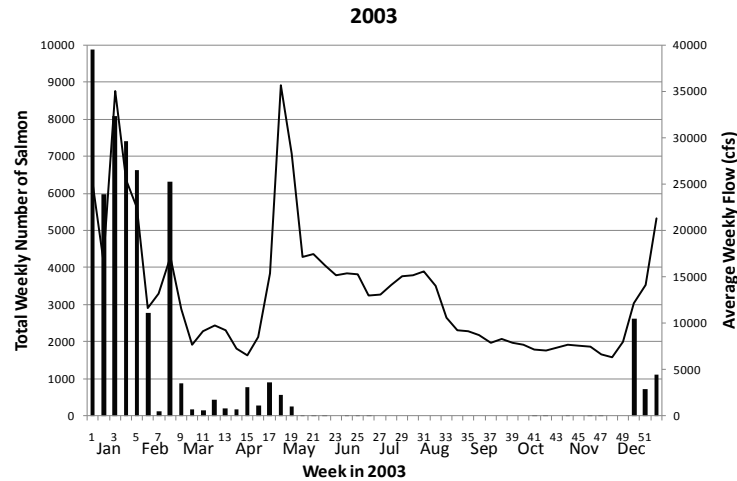
2003

Figure 34. Total weekly numbers of juvenile Chinook salmon (all runs combined) captured with two rotary screw traps near Knights Landing during 2003 compared to average weekly flow (cfs) at Bend Bridge. Monitoring is not conducted during the summer months. (from Vogel 2011)

In 1981, Quelvog (1981) reported only three fish screens in operation on the mainstem Sacramento River. These were located at the ACID diversion (max. 400 cfs) (installed 1969), the Tehama-Colusa Canal diversion (max. 2,700 cfs) (installed 1966), and the GCID diversion (max. 3,000 cfs) (originally installed in 1935, and initially replaced in 1972). As of the early 1990s, there were very few fish screens in operation on the mainstem Sacramento River (Phil Warner, DFG, pers. comm.; Nick Villa, DFG, pers. comm.). In 1990, the DFG stated that only four diversions on the Sacramento River had fish screens of which only two were considered adequate (Reynolds *et al.* 1990).

The largest Sacramento River mainstem diversion occurs at GCID's Hamilton City 3,000 cfs capacity pumping station (Figure 35) which is within the rearing area for anadromous fish. Phillips (1931), as reviewed by Ward (1989), reported the results of the first fisheries monitoring investigation at GCID which consisted of fish sampling in the diversion canal below the old pumping plant. Based on these findings and a court ruling in 1931, a fish screening device was installed in 1935 to reduce fish entrainment at the old pump station. This original apparatus remained in place until 1972 after which DFG installed a large rotary-drum fish screen facility. However, the newer fish screen provided inadequate protection of young salmon primarily due to entrapment zones under the screens (Fish Entrapment Zone), insufficient fish bypasses, leaks in screen seals, and screen mesh large enough to pass salmon fry. A major flow event in the 1980s degraded the riverbed elevation in the river outside of the diversion's oxbow location, reduced water surface elevations on the screens and created reverse flow conditions in the lower oxbow which was previously used to bypass fish past the screens and out to the main river. Ward (1989) concluded that, historically, large numbers of juvenile salmon annually may have been lost at the diversion. The losses were not specifically attributed to any one particular mortality factor, but were due to a combination of suspected predator congregations near the fish screens and in the oxbow, impingement on the fish screens, and entrainment through the screen facility.

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Based on results from other studies and on a reputation of pikeminnow for adapting to and exploiting man-made habitat alterations to their advantage, predation by pikeminnow on juvenile salmon was believed to be potentially problematic at the site (Garcia 1989). More recent research indicated that both pikeminnow and striped bass were principal predators at the GCID screen (Vogel 2008a). Interim measures taken by GCID (*e.g.*, flat-plate screens installed in 1993, increased sweeping and bypass flows, and use of alternative water supplies, including groundwater pumping) increased fish protection at the pump station. However, these measures did not accommodate key fish screen criteria [*i.e.*, approach velocity of 0.33 feet per second (ft/s) as specified by DFG and bypass flows of 500 cubic feet per second (cfs) as specified by a USACE permit (1996)]. Therefore, a new fish screen facility was deemed necessary for meeting fish protection requirements. Ultimately, a new 3,000 cfs capacity 1,000-ft-long, flat-plate fish screen was completed in 2001 and a gradient facility to re-aggrade the riverbed and alter channel hydraulics at a cost of $76 million (combined) was completed in 2000 (Figure 35). Extensive hydraulic and biological evaluations of the facility were conducted following completion and the screen was recently determined to meet state and federal standards for fish protection.
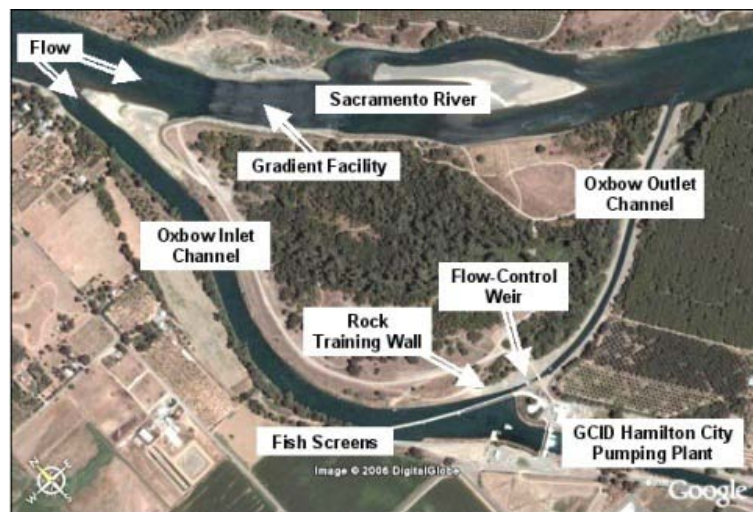
Figure 35. Aerial view of the new GCID fish screens and gradient facility on the Sacramento River near Hamilton City (from Vogel 2008a).

Screening of agricultural diversions has been a common practice in recent years in order to conserve and restore populations of anadromous fishes in the Central Valley. During the 1990s, fish screening projects increased significantly, largely as a result of new state and federal funding with principal focus on protecting winter, spring, fall and late-fall runs of Chinook salmon and steelhead, as they migrate down the Sacramento River. For example, prior to installation of both the interim and long-term screens at GCID, new angled rotary drum screens (Figure 36) were installed at the Tehama-Colusa Canal (TCC) headworks at RBDD to replace the inefficient fish louvers which were found to entrain fish into the TCC and Corning irrigation canals (2,700 cfs capacity diversion) (Vogel 1989). Subsequent USFWS research at the site demonstrated that the new screens eliminated the fish entrainment problem (Johnson 1991, Johnson and Croci 1994). Additionally, a new fish screen bypass routed juvenile fish further downstream from RBDD to

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alleviate the previous problem of predation (Vogel *et al.* 1988, Vogel *et al.* 1990).

Figure 36. State-of-the-art angled rotary drum screens installed at the headworks to the Tehama-Colusa Canal and Corning Canal at RBDD in 1990. Photo by Dave Vogel.

Since installation of the new screens at RBDD, there have been significant efforts under both the CVPIA and the CALFED Bay-Delta Program to screen agricultural diversions in the Central Valley, particularly the larger unscreened diversions (over 150 cfs) on the Sacramento River. For example, further downstream from GCID, two large-scale fish screening facilities meeting state and federal criteria for fish protection have been completed at Reclamation District (RD) 108. The $11 million Wilkins Slough diversion screen (830 cfs capacity) went into operation in 1999, and the $30 million 300 cfs capacity Poundstone pumping plant diversion and fish screen (which consolidated and removed three previously unscreened diversions and resulted in lower total water diversion requirement) was completed in 2008.   Additional state/federal funded fish screens have recently been installed on the mainstem river at Wilson Ranch, M&T Ranch, Princeton-Codora-Glen & Provident Irrigation District, RD 1004, Maxwell ID, Sutter Mutual Water Company, Pelger Mutual Water Company, City of Sacramento, RD 999, Meridian Farms, and other sites, including Suisun Marsh. In 1992, new fish screens were also installed at the ACID dam (Figure 37) at a cost of $11,600,000 (including two new fish ladders) and ACID's diversion near South Bonnyview Bridge (USBR 1992). Additionally, in an area critically important for winter-run Chinook salmon rearing, the City of Redding installed new fish screens at its municipal water intake upstream of ACID dam. The most-expensive project currently underway is construction of new 2,500 cfs capacity flat-plate screens for the Tehama-Colusa Canal anticipated to be completed in 2010 at a cost of $220,000,000 (including a pumping plant and associated facilities) (Table 6). Dozens of other small diversions in the Sacramento River have recently been or will soon be similarly screened for fish protection (Tables 7 and 8) (Figure 38).

Figure 37. The ACID dam on the Sacramento River in Redding, California.

Project Name	Location	Total Costs	Federal Share	Capacity (cfs)	Year Completed
Table 6. Recently completed or soon-to-be constructed fish screen/fish passage projects (costs are estimated for projects not completed).					
GCID	Sacramento River	$76,000,000	$57,000,000	3,000	2000
ACID	Sacramento River	$11,600,000	Unknown	450 (includes ladders)	2001
Meridian Farms	Sacramento River	$26,272,000	$12,850,000	165	2013
Natomas Mutual	Sacramento River	$52,000,000	$26,000,000	434	2013
RD 2035	Sacramento River	$26,240,000	$12,873,000	400	2016
Tehama-Colusa	Sacramento River	$220,000,000	$209,000,000	2,500	2012
Anadromous Fish Screening Program projects summary (provided by Dan Meier, USFWS).					
Maxwell ID	Sacramento River	$1,545,000	$709,000	100	1997
Pelger Mutual Water Co.	Sacramento River	$278,000	$139,000	40	1996
Wilson Ranch	Sacramento River	$231,000	$90,000	40	1996
M&T Ranch	Sacramento River	$4,584,000	$2,200,000	150	1997
RD 1004	Sacramento River	$7,250,000	$1,535,000	290	1999
RD 108 – Wilkins Slough	Sacramento River	$12,051,000	$6,101,000	832	2000
RD 108 – Poundstone	Sacramento River	$30,170,000	$14,938,000	300	2008
Adams Ranch	Butte Creek	$1,090,000	$545,000	135	1999
Gorrill Land Co.	Butte Creek	$1,516,000	$756,000	122	1999
Western Canal Water District	Butte Creek	$9,068,000	$3,023,000	Siphon	1998
Lower Butte Creek/Ducks Unlimited	Butte Creek	$480,000	$240,000	Fish Ladders and Barriers	2003
Princeton-Codora Glenn/Provident ID	Sacramento River	$10,958,000	$5,350,000	605	1999
Meridian Farms	Sacramento River	$5,000,000	$2,500,000	30	2009
RD 999	Sacramento River	$636,000	$318,000	100	2006
Sutter Mutual	Sacramento River	$21,500,000	$10,046,000	960	2007
Browns Valley ID	Yuba River	$298,000	$107,000	65	1999
City of Sacramento/Fairbairn	Sacramento/American Rivers	$44,000,000	$3,685,000	245/210	2005/2004
Dayly Lee	Steamboat Slough	$38,000	$0	20	2000
Suisun Resource Conservation District (5 screens)	Suisun Marsh	$900,000	$621,000	93	1997
TOTALS:		**$563,705,000**	**$370,626,000**	**11,286**	

Table 7. Family Water Alliance Fish Screening Program projects summary.				
Project Name	**Project Location**	**Project Cost**	**Capacity (cfs)**	**Year Completed**
Oji Bros. Farms	Sacramento River	$ 181,513	20	Prior to 2002
Cliff Liddy	Sacramento River	$ 4,640	1	Prior to 2002
Steidlmayer	Sacramento River	$ 101,489	15	Prior to 2002
Tiff Farms	Feather River	$ 97,201	9.3	Prior to 2002
Andreotti #1 & #2	Sacramento River	$ 263,347	30	2002
Davis Ranches #6	Sacramento River	$ 186,900	15	2002
Butte Creek Farms #3	Butte Creek	$ 80,000	15.5	2002
Rancho Caleta #3	Butte Creek	$ 86,000	15.5	2002
Tom Ellis	Sacramento River	$ 79,500	6	2002
Tom Gross	Sacramento River	$ 160,000	23	2002
Joyce Wells Trust	Sacramento River	$ 125,000	18	2002
Butte Creek Farms Replacement	Sacramento River	$ 132,946	38	2002
Roberts Ditch Irrigation Company	Sacramento River	$ 176,940	36	2003/2004
Jerry Forster	Sacramento River	$ 147,800	41	2003/2004
Williams Ranch	Sacramento River/Delta	$ 84,800	18.6	2003/2004
Tisdale Irrigation and Drainage	Sacramento River	$ 110,500	21	2003/2004
A & L Ag Rental and Leasing	Sacramento River	$ 95,000	15	2003/2004
Davis Ranches Site 1	Sacramento River		30	
Davis Ranches Site 1	Sacramento River	$ 615,800	20	2003/2004
Davis Ranches Site 1	Sacramento River		30	
Ferraro-Locvich	Sacramento River	$ 76,000	7	2003/2004
Reclamation District No. 999/307	Sacramento River/Delta	$ 645,947	100	2006
H & L Partnership & Wallace	Sacramento River	$ 220,000	25	2007
Larry Pires Farms	Sacramento River	$ 145,000	13	2007
SMWC State Ranch Bend Pumping Plant	Sacramento River	$ 1,252,000	128	2010
Sycamore Mutual Water Company	Sacramento River	$ 503,000	65	2010
River Garden Farms #2 Missouri Bend	Sacramento River	$ 303,000	32	2010
SMWC Portuguese Bend Pumping Plant	Sacramento River		106	2011
Reclamation District No. 108 So. Stiener	Sacramento River		30	2011
Windswept Land & Livestock #3	Sacramento River		9	2011
Oji Bros. Farms Kirkville Diversion	Sacramento River		25	2011
River Garden Farms #3 Town Site	Sacramento River		62	2012
Tisdale Irrigation District #2	Sacramento River		27	2012
Alamo Farms #1	Sacramento River		35	2012
Cranmore Farms #1	Sacramento River		36	2012
Joe Sanchez Farms	Steamboat Slough/Delta		25	2012
	TOTALS:	**$ 5,874,323**	**1,143 cfs**	

Table 8. Additional Intake Screens Inc. fish screening projects not included in Table 7 (provided by Russ Berry, ISI).					
Project Name	**Project Location**		**Project Cost**	**Capacity (cfs)**	**Year Completed**
	Latitude	**Longitude**			
Club 506	38°10'16.07"N	122° 1'3.40"W	$ 240,000	11	1996
Club 502	38° 9'27.96"N	122° 2'48.21"W	$ 245,000	17	1996
Club 425	38° 09' 11.77"N	122° 02' 59.40"W	$ 240,000	11	1996
Club 426	38° 08' 26.23"N	122° 03' 26.39"W	$ 250,000	26	1996
RD 2112	38° 08' 05.03"N	121° 54' 55.67"W	$ 250,000	26	1997
Club 625	38° 8'17.57"N	121°54'45.30"W	$ 240,000	11	1997
Club 527	38°10'12.48"N	121°57'32.84"W	$ 245,000	17	1997
Club 501	38° 9'27.44"N	122° 2'48.64"W	$ 250,000	26	1997
Club 503	38° 9'54.68"N	122° 2'27.30"W	$ 250,000	26	1997
Club 525 East	38°10'14.19"N	121°57'40.72"W	$ 250,000	26	1997
Club 525 West	38°10'14.29"N	121°57'40.95"W	$ 250,000	26	1997
Lower Joyce	38° 9'18.03"N	122° 3'12.66"W	$ 300,000	26	1997
Boeger / Anderson	39°15'53.33"N	121°59'55.89"W	$ 126,000	24	2002
Butte Sink - Ducks Unlimited - F&WS	39°14'21.86"N	121°56'48.33"W	$ 75,000	11	2003
City of Redding	40°35'32.72"N	122°24'26.34"W	$ 900,000	74	2006
Berryhill 16" Siphon	38° 4'33.21"N	121°28'13.90"W	$ 43,000	11	2007
Mark Lasher	38°15'58.73"N	121°38'31.46"W	$ 16,000	4	2007
Joe Suprenant 16" Siphon	38° 3'57.61"N	121°29'58.25"W	$ 43,000	11	2008
Al Medvits	38° 6'41.33"N	121°42'50.74"W	$ 15,000	9	2008
		TOTALS:	**$4,228,000**	**393 cfs**	
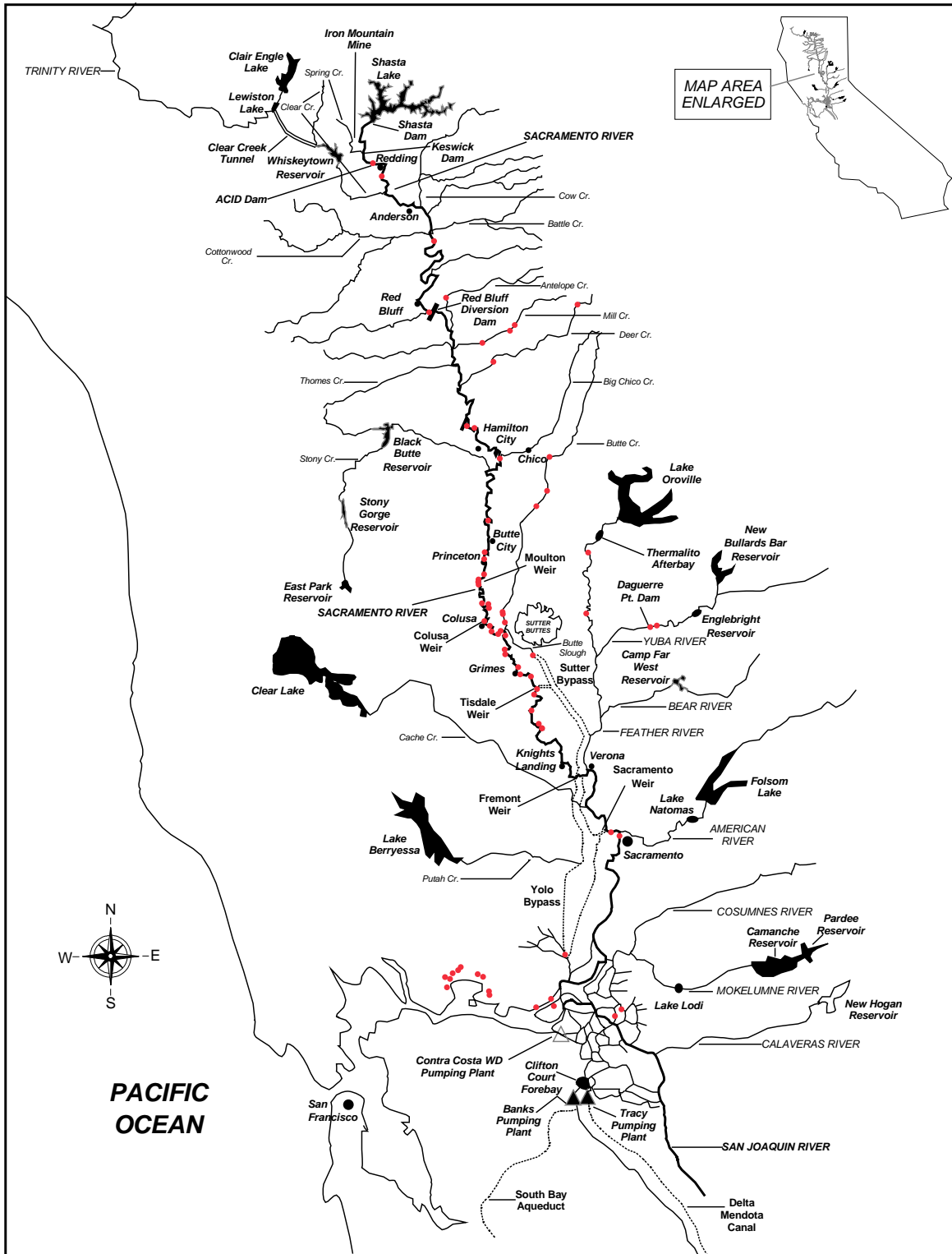
Figure 38. Recent fish screening projects (depicted by red dots).

There are many small and moderate sized agricultural diversions (under 150 cfs) on the Sacramento River that remain unscreened. However, there is a general lack of data available about the potential effects of these agricultural diversions on existing fish populations (Vogel 2011). In an effort to prioritize unscreened water diversions in the Sacramento River for possible future installation of fish screens, the Anadromous Fish Screen Program (AFSP), administered by the USBR, the USFWS and the CALFED Ecosystem Restoration Program, recently initiated a process to acquire detailed information at smaller diversion sites. The objective of this project is intended to lead to a better understanding of which diversions are most important to screen by quantifying site-specific characteristics. The ultimate project goals are to correlate fish entrainment data (from past and future monitoring efforts) at unscreened diversions with the physical, hydraulic, and habitat variables at diversion sites. The in-river survey was conducted in the Sacramento River between Red Bluff and Verona (Figure 1) by collecting extensive data using new technology to measure bathymetry, hydraulic, physical, and biological characteristics at each site (Vogel 2008b). A dozen diversion sites were selected by state and federal agencies for monitoring of fish entrainment during the irrigation season. Fyke nets are placed in the irrigation canals and fished continuously during the irrigation season to determine daily and total fish entrainment (Figure 39). To date, no significant losses of anadromous fish have been detected at sites monitored, although some of the early season sampling was limited due to Section 10 permit delays and an unusually late onset of irrigation (Vogel 2009, 2011).

Figure 39. Examples of unscreened diversions sampled for fish entrainment by Natural Resource Scientists, Inc. Photos by Dave Vogel.

A potentially serious problem for outmigrating anadromous fish in the lower Sacramento River near Verona exists. When water diversions in the Natomas Cross Canal exceed positive flows down the Canal, reverse flows may occur at the Canal's confluence with the Sacramento Rier.

Water can be diverted into the Natomas Cross Canal through pumping activities off the mainstem river. Under certain conditions, a temporary dam is installed to partially control the water elevation in the canal and water is pumped through the dam into the canal (Figure 40). These conditions create reverse flows in the canal and could divert outmigrating anadromous fish off the mainstem Sacramento River into the canal with no means of return back to the river. The presently unknown severity of the problem depends on the timing of diversions and the seasonal presence of fish. Because flows from the Feather River enter the Sacramento River immediately upstream of the Natomas Cross Canal on the same side of the river, it may pose greater hazards for Feather River outmigrating fish. Attempts to determine fish entrainment at Verona Dam were largely unsuccessful because of physical limitations at the site (Vogel 2009).
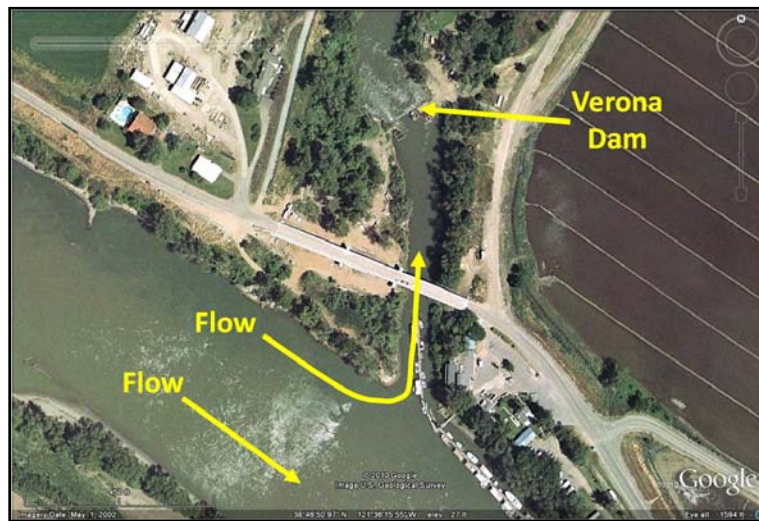
Figure 40. Location of Verona Dam in the Natomas Cross Canal on the lower Sacramento River.

5.5.2.2. *Predation*

Predation can be a serious problem contributing to losses of young anadromous salmonids. The principal predator on juvenile salmon at riverine sites is commonly the Sacramento pikeminnow (a native species), although other highly predacious species (*i.e.*, striped bass and largemouth bass -- both popular sport fish, but non-native species; Figure 41) contribute to these losses. The feeding behavior of pikeminnow is dependent on the abundance and size of their prey, water temperature, physiological and health conditions, and nutritional status and time since last feeding (Vigg 1988, Vigg *et al.* 1991). Pikeminnow generally ambush their prey either solitarily from concealed locations (*e.g.*, underwater structures such as boulders and submerged vegetation) or in large roving schools, particularly in areas where the salmon are disorientated such as at dam spills (Moyle 1976, Vogel *et al.* 1988, Garcia 1989). The number of juvenile salmon consumed by individual pikeminnow is related to the environmental factors previously mentioned and is highly correlated with the size of the pikeminnow (Vigg *et al.* 1991, Vondracek and Moyle 1983). In the Sacramento River, predation may be highest at localized sites (*e.g.*, diversions) where habitat conditions favor predatory fish (*e.g.*, Pikeminnow at Intake)

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Figure 41. Sacramento pikeminnow (4 pounds) on left (photo by Dave Vogel), striped bass (38 pounds) in middle (photo by Matt Manuel), and largemouth bass (8.9 pounds) on right (photo by Dave Vogel).

There is currently no information to indicate if predation immediately downstream of ACID, a gravity water diversion dam, is a problem for anadromous fish. Striped bass and largemouth bass are not known to inhabit this area although Sacramento pikeminnow are present. Historically, striped bass and largemouth bass were present in this area prior to Shasta Dam but were largely absent after construction due to a cooler thermal regime (Moffett 1949) which was a significant benefit to salmonids. Reduced populations of these highly predacious fish in the area are particularly important because of the high concentration of many juvenile anadromous salmonids rearing between Keswick Dam and Red Bluff. However, trout fishing in the area just downstream of ACID Dam is known to be excellent and those fish could potentially prey on juvenile fish, particularly winter-run Chinook fry, as the young fish are exposed to turbulence and disorientation passing over the dam (Figure 37).

Fishery resource investigations conducted at RBDD, another gravity water diversion dam, during the 1970s and 1980s identified severe downstream anadromous salmonid passage problems (Vogel *et al.* 1988). DFG study results indicated that substantial losses of juvenile salmonids were attributable to the dam's operations for water diversions into the adjoining canals (Hall 1977, Hallock 1980, Hallock 1983). For example, a DFG study conducted during the 1970s suggested that losses of young salmon could be in the range of 29% to 77% (Hallock 1983). Largely as a result of these and other prior investigations, the USFWS began intensive studies (performed by this author) in the early 1980s to determine specific sources of fish mortality at the water diversion facilities (Vogel *et al*. 1988). The majority of the mortality was attributed to Sacramento pikeminnow predation (Figure 42). Based on that research, numerous corrective actions were incrementally implemented to reduce predation impacts (Table 9). It is reasonable to conclude that predation on anadromous fish at RBDD has been significantly reduced since the mid-1980s to the present.
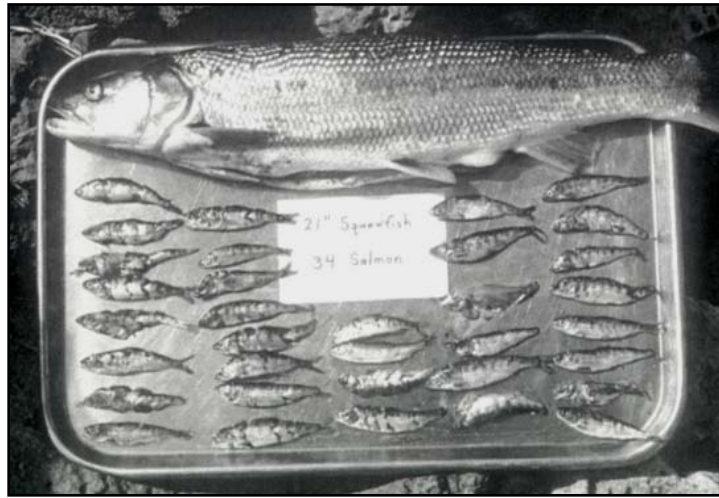
Figure 42. A 21-inch long Sacramento River pikeminnow (previously called squawfish) captured just downstream of Red Bluff Diversion Dam and 34 juvenile salmon removed from its stomach. Photo by Dave Vogel.

Fish Protection Measure	Effective Date	Fish Passage Improvement
Table 9. Downstream fish passage improvements at Red Bluff Diversion Dam (RBDD).		
RBDD lights off at night	1983	Significant reduction in predation when RBDD gates in
Improved louver maintenance	mid-1980s	Major reduction of entrainment when RBDD gates in
Unclogging fish bypass pipe	1985	Major elimination of physical injury when RBDD gates in
Elimination of flow-straightening vanes inside fish bypasses	1985	Elimination of physical injury and mortality of large numbers of juvenile fish
Implementation of spring pulse flow	1985	Significant reduction in salmon mortality at RBDD
Fixing leaks on the Dual-Purpose Canal fish screens	1985, 1986	Elimination of fish entrainment into the Tehama-Colusa irrigation canal
Change in Acrolein treatment in the Dual-Purpose Canal	mid-1980s	Elimination or significant reduction in juvenile salmon mortality
TCC headworks deflector wall	late 1980s	Significant reduction in entrainment when RBDD gates in
RBDD gates out 6 months/year	1987	Major seasonal elimination of predation and significant reduction of predation when RBDD gates in
Abandonment of salmon spawning channels	1987	Elimination of seasonal entrainment and significant reduction when RBDD gates in
Installation of new fish screens	1990	Elimination of entrainment when RBDD gates in
Installation of new fish bypass	1990	Major reduction of predation when RBDD gates in
RBDD gates out 8 months/year	1993	Major seasonal elimination of entrainment and significant reduction of predation when RBDD gates in

5.5.2.3. *Water Quality and Temperature*

Water quality in the mainstem Sacramento River may affect outmigrating juvenile anadromous fish. A DWR literature review in the 1980s found that the major sources of water quality degradation for the Sacramento River include municipal wastes, industrial wastes (primarily food processing and lumber industries), agricultural drainage, and acid mine wastes (Boles and Turek 1986). Among these, the most significant sources potentially affecting salmonids appear to be acid mine drainage in the upper Sacramento River (previously discussed) and agricultural drainage in the lower Sacramento River. Water quality problems in the Sacramento River basin associated with irrigated agriculture and municipal and industrial discharges, however, are relatively minor compared with these types of problems in other parts of the Central Valley. This lower effect is partially because of the use of the Sacramento River to convey increasing quantities of water developed within the Sacramento River basin and imported from the North Coastal basin (SWRCB 1995).

The major source of waste water is agricultural drainage which historically contributed to lower water quality during low flow periods in the Sacramento River and lower reaches of the major tributaries. As described by SWRCB (1995), "*Water quality concerns in tributaries include: low dissolved oxygen levels in Butte Slough, Sutter Bypass, and Colusa Basin Drain; high water temperatures below diversion structures on Butte Creek; concentrations of minor elements (chromium, copper, iron, lead, manganese, selenium, and zinc) that exceed beneficial use criteria in the Sutter Bypass; and pesticide residues in the Sutter and Yolo bypasses and Colusa Basin Drain. Additional concern exists for effects of tributary discharges to the Sacramento River, including elevated temperature, dissolved solids, minor elements, pesticides, and turbidity, especially from the Sutter and Yolo bypasses and Colusa Basin Drain.*" Rice field herbicides caused the most significant water quality degradation in the past, but recent efforts by the State Department of Food and Agriculture (DFA) and the Central Valley RWQCB have largely controlled this problem (SWRCB 1995).

Recently there has been increased attention focused on the potential role of agricultural chemicals in the decline of Central Valley fish species. Information presented in Bailey *et al.* (1994) and earlier SWRCB proceedings describe some of the possible causal impacts of those chemicals on fish such as striped bass. Much of that information focused on non-winter seasons and is not particularly relevant to winter-run, late-fall run, spring-run, and fall-run Chinook and steelhead because of minimal presence of their early life phases within the potential geographic zone of impact. Insufficient information is available for green sturgeon to derive any conclusions.

Relatively recently, additional information has been developed on the potential harm to the aquatic ecosystems resulting from agricultural chemicals introduced into the riverine environment during the winter months (*e.g.*, diazinon, a dormant spray on tree crops) when it is relevant to anadromous salmonids. With the possible exception of dormant spray applications (discussed below), it appears that agricultural drainage probably has not played a significant role affecting anadromous fish because the location, timing and nature of the drainage does not

correspond well to the time periods when the anadromous fish are present in relevant areas of the Sacramento River system.

It has been hypothesized that some chemicals used in Sacramento Valley agricultural operations, although not acutely toxic to salmonids in the river, may indirectly impact salmonids by affecting their food organisms. The off-site movement of pesticides used in Sacramento Valley agriculture is a potential concern to downstream fisheries because as much as one-third of the flow in the Sacramento River at certain times of the year can originate from rice fields. In 1988, insecticides (*e.g.*, carbofuran and methyl parathion) were shown to cause mortality in aquatic invertebrates in agricultural drains and possibly the Sacramento River (Saiki and Finlayson 1993). An ecological risk assessment of diazinon in the Sacramento and San Joaquin River basins found that the principal risk to anadromous salmonids was from the potential effects on their food organisms, and not direct acute toxicity (Giddings *et al.* 1997). The timing of potential impacts on food organisms from dormant sprays was during January and February, important rearing months for some anadromous fish. Giddings *et al.* (1997) concluded: "*Indirect effects on some fish populations cannot be dismissed if sensitive native arthropods are reduced at critical periods when they are needed as food by early life stages of fish.*" However, the most significant impacts (but brief) were believed to occur on cladocerans, which are not a primary food organism for anadromous fish. As a result, the relative effects of this source of pollution on salmonids relative to other factors must be considered as low.

Because the large dams in the Sacramento River basin, including the Feather and Yuba rivers, release large quantities of cold water for conveyance to downstream areas during the period when air temperatures are seasonally warm, anadromous fish have benefited from an improved thermal regime. In the Sacramento River, this benefit was recognized as early as 1949 (Moffett 1949). However, high summer water temperatures in the lower Sacramento River and Delta present a thermal barrier to juvenile salmon downstream migration (Kjelson *et al.* 1982). In the Sacramento River, subyearling salmon emigration is related to the avoidance of high summer water temperatures (Gard 1995). During the late spring through summer periods when air temperatures are the warmest, releases of cold water from the large dams are often high but the dams are far upstream from the lower Sacramento River and Delta. Therefore, ambient conditions control temperatures in these downstream areas. Additionally, the emigration of most juvenile anadromous fish to downstream areas has ceased by the time water temperatures are the warmest. For example, DFG does not conduct downstream migrant salmonid monitoring at Knights Landing because of the low presence of those species. There are no indications that water temperatures in the lower river and Delta have been a factor in fish population declines or that water temperatures in these areas in recent decades have changed appreciably.

5.5.2.4. *Flows*

The primary focus on flows for outmigrating juvenile anadromous fish has been in the Delta. Because of the interrelationships between mainstem flows and outmigrating anadromous fish, this topic will be discussed in Section 5.5.3.1.

5.5.3 Delta

The CVPIA fish restoration program has focused on actions in the Delta region as the highest priority within the Central Valley because it is exceedingly degraded (due in part to CVP and SWP operations), because all anadromous fish must pass through the Delta as juveniles and adults, and because some of these fish rear there (Cummins *et al.* 2008). Impacts on young salmonids entering the Delta are significant because the fish have already survived density-dependent (*e.g.*, redd superimposition, disease) and density-independent (*e.g.*, temperature, dessication, siltation) factors in upstream areas. In other words, those fish reaching the Delta would be expected to have the highest survival *rates* as compared to all earlier life phases (*e.g.*, a salmon smolt reaching the Delta has a higher probability of surviving to an adult fish than a salmon fry in one of the upstream-most river reaches). The earliest life phases suffer the greatest losses, whereas the later life phases can be expected to have higher survival rates and more likely reach the adult life phase, perpetuating the population. Ultimately, minimizing exposure to potentially lethal factors in the Delta will provide a major complement to ongoing efforts to save emigrating salmonids in upstream areas of the Sacramento River basin.

Because of its relevance and timeliness, most of the following information (unless otherwise noted) is extracted from the NMFS Winter-Run Chinook Salmon Recovery Plan (NMFS 1997). The probable impacts of various anthropogenic factors affecting salmon are described in the NMFS Recovery Plan. Much of the information presented here is similarly described in public documents such as the SWRCB 1995 Environmental Report, and Biological Assessments and Biological Opinions on the CVP and SWP.

> "*As flow has become highly manipulated in the Delta, a broad scope of direct and indirect impacts has likely diminished winter-run Chinook survival. These problems are primarily related to changes in hydrology, whereby the timing, quantity, export and distribution of water flow into and through the Delta have been altered. The primary factors causing salmon mortality in the Delta are considered to be: 1) the diversion of winter-run Chinook from the main stem Sacramento River into the central and south Delta where environmental conditions are poor; 2) reverse flow conditions created by pumping; and 3) entrainment at CVP and SWP pumping plants and associated problems in Clifton Court Forebay. In addition, poor food supply may limit the rearing success of winter-run Chinook. There are other related water management projects which may adversely affect winter-run Chinook, including barriers at Grant Line Canal, the head of the Old River, Old River at Tracy, and the Middle River.*" (NMFS 1997)

> "*The sources of mortality for fish entering into the central Delta are likely a combination of adverse conditions resulting from: CVP and SWP operations; poor riparian, tidal marsh and shallow water habitat conditions; predation; and a longer migration route to the ocean (USFWS 1992a; IEP Estuarine Ecology*

Project Work Team 1996). The central Delta also has a greater number of agricultural diversions and more complex channel configurations than the main stem Sacramento River. The channel complexity, in conjunction with the tidal and reverse flow patterns, likely delays migration to the ocean, which increases the length of time that smolts are exposed to adverse conditions. Also, susceptibility to diversion into Clifton Court Forebay or entrainment at the CVP and SWP pumping plants is more likely for fish migration through the central Delta than for those migrating down the main stem Sacramento River (USFWS 1992a). Historically, the central Delta was probably beneficial for rearing juvenile Chinook salmon, including winter-run Chinook, due to the extensive acreage of tidal marsh habitat and its associated nutritional and cover benefits. However, degradation of central Delta waterways have [sic] led to adverse conditions for the rearing and migration of winter-run Chinook." (NMFS 1997)

NMFS summarized the impacts to winter-run Chinook attributable to CVP/SWP pumping operations in the following manner.

"*The indirect effects from operating the DCC and pumping plants likely have far greater impacts on the winter-run Chinook population than is indicated by the number of fish surviving to the salvage facilities. More likely, the vast majority of juvenile Chinook mortality results from the indirect effects of pumping operations, rather than actual entrainment at the pumps. Specifically, juvenile Chinook diverted into the central and south Delta experience higher mortality through reversed flows, predation, reduced shallow water habitat for fry, higher water temperatures, possibly small agricultural water diversions, and reduced river inflows during the spring which decreases available nutrients, turbidity, and transport flows for migration. If the DCC gates were not open, fewer juveniles would move into the central and south Delta and in the absence of CVP/SWP, aquatic habitats throughout the central and south Delta would be markedly better for migrating smolts and rearing fry. Finally, the specific mechanisms by which pumping operations influence fish behavior and movement are not well understood. However, salmon arrive in pulses at the pumping facilities indicating that entrainment is not a random process but likely to be directly related to pumping operations.*" (NMFS 1997)

5.5.3.1. *Flows*

Based largely on tagging studies of hatchery fish, a significant increase of freshwater flow in the Delta has been suggested as a principal factor benefiting survival of anadromous fish (Brandes and McLain 2001). Juvenile anadromous salmonid emigration through the Delta usually occurs during the fall, winter, and spring months, depending on the particular species and run. High flow years during wet hydrologic conditions are generally believed to provide favorable conditions for juvenile fish in the Delta. The factors affecting green sturgeon survivability in the Delta remain largely unknown. White sturgeon exhibited large year-classes during years with

exceptionally high spring outflows and juvenile recruitment also appears related to the magnitude of spring flows (Fish 2010). If green sturgeon life history attributes in the Delta are similar to white sturgeon, that species may be similarly affected by high outflow, but it has yet to be ascertained.

The specific threshold of flow necessary to provide good survival for anadromous fish has yet to be determined. The causal effects of flow/survival relationships have been difficult to determine because of complex inter-relationships with numerous variables associated with flow. The following are just some examples, and many others exist. Flow can affect turbidity, which is known to stimulate juvenile salmon outmigration. Higher turbidity, increased channel velocities, and faster outmigration timing may positively affect juvenile fish survival by reducing predation and exposure to hazards. Increased flows of high magnitude can result in large numbers of young fish using flood bypasses where survival and growth may be better than mainstem reaches (discussed in Section 5.5.3.5). Increased flows can affect the proportional distribution in various migration routes in the north Delta (*e.g.*, mainstem, Sutter, Steamboat, and Georgiana Sloughs) where survival rates can be different (discussed in Section 5.5.3.5). The magnitude of flow alters the extent of tidal excursion in some lower reaches (discussed in Section 5.5.3.5), which can alter migration timing and routes. Increased flows may affect the relative abundance and distribution of predatory fish in key salmon migration corridors. Higher flows may provide a dilution effect and alter lateral fish distribution in river channels, thereby reducing the numbers of fish entrained into unscreened diversions.

However, little progress has been made on parsing out the various factors related to flow that may influence fish survival. Most fish tagging studies over the past several decades have appeared to simply conclude "more flow is better" without determining numerical thresholds or examination of site-specific causal mechanistic effects of flow on survival. This circumstance is partially attributable to study designs reliant on relatively few releases of coded-wire tagged salmon annually at only several locations under limited environmental conditions. Additionally, those studies required years to complete due to waiting for tag recoveries from adult fish that are captured in the fisheries or return to the rivers, resulting in only a few data points for each year. Perhaps most importantly, there has been a lack of data collected on other factors (*e.g.*, site-specific environmental conditions in the Delta, relative distribution and abundance of predatory fish) that could have affected survival after juvenile fish were released. Plainly stated, the traditional coded-wire tagged hatchery salmon studies have run their course. Future research should place more focus on this topic using different (and more modern) techniques and analytical tools. There is promise in this area of research with using miniaturized acoustic transmitters to evaluate fish movements, but some of these studies are prone to errors if not properly implemented and analyzed (Vogel 2010a) and, very importantly, have not been designed to determine specific sources of fish mortality. Much like the coded-wire tag studies, some recent telemetry studies are only oriented toward attempts to estimate overall survival in very long reaches of the Delta. This is unlikely to yield site-specific data, which can lead to remedial actions to increase fish survival. Enough studies have been conducted over the decades to demonstrate overall fish survival through the Delta is poor. A new approach should be designed and implemented to determine exactly where mortality is occurring and how to fix the

specific problems where they are occurring.

The large-scale increases in reservoir releases that would be necessary to implement proposed new Delta flow criteria (SWRCB 2010, DFG 2010) are examples of a proposed approach to use flow, and flow alone, as a possible means to try to alleviate non-flow related stressors in the Delta. As described above, there are many variables intertwined with flow that may be the most important variables affecting fish survival. Depending on the timing, magnitude, and duration of flow increases, reservoir releases to downstream areas according to schedules different than existing regimes could have beneficial effects on anadromous fish (if those releases do not impact cold-water storage and water supplies needed at other important periods for fish). For example, increased reservoir releases at appropriate times could have beneficial effects on outmigrant fish through enhanced floodplain rearing; alternatively, if not appropriately implemented, such releases could be devastating to large numbers of fish through fish stranding and high predation mortality in flood bypasses. Increased transport timing through appropriately timed pulse flows could increase turbidity, stimulate outmigration, and reduce transport timing from upstream to downstream areas. In the Sacramento River basin, such flows already frequently occur through accretions and flood control operations. However, flows must be carefully timed and tailored to specific needs instead of one rule-of-thumb percentage of unimpaired flow throughout much of the year and in every watershed as contemplated by SWRCB (2010). The problem is that the underlying reasons for how flow specifically affects survival of fish in the Delta are lacking and the site-specific problems are not being addressed (discussed later).

5.5.3.2 *Water Quality*

Presently, although contaminants in the Delta are considered one of the contributing factors in the decline of pelagic organisms in the Delta (EPA 2011), adverse water quality conditions in the region have not been implicated as a significant problem for Sacramento River basin juvenile native anadromous fish. Most of the attention on pollution impacts in the Delta has been on potential effects on the food chain and other fish species (*e.g.*, Delta smelt) or within the San Joaquin River drainage. However, DFG has reported that there is no direct evidence of food limitation for young salmon in the Delta or lower estuary (DFG 1998). From 1990 to 1996, routine water quality monitoring in the Sacramento River below the city of Sacramento found conditions that were toxic to larval fathead minnow about 50 percent of the time and prompted a hypothesis that an unknown toxin has contributed to the decline in a number of species such as striped bass (Fox and Miller 1996). There have been periodic episodes of unexplained fish mortality (primarily to sub-adult striped bass) at the Tracy Fish Facilities in the south Delta (Thompson 1996), the cause of which has not been determined. Numerous pollutants are present in the Delta [*e.g.*, 160 pesticides (EPA 2011)], so it would not be surprising if future research were to reveal adverse impacts on native anadromous fish as well.

5.5.3.3 *Habitat Quantity and Quality*

All juvenile anadromous fish utilize the Delta for rearing in some degree. However, the length of rearing is dependent on the species, race of salmon, and complex environmental variables. Juvenile salmon may enter the Delta as fry-sized fish during the winter months (Brandes and McLain 2001) and rear to smolt-sized fish prior to entry into salt water. Previously, the large emigration of salmon fry from the upper river system to the Delta precipitated by high flows and turbidity were deemed "washouts" and were not believed to significantly contribute to subsequent salmon runs. However, the advent of technological advances in the late 1970s, allowing coded-wire tagging of fry-sized salmon with "1/2-sized tags", demonstrated that "washout" fry can contribute substantially to salmon runs. Nevertheless, fry survival in the Delta is less than survival from fry rearing in the upper Sacramento River, especially in wet years (Brandes and McLain 2001). Also, the survival rate of hatchery-tagged fry-sized salmon is less than that for the larger, later life phases of juvenile salmon. Based on a comparison of coded-wire tagging of fry-sized, smolt-sized, and yearling-sized fall-run Sacramento River Chinook salmon, Reisenbichler *et al.* (1981) found that survival increased (but at a decreasing rate) with larger fish sizes.

For those juvenile salmon sufficiently large enough to smolt and emigrate to salt water, the time of passage through San Francisco Bay is rapid; however, the rate of growth is slow compared to the growth rate upon first entry into the ocean (when growth increases) (MacFarland and Norton 2002). This slow pace of growth suggests that the priority of rearing of larger-sized salmon in the estuary may not be as important as previously believed. However, the rearing of fry-sized fish in the Delta remains vital but is most likely limited by loss of shallow-water rearing habitats.

Characteristics of juvenile steelhead rearing are considerably more complex than salmon. During the 1980s, the author conducted an extensive analysis of fish scales collected from *O. mykiss* throughout different regions of the Central Valley over a long time scale. The study was initiated after it was determined that a portion of juvenile steelhead released from Coleman National Fish Hatchery took up residency in the river instead of migrating to the ocean. Hundreds of scales were collected from a variety of locations in the Sacramento River basin, including DFG archives scales, and analyzed to determine life history characteristics. Growth features of rainbow trout and steelhead scales collected from Sacramento River tributaries, the upper and lower mainstem, and the Delta encompassing several decades were compared. It was found that a wide diversity in patterns existed. In particular, it was evident that fish migrating and rearing in different parts of the river system, including fish remaining in the upper river, fish that migrated to the lower river and Delta, and fish migrating to the ocean, had different growth rates. In summary, it was established that Sacramento River *O. mykiss* exhibited short, medium, and long migrations as a continuum, not simply two discreet migration phases as suggested by NMFS to justify the ESA listing of the species. That analysis of hundreds of scales indicated that there were at least three types of freshwater rearing characteristics for *O. mykiss*: fish that remained in the upper river system for their entire lives, fish that migrated to and reared in the ocean, and fish that migrated to and reared in the Delta prior to returning to the upper river system (D. Vogel, unpublished data). More recent analyses have also indicated that at least some

steelhead rear in the Delta for extended periods (*e.g.*, months) (Foss 2005). Presently, USFWS personnel at Coleman National Fish Hatchery cannot accurately discriminate between resident and ocean-run *O. mykiss* in their broodstock selection program[12] (USFWS, unpublished information).

The loss of shallow-water rearing locales for salmon in the Delta has been severe (Cummins *et al.* 2008). The available habitats where USFWS personnel can seine in the Delta to monitor the relative abundance and distribution of rearing fish are limited due to the low presence of naturally occurring shallow water areas. In some instances, recreational swimming beaches and boat ramps have been used to sample fish because most areas are deep and rip-rapped. In studies where fish sampling to compare shallow beaches with rip-rapped zones was achieved, salmon fry densities were higher in shallow beach areas (McLain and Castillo 2009). An obvious restoration measure which should be pursued to a larger degree because of its high probability of success is the re-creation of shallow, near-shore water habitats that juvenile salmon prefer in the Delta (as contrasted to flooded islands described later in this report). Importantly, these sites must be designed to avoid creation of predatory fish habitats and be established in locations likely to be utilized within the principal fish migration corridors.

5.5.3.4 *Entrainment*

It has been commonly cited that there are approximately 1,800 unscreened diversions in the Delta that may cause significant fish losses (*e.g.*, Reynolds *et al.* 1990). More recently, Herren and Kawasaki (2001) counted the number of smaller diversions in the Delta at 2,200. Most of these are 12 to 24 inches in diameter, draw water two to three feet off the bottom, and are unscreened (Matica and Nobriga 2002, Nobriga *et al.* 2002). However, the fish losses at these diversions are primarily to non-salmonid species. Because of the nature and timing of diversion activities, there is no strong evidence that they measurably impact threatened or endangered anadromous salmonids. An exception is located near the western edge of the Delta in Suisun Marsh. This highly managed wetland relies on the operation of water diversion facilities which do operate when juvenile salmon are present. Furthermore, entrainment studies conducted in 1981 and 1982 confirmed that juvenile Chinook salmon were vulnerable to entrainment in Montezuma Slough through unscreened diversions (Wernette 1995). A fish screen was installed on DFG's diversion intake in Grizzly Slough just prior to 1995 (Wernette 1995) and several other diversions in the area have been similarly screened (Figure 38).

Although Delta irrigation diversions (principally non-export use of water in the Delta) are relatively large[13] (Figure 43), they are primarily operated during the summer months when environmental conditions are generally unfavorable for salmonids in the Delta. The timing of these diversions does not correspond well with the primary migration period of juvenile spring-

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[12] In 1988, the author initiated a USFWS steelhead broodstock selection program of using only sea-run fish based on scale analyses which DFG referred to as a "Blue Ribbon" steelhead strain but was since abandoned for unknown reasons [similar to a program conducted in the 1950s and also abandoned (Hallock 1989)].

[13] The peak summer diversions collectively exceed 4,000 cfs (DWR 1995).

run, late-fall-run, winter-run Chinook, and likely steelhead, in the Delta. However, during the spring months, a large portion of the non-ESA-listed fall-run juvenile population is in the region and some overlap in seasonal presence and agricultural operations can occur, particularly during drought years. However, overall, fish entrainment in the Delta is not considered to have been a major contributing cause to recent declines in the threatened or endangered anadromous salmonid populations because of poor correspondence between water diversions and the primary presence of the species. The effects of these diversions on juvenile green sturgeon are unknown.
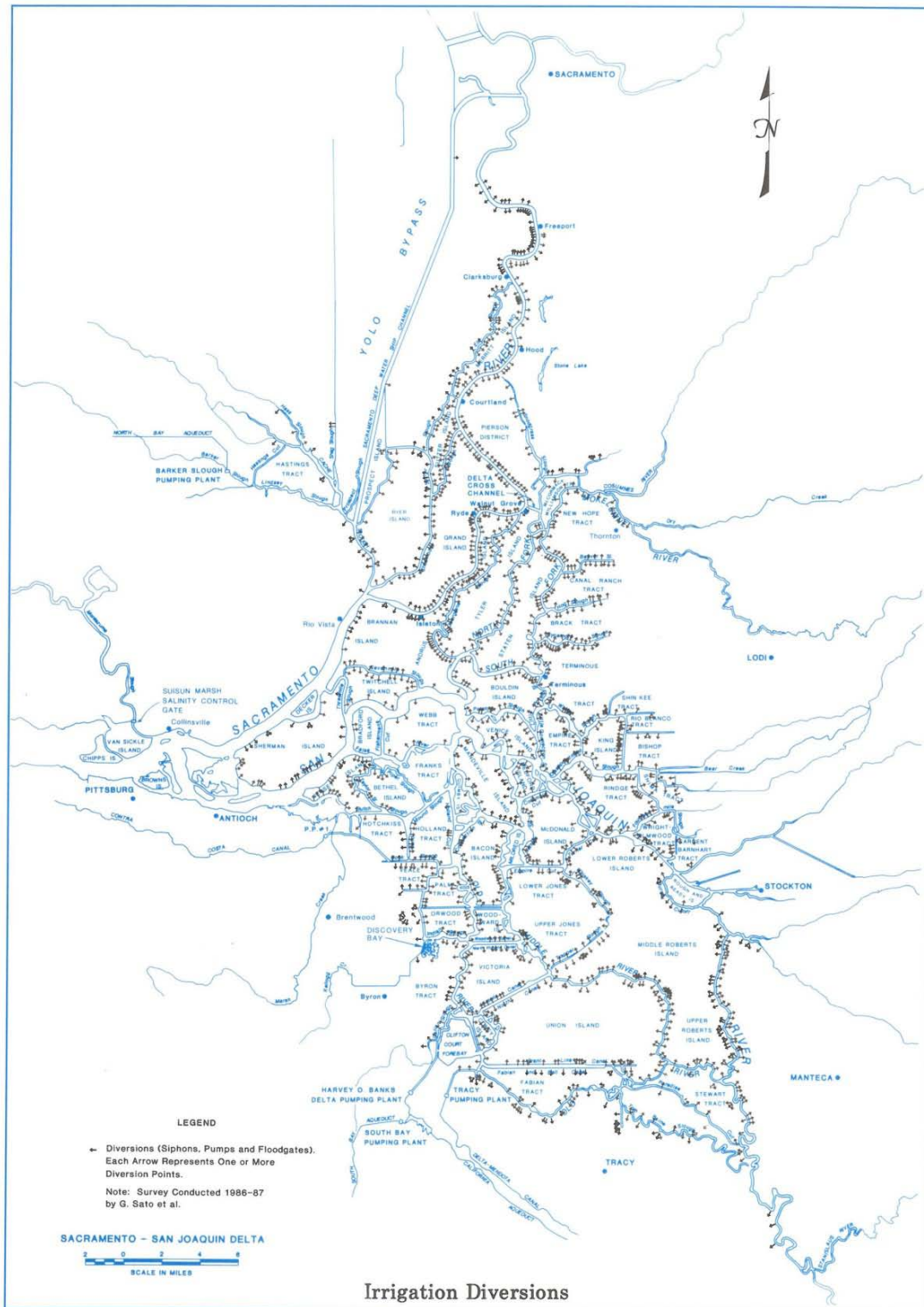
Figure 43. Location of irrigation diversions in the Delta (from DWR's Delta Atlas).

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5.5.3.5 *Migration Routes*

The pathways used by outmigrating juvenile anadromous fish from the river and through the Delta are known to affect fish survival. Each of these migration routes possesses unique characteristics that could be beneficial or detrimental to the survival and growth of juvenile fish.

For example, fish originating in the upper Sacramento River may be entrained into one of five flood-control weirs upstream of the Delta: Moulton, Colusa, Tisdale, Fremont, and Sacramento (Figure 1). Depending on the timing and magnitude of the salmonid emigration, if high flows cause flood control weirs to crest, fish may be swept out of the main river channel and over or through Moulton, Colusa, or Tisdale weirs into the lower Butte sink. The lower Butte sink is a highly complex wetlands basin; flood flows ultimately re-enter the Sacramento River just upstream of the Feather River confluence. Additionally, under high-flow conditions fish can pass the Fremont or Sacramento weirs and enter the Yolo Bypass which empties into Cache Slough in the northern Delta. The overall biological significance of fish utilizing these routes is unknown and has been debated for many years. These routes may be highly beneficial to fish through enhanced growth rates in flood plains and higher survival through a variety of mechanisms or, alternatively, may subject the fish to significant losses through high levels of stranding and predation.

Utilization of juvenile salmon emigrating through Sacramento River bypasses such as the Yolo Bypass many enhance nursery habitat for juvenile salmon (Sommer *et al.* 2003). Data suggest that growth rates of juvenile salmon in the bypass are higher than those salmon remaining in the Sacramento River (Sommer *et al.* 2000), perhaps at least partially because of warmer water in the bypass than in the river (Sommer *et al.* 1998). A potential advantage of salmon utilizing the bypass for a migration corridor is reduced exposure time to mortality in the Delta from predation and water diversions (Sommer *et al.* 2000). Additionally, fish entering the Delta via the Yolo Bypass into Cache Slough are not exposed to undesirable migration routes further downstream at the DCC and Georgiana Slough (discussed below).

There is a risk that salmon can be trapped and perish in the flood bypasses when waters recede (Sommer *et al.* 1998, Sommer *et al.* 2000), and that these fish, possibly number in the hundreds of thousands, depending on various assumptions (Sommer *et al.* 1998). The stranding and loss of juvenile salmon in flood bypasses has been known for years. Quantification of fish fatalities in these areas has been difficult to determine. In 1996, five concrete ponds with a total surface area of one acre behind the Sacramento weir in the Sacramento bypass were seined to capture and remove fish. A limited effort over two days using a 50-ft long net captured about 11,000 juvenile Chinook salmon. These fish would have otherwise died. Although it would be difficult to extrapolate these results to the entire bypass, the sampling indicated that during periods when bypasses flood, large numbers of salmon may perish (IEP 1996). Fish losses in the flood bypasses are difficult to detect due to bird predation and other predatory fish which may reside in isolated stranding pools. Losses of fish entering into the Butte Sink have not been evaluated and would be considerably more difficult to assess, given the complexity of wetlands and waterways. Recent advances in technological tools (*e.g.*, acoustic telemetry) could potentially be used to

estimate fish survival among the different migration routes through the various bypasses.

The flood bypasses have been in place for many decades, even pre-dating large dam construction. During this period, there have been both large and small runs of anadromous fish. There is nothing apparent in changes to flood bypass operations which would suggest these bypasses are a significant contributing factor to fish population declines. Studies are underway to determine if an increase of fish utilization of the bypasses would potentially benefit the populations. However, this must be tempered with the realization that fish stranding could pose major hazards if flows and flood channel topography for appropriate drainage are not carefully managed. For example, early season, short-term pulses of water into the bypasses may inadvertently trap large numbers of fish emigrating from the upper rivers during the first high flow, high turbidity events. A delay in the use of the bypasses, or sufficient duration of flows after such early events might help to ensure the vast majority of fish exit the bypass prior to flow recedence. However, without proper implementation, providing such flows would likely result in significant upstream reservoir drawdown, and a loss of carryover storage for temperature control (MBK 2010).

Downstream of the flood bypasses, there are five primary routes where juvenile anadromous fish enter the Delta: the mainstem Sacramento River, Sutter Slough, Steamboat Slough, Delta Cross Channel, and Georgiana Slough (Figure 44). The most-studied fish migration routes affecting survival have pertained to the DCC and Georgiana Slough in the north Delta (Figure 44). Studies using coded-wire tagged fry- and smolt-sized Chinook salmon have demonstrated that fish survival is lower in the central Delta relative to the north Delta. Generally, these studies and the conclusions were based on releasing paired groups of thousands of differently marked/tagged young salmon upstream and downstream of the flow splits and within the channels downstream of each flow split. Tagged salmon released in the Sacramento River upstream of the DCC and Georgiana Slough generally exhibit lower survival than tagged salmon released further downstream in the mainstem (Kjelson 1989).

Figure 44. Migration routes for juvenile anadromous fish entering the Delta.

Young salmon diverted into the central Delta via the DCC or Georgiana Slough have reduced survival compared to fish remaining in the Sacramento River downstream of those diversion points, not only in the spring, but also during the winter (Brandes and McLain 2001). The

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earliest salmon tagging studies conducted in the north Delta focused on fall-run Chinook which usually emigrate as smolts during April and May. The low survival of fall-run Chinook entrained into the central Delta has been well established and the causal mechanisms for mortality have been attributed to warm water temperatures and predation (Wullschleger 1994). Similar experiments using late-fall run Chinook, as surrogates for winter-run Chinook, both of which migrate through the Delta during winter months have also demonstrated lower survival when these fish are diverted into the central Delta (Wullschleger 1994).

Experiments conducted at the DCC during 2000, 2001, and 2002 using radio-tagged juvenile salmon indicated that fish entrainment into the DCC depends on site-specific flow conditions at the time juvenile salmon encounter the flow split (Vogel 2004). For example, during ebb tide conditions, fish released upstream of the DCC migrated past the DCC when flow in the DCC was minimal. Conversely, during flood tide conditions, fish released upstream of the DCC were swept into the DCC when flow was high entering into the Mokelumne River portion of the Delta. It was also determined that even when fish successfully passed the DCC during ebb tides and remained in the Sacramento River, the fish could be subsequently advected back upstream and into the DCC with subsequent flood tidal conditions (Figure 45).

Figure 45. The lower Sacramento River at Walnut Grove with depicted pathway of juvenile salmon movements passing the DCC on an ebb tide then advected back upstream and into the DCC on a flood tide [based on juvenile salmon radio-tagging studies by Vogel (2000, 2001)].

As previously discussed, it has been commonly assumed that one of the primary reasons for the dramatic decline in winter-run Chinook was caused by the drought-induced reservoir drawdowns in 1976 and 1977 depleting much of the hypolimnion in Shasta Reservoir, which caused releases of warmer-than-suitable water into downstream areas, causing salmon egg mortality. However, the drought also resulted in no DCC gate closures during the period when the 1976 and 1977 progeny would have emigrated (Figure 46). This circumstance would have been expected to cause greater entrainment into the central Delta where mortality can be high and could have been a significant additional contributing cause for the poor fish returns from those brood years.
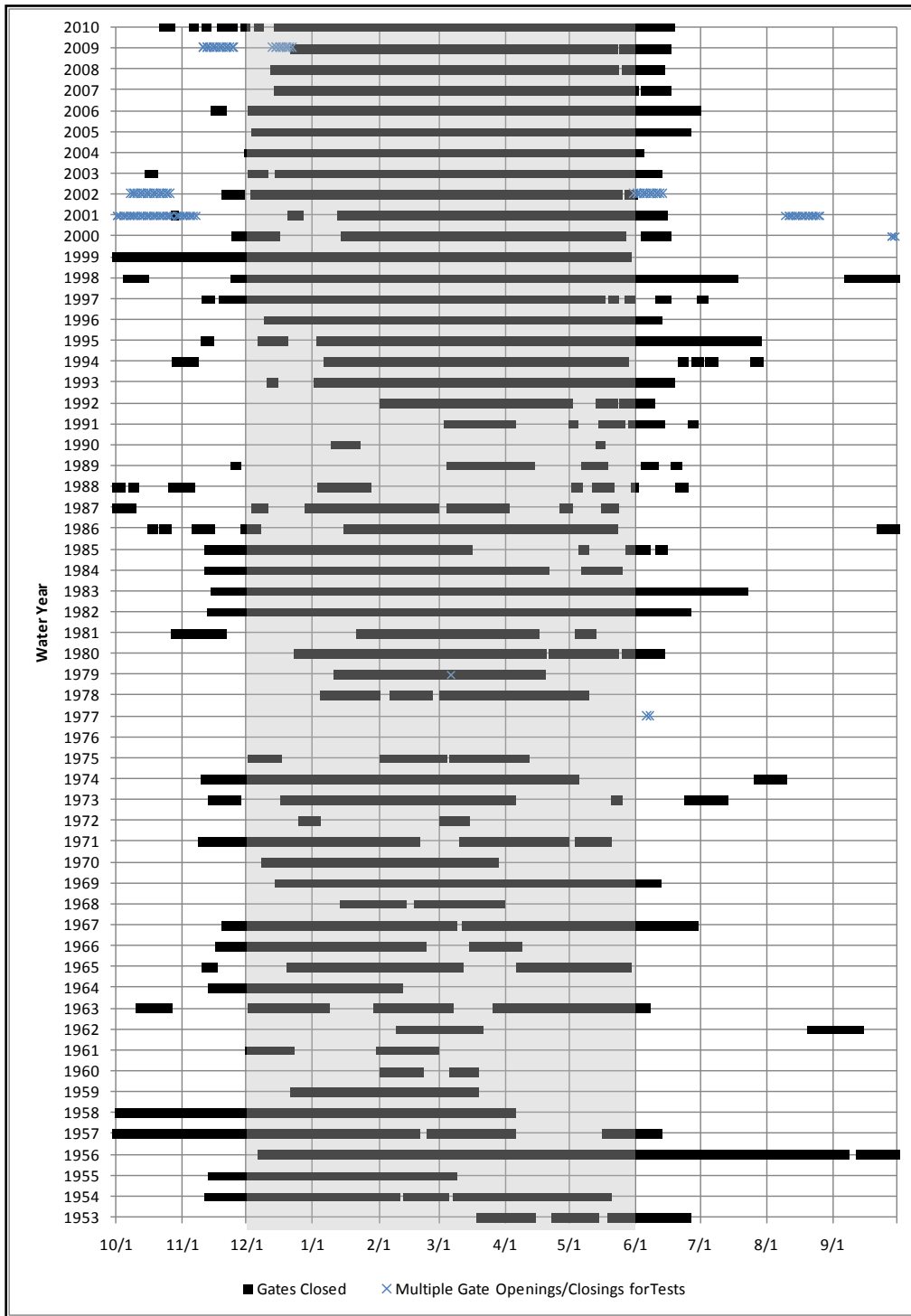
Figure 46. Historical operations of the DCC gates showing periods when the gates have been closed and the generalized primary presence of juvenile salmon (shaded).

Based on the historical record of DCC gate operations (Figure 46), it is evident that protection for native anadromous fish has increased in recent years due to much more frequent closures of the gates to minimize entrainment of fish into the central Delta where fish mortality is higher.

To date, no simple solution for operating the DCC for concurrent fish protection and water conveyance through the north Delta has emerged. As a result, complete closure of the DCC gates during portions of the fish migration period has been implemented. Since just prior to and after the listing of the winter-run Chinook as a threatened or endangered species, mandatory measures have been implemented to reduce fish entrainment at the DCC. The 1995 SWRCB Water Quality Control Plan provided for 45 days of DCC gate closure from November 1 through January 31; after January 31, the gates were closed until mid-May under the Winter Run Protection Plan (Chappell 2003). The more-recent NMFS Biological Opinion stipulates even greater closures of the DCC.

During SWRCB workshops in July 1994, the author testified as to the potential benefits of implementing a near- or real-time monitoring program to detect the emigration of juvenile salmon approaching the DCC. As far as the author's knowledge, this was the first formal recommendation on the topic. The rationale of such a program would be to implement protective fish measures such as closing the DCC gates prior to the arrival of large numbers of fish. Pilot testing of a real-time monitoring effort demonstrated its feasibility and is now a standardized program conducted every year. Sufficient data have been collected over the years which have resulted in criteria (*e.g.*, changes in flow, temperature, and turbidity) to predict the emigration of salmon from the upper river system to the Delta, and facilitate timing of the DCC gate closure periods (Chappell 2003). For example, the average catch of juvenile salmon in beach seines during the USFWS fish monitoring program in January through March is significantly positively related to flow measured at Freeport (Burmester 2001) providing empirical support to justify specific times of DCC gate closures.

Even when the DCC gates were closed, studies have demonstrated that the diversion of young salmon into Georgiana Slough negatively affects their survival (Brandes and McLain 2001). Once entering the Slough, fish are unlikely to re-emerge back into the Sacramento River because the Slough's flows generally do not reverse with tidal phase. A recent study conducted by releasing radio-tagged juvenile Chinook salmon in upper Georgiana Slough and in the lower Sacramento River downstream of Georgiana Slough found a higher rate of fish mortality in the former release location. The difference was attributed to nearly three times greater predation losses on radio-tagged salmon in Georgiana Slough compared to those fish migrating down the lower Sacramento River (Vogel 2004). Flow in Georgiana Slough is largely unidirectional and, unlike the DCC, fish may enter Georgiana Slough under both ebb and flood tide conditions (Figure 47).
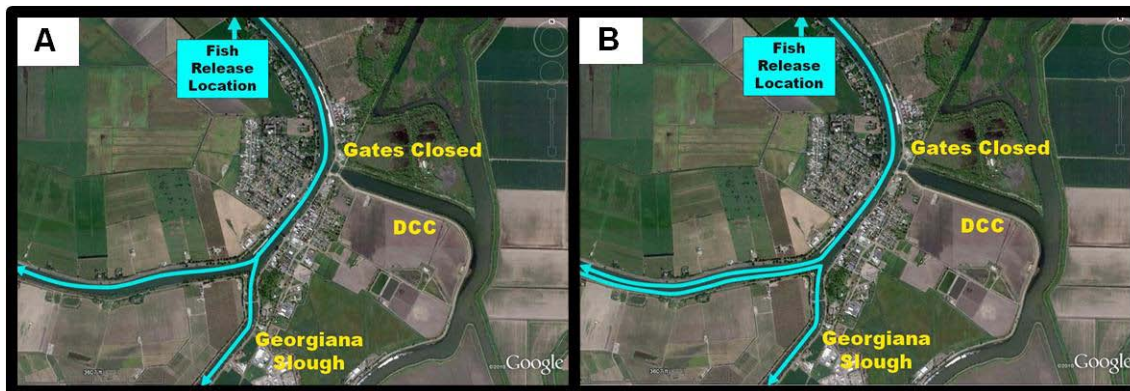
Figure 47. The lower Sacramento River at Walnut Grove with depicted pathway of juvenile salmon movements passing Georgiana Slough on: (A) an ebb tide and (B) an ebb tide then advected back upstream and into the Slough on a flood tide [based on radio-tagging studies by Vogel (2001)].

There are obviously numerous variations of fish movements at the DCC and Georgiana Slough flow splits depending on the magnitude of river flow and tidal phase. These studies showed the highly complex and continually changing hydrodynamic conditions and fish behavior at these flow splits.

Preventing or minimizing fish entrainment into Georgiana Slough is problematic because, unlike the DCC, there are no physical structures at the location to alter flow conditions. However, there have been attempts to reduce fish entrainment into Georgiana Slough using behavioral barriers when the DCC gates are closed. In 1993 and 1994, an acoustic fish behavioral barrier was tested to determine if juvenile salmon could be deterred from entry into the slough (IEP 1995). The results of this measure were mixed. For example, during high flow conditions in 1996, the study at the barrier indicated that juvenile salmon were not deterred away from Georgiana Slough and extensive damage to the mooring system and cables was caused by the high flows (Coulston 1997). DWR is testing a new fish behavioral barrier at the flow split in early spring of 2011 using a combination of lights, bubbles, and sound. Even if the device shows some measure of success, the typical conditions present during high fish migration under elevated, turbid flows will likely diminish its effectiveness as compared to low, clear-water conditions. This fish migration route remains a problem with no clear solution in sight.

Research using both coded-wire tagged salmon and acoustic-tagged salmon has also focused on potential effects of fish utilizing Sutter and Steamboat Sloughs just upstream of the DCC and Georgiana Slough. It has been hypothesized that fish migrating through these sloughs may exhibit higher survival that those fish exposed to the DCC and Georgiana Slough by avoiding entrainment into the Central Delta where survival is lower. Studies using coded-wire tagged fish have shown that juvenile salmon utilizing Steamboat or Sutter Sloughs generally exhibit higher survival than fish exposed to the DCC and Georgiana Slough (Kjelson 1989). More-recent

research in the north Delta (Figure 48) found that acoustic-tagged juvenile salmon were diverted into Sutter and Steamboat sloughs in relatively high proportions both when the DCC gates were opened and closed (26% and 37%, respectively) (Figure 49) (Vogel 2008c). When the DCC gates are closed, there is a decrease in net flows in the Sacramento River just upstream of the DCC which results in increased flow into Sutter and Steamboat Sloughs (Oltmann 1995). This may be favorable for fish survival, but it has not yet been empirically confirmed. However, further downstream, fish exposed to the Georgiana Slough flow split entered the Slough in a higher proportion than when the DCC gates were opened (Figure 49).
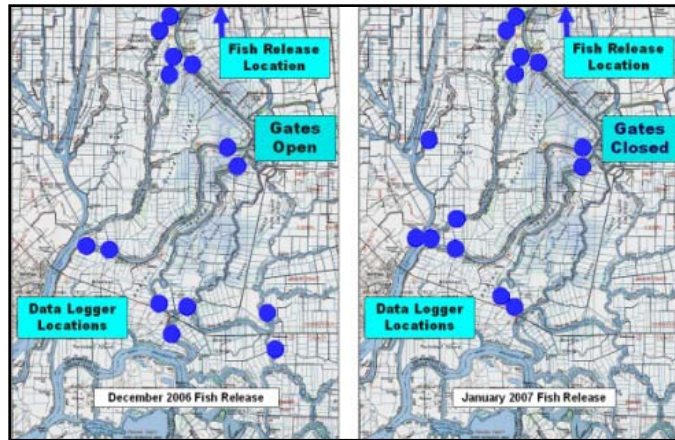
Figure 48. Approximate locations of acoustic receivers positioned in the Delta reaches downstream of acoustic-tagged juvenile salmon released during December 2006 and January 2007 in the Sacramento River at West Sacramento with the DCC gates open and closed, respectively (from Vogel 2008c).
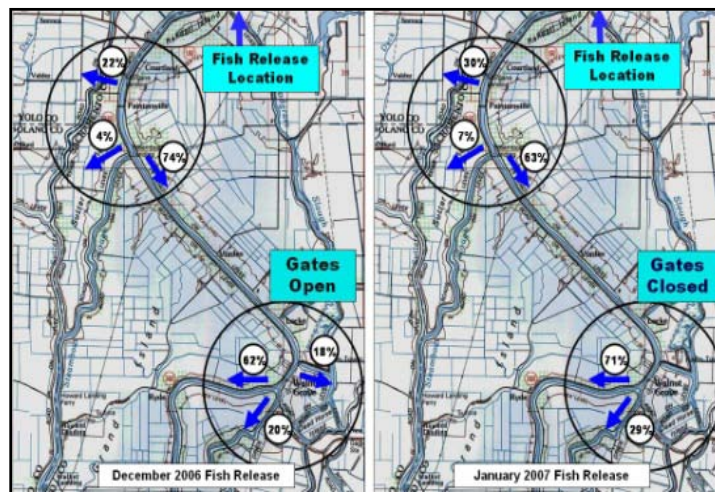
Figure 49. Proportional distribution of acoustic-tagged juvenile salmon entering channels at flow splits near the Sutter/Steamboat Slough region and the DCC/Georgiana Slough region in December 2006 when the DCC gates were open and January 2007 when the DCC gates were closed (from Vogel 2008c).

Compounding the problem of evaluating anadromous fish movements in the Delta is the inability to accurately quantify fish survival within the complex, multi-channel tidal environment. A recent attempt by USGS to quantify fish survival in the Delta by releasing acoustic tagged fish in

the north Delta and recording their movements at strategically-placed dataloggers in downstream channels has not yet been completed. However, numerous concerns with the experimental design of the USGS study were expressed by a CALFED Science Review Panel (Monismith *et al*. 2008, as cited by Larry Walker Associates 2010). Additionally and unfortunately, more-recent research has clearly demonstrated that the accuracy and precision of survival estimates of acoustic-tagged salmon are highly prone to error and misinterpretation because tagged salmon consumed by predatory fish and subsequently detected on the dataloggers can, in many instances, be misconstrued as a live salmon (Vogel 2010a). Worse, if invalid salmon survival estimates were used for management decisions in the Delta, inappropriate measures could be implemented and considerable time, resources, and fish could be lost. Until methods or technologies are developed to differentiate between live tagged salmon and tagged salmon eaten by predators, such survival studies will be prone to misinterpretation and error.

After Sacramento River juvenile salmon enter the central Delta either through the DCC or Georgiana Slough, the mechanisms by which salmon subsequently enter the south Delta remain perplexing. For example, experiments conducted by releasing radio-tagged salmon in the South Fork of the Mokelumne River showed that fish can enter the mainstem San Joaquin River, but be subsequently advected back upstream in the mainstem and enter channels such as Middle River south of the mainstem (Figure 50) (Vogel 2010a).
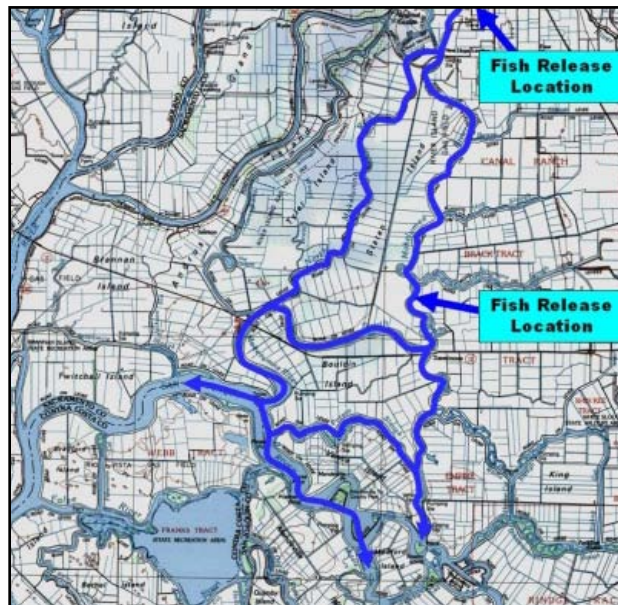
Figure 50. Migration pathways for radio-tagged salmon observed for fish released in the lower Mokelumne River in the north Delta (Vogel 2010a).

Fish emerging from the north Delta, but subsequently moving to the south Delta must traverse across the mainstem San Joaquin. The maximum tidal flow exhibited in the San Joaquin at Jersey Point during ebb and flood is about 150,000 cfs (Oltmann 1995), so it is surprising fish can enter south Delta channels. Even during wet year conditions, tagging studies demonstrated

that a significant fraction of juvenile salmon entrained into the central Delta via Georgiana Slough subsequently enter the south Delta (Winternitz *et al.* 1995). Juvenile steelhead have also been documented to move from the north to south Delta (Foss 2005). This southerly movement of fish off the San Joaquin River into the south Delta has also been empirically confirmed for fish released in the San Joaquin upstream of flow splits into the south Delta (Figure 51). In one instance, a radio-tagged salmon released in the mainstem San Joaquin River downstream of Stockton was later recaptured live at the south Delta Tracy Fish Facilities (Vogel 2002).
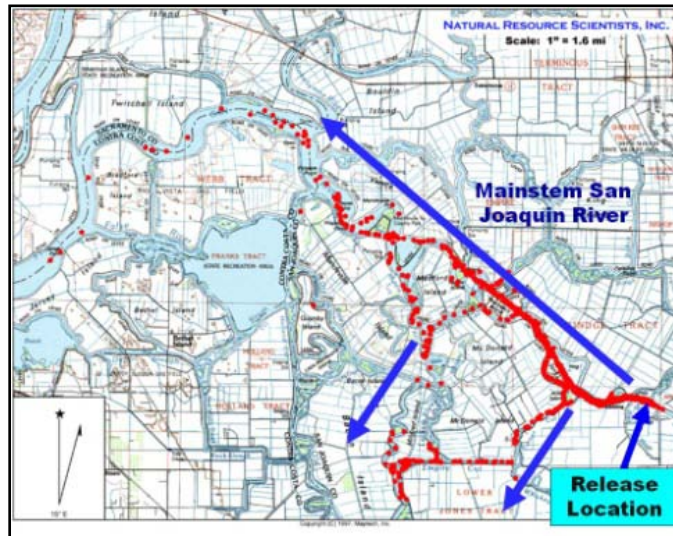
Figure 51. Telemetered locations of approximately 100 radio-tagged salmon smolts released in the lower San Joaquin River near 14-Mile Slough (data from Vogel 2002).

For those fish present in south Delta channels in close proximity to the south Delta export facilities, southerly fish movement (as compared to northerly movement leading to salt water) has been empirically confirmed. For example, radio-tagged juvenile salmon released in northern Old River north of Clifton Court Forebay showed strong southerly movements directly into the Forebay. These occurrences were evident under both medium and low water export conditions (Figure 52) (Vogel 2002).
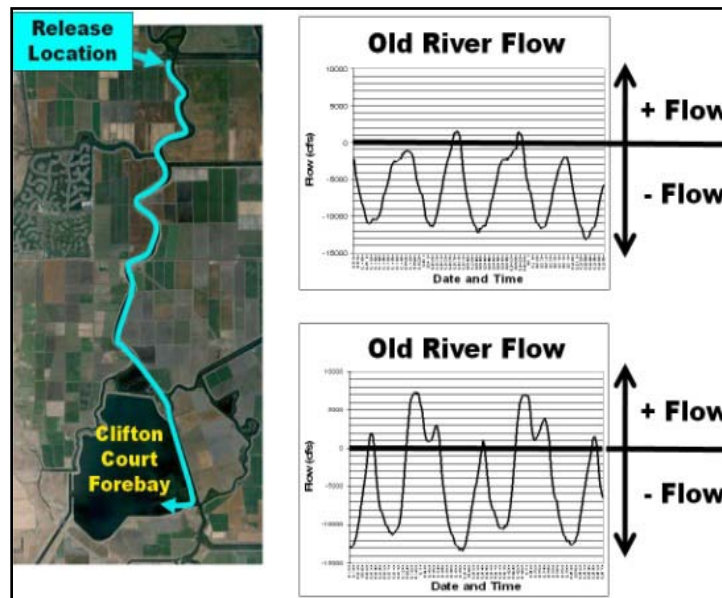
Figure 52. Typical migration pathway for radio-tagged Chinook salmon smolts released in northern Old River during medium- and low-level south Delta water exports (data from Vogel 2002).

The increase in south Delta water exports corresponds with the period when significant declines of anadromous fish occurred. Reverse flows, entrainment of fish into the pumping facilities, and increased predation at water facilities have been believed to be problems for salmon for a long time (Reynolds *et al.* 1993). Additionally, operations of the CVP and SWP have been believed to have had a detrimental effect on steelhead smolts emigrating through the Delta (Reynolds *et al.* 1993). The consensus of California steelhead experts in the late 1970s attributed the overall decline in steelhead to the significant increases in south Delta exports (Vogel 1984). Recently, Lindley *et al.* (2009) suggest that "*... the biggest problem with the state and federal water projects is not that they kill fish at the pumping facilities, but that by engineering the whole system to deliver water from the north of the state to the south while preventing flooding, salmon habitat has been greatly simplified.*" Effects of south Delta exports on green sturgeon are largely unknown.

Prior to 1966 and during the earlier era of the CVP (pre-San Luis Reservoir), CVP south Delta exports were concentrated in the spring, summer, and early fall, with only minor exports in the late fall and winter. More specifically, the seasonal Delta export pattern was a peak in summer and a low in winter (Figure 53). The timeframe of this pattern was when the populations of the anadromous salmonids were large. After the mid-1960s when the SWP and San Luis Reservoir facilities began operation, the south Delta exports continued year-round with more reliance on winter-spring diversion after San Luis Reservoir operation; this era corresponds to the period when the populations of anadromous salmonids experienced a precipitous decline. More recently, total annual exports from the Delta increased from a maximum of about 5 million acre-feet (MAF) in the late 1990s to about 6 MAF after 2000 (EPA 2011).
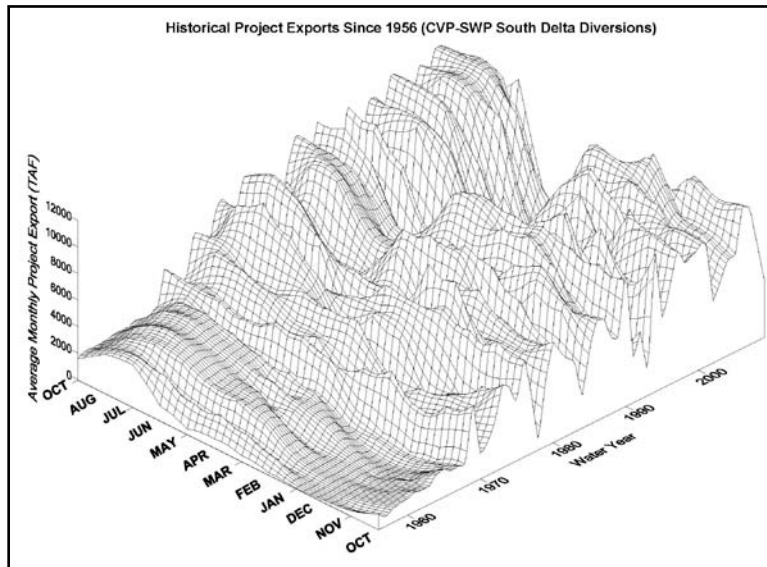
Figure 53. Historical south Delta exports (SWP and CVP combined) since 1956 (data from DWR DAYFLOW).

5.5.3.6 *Predation*

Predation of anadromous fish has emerged as one of the hypothesized primary sources of mortality in the Delta. Although over 200 exotic species have been introduced into the estuary and the rate of invasion is apparently increasing (Cohen 1997), the greatest probable impact to native anadromous fish would be expected from only several introduced predatory species (*e.g.*, striped bass and largemouth bass). Beginning in 1992, DFG ceased stocking juvenile striped bass in the Delta due to concerns of impacts on winter-run Chinook salmon (IEP 1992). Nevertheless, the population of sub-adult and adult striped bass capable of preying on native juvenile anadromous fish remains large. DFG introduced the Florida strain of largemouth bass into the Delta in the early 1980s and the sport fishery for largemouth bass has become increasingly popular during recent decades (Lee 2000). Amazingly, given all the focus on anadromous fish protection and enormous expenditures in upstream areas, predation mortality in the Delta has received little attention in the form of remedial actions. For many years most of the attention has focused on predation in the south Delta, keying in on the two large water export facilities, but little or no corrective actions have been implemented.

Clifton Court Forebay (CCF), in the south Delta (Figure 1), is a 2,200 acre reservoir, located just upstream of the SWP Banks Pumping Plant. Large radial gates are usually opened during high tide to flood the Forebay, then closed, to facilitate pumping at the SWP. Fish entrained into CCF but not reaching the fish salvage facilities upstream of the pumping plant are called "pre-screen losses" which have been measured through juvenile salmon studies at about 75% mortality (IEP 1993) and have ranged from 63% to 97% (Schaffter 1978, Hall 1980, Kano 1985, Kano 1986, as cited by Kano 1990). Gingras (1997) summarized the results of 10 DFG studies on pre-screen fish losses conducted from 1976 through 1993 which ranged from 63% to 99%. Since the late 1970s, DFG has been studying this pre-screen loss and attributes the fish mortality

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to predation, primarily by striped bass (Coulston 1993), which are the primary predator in the Forebay (IEP 1993). Recent studies using acoustic-tagged juvenile salmon have also confirmed extremely high predation rates in the Forebay, also believed to be attributable to striped bass (Vogel 2010b).

Apparently, numerous studies of predators in CCF have been conducted, but little action has transpired to control the predators or alleviate the site-specific problem (other than federal Biological Opinion measures controlling water exports). In 1984 and 1985, striped bass movements inside CCF were monitored and it was demonstrated that the fish can exit the Forebay into the Delta (IEP 1992). It was subsequently confirmed through additional large-scale tagging studies that striped bass move in and out of the Forebay (IEP 1993). In 1991, DWR contracted with a commercial fisherman to seine CCF as a potential measure to control predatory fish populations; that effort netted numerous striped bass (IEP 1991). In 1992, 2,000 predators were removed from CCF and relocated elsewhere in the Delta; population estimates associated with that effort indicated the population of striped bass was about 150,000 fish inhabiting the Forebay (Coulston 1993). A subsequent, similar predator removal project ending in 1993 removed more than 32,000 predators (including nearly 29,000 striped bass) and the striped bass population estimate grew to about 200,000 fish (Coulston 1993). Additional research at CCF in 1994 and 1996 provided strong evidence that emigration and immigration of sub-adult and adult striped bass frequently occurs when the gates are open which would significantly hamper predator control efforts in the Forebay (Gingras and McGee 1996, McGee and Gingras 1996).

Because of the concern about predation in CCF, a workshop was held in 1993 to discuss options to reduce predatory fish in the Forebay. The principal options examined included an increase in recreational fishing opportunities and an aggressive, non-lethal removal and relocation program. Interestingly, two of the primary reasons posed for not pursuing these actions were largely policy related. Water exporters were concerned that predator removal would result in increased numbers of salmon reaching the fish salvage facilities and would penalize exports due to a perceived increase in "take" of winter-run Chinook (unless a relaxation in the NMFS pre-screen loss estimates for winter-run Chinook was initiated). Conversely, recreational fishing interests were opposed to predator removal because of their concern that increased water exports would take place, resulting in greater indirect losses of salmon (Coulston 1993).

Recent studies using acoustic-tagged juvenile salmon and acoustic-tagged striped bass also empirically demonstrated the severe predation problem in Clifton Court Forebay. Specifically, the small area immediately behind the CCF gates was shown to harbor striped bass for extended periods (Vogel 2010b, 2010c) and mortality was severe when salmon passed under the gates (Figure 54) and were eaten by predators (Vogel 2010b). This very small isolated area undoubtedly causes the highest mortality for anadromous fish reaching the south Delta. This predator haven has been, and will continue to be, severe without corrective measures.

Figure 54. Clifton Court Forebay showing turbulence behind the radial gates. Photo by Dave Vogel.

Predation mortality at the Tracy Fish Facilities (TFF) (Figure 55) is also an extremely serious problem for anadromous fish and has been known for a long time. These issues are well-described in a recent peer review of CVPIA restoration program activities, which was highly critical of the lack of significant efforts to correct the problem:

> *"… the operation of the Tracy Pumping Plant and Fish Collection Facility is a serious mortality source for salmon and steelhead (and for Delta smelt). All aspects of the pump operations have significant adverse impacts on salmon and steelhead, from the way juveniles are drawn to the pumps and away from the natural migration routes out through the Delta, to predation and other mortality factors in the channels leading to the pumps, to high mortalities at the out-dated louvers screening the pumps, to even higher mortalities likely during the archaic "salvage" collection and transport operation at the pumps, to predation mortality at the point of re-release, and finally to the overall adverse effects on salmon survival and productivity from regulating and diverting that much of the natural Delta outflow. Data on direct and indirect juvenile mortality is uncertain but likely to be high, and may run as high as 50% for spring-run Chinook and steelhead, and possibly 75% for winter-run Chinook."* Cummins *et al.* 2008.

Figure 55. Location of extremely high mortality of acoustic-tagged juvenile salmon at the Clifton Court Forebay gates and in front of the Tracy Fish Facilities (from Vogel 2010b).

Recent studies using acoustic-tagged juvenile salmon found that fish mortality near the TFF may be much higher. For example, in 2007, mortality of tagged salmon in front of the facilities was estimated at 100% and no tagged salmon successfully reached the downstream fish salvage facilities (D. Vogel, unpub. data). Detailed analyses of recorded acoustic "signatures" from data loggers at the site determined that predators just upstream and downstream of the trashracks in front of the TFF (Figure 56) had consumed the tagged salmon. The magnitude of striped bass accumulation in the area was demonstrated in 1991 when the USBR removed 1,925 striped bass from the TFF (IEP 1992). USBR periodically removes striped bass from the area between the trashrack and fish louvers (Figure 57).
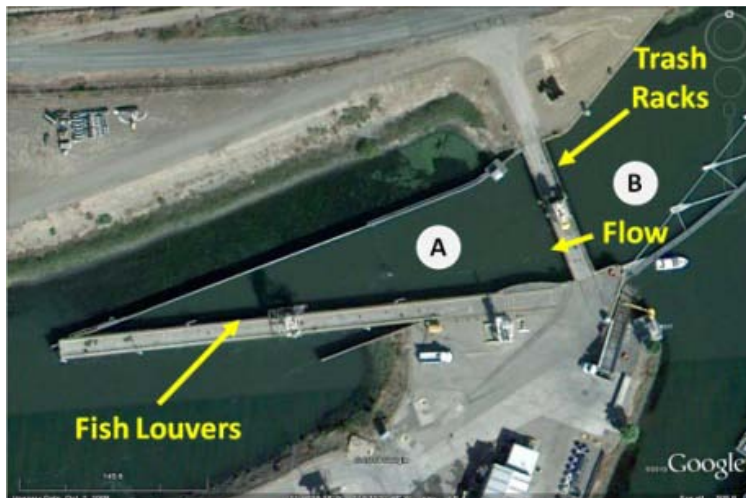
Figure 56. Aerial view of the Tracy Fish Facilities in the south Delta showing locations where high predation mortality occurs (A) between the trashracks and the trashrack and (B) in front of the trashracks.

Figure 57. Removing striped bass (seven in picture) by gill netting behind the trashracks and in front of the fish louvers at the Tracy Fish Facilities. Photo by Dave Vogel.

Until the site-specific predation issues are resolved at CCF and TFF, mortality of juvenile salmonids reaching the south Delta will continue to be significant.

Predation in the Delta (outside of CCF and TFF). Over the past 15 years, this author has become extensively familiar with the primary waterways in the Delta where juvenile anadromous fish may be present and the associated habitats. Most of this familiarity was derived from conducting more than 20 telemetry studies on both juvenile salmon (Figure 58) and predatory fish in the Delta [including wide-ranging mobile telemetry surveys tracking fish throughout the region (Figure 59)]. Additionally, numerous surveys at a variety of sites in the Delta were conducted using a Dual-Frequency Identification Sonar (DIDSON^{TM}) camera which is capable of underwater viewing and recordation of fish and structures over long distances in turbid water (Figure 60). During the course of these studies, numerous observations and findings relevant to this report were made and are discussed here.

Figure 58. Radio-tagged and acoustic-tagged salmon smolts used in Delta telemetry studies (photos by Dave Vogel).
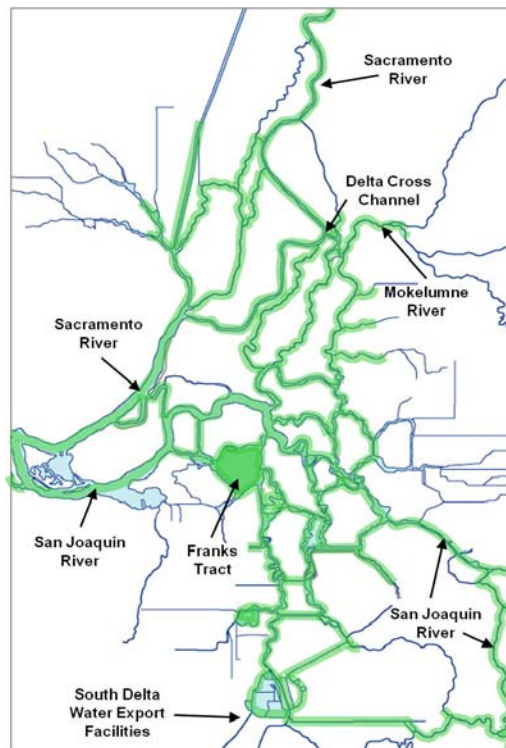
Figure 59. Map of the Sacramento – San Joaquin Delta showing areas (shaded in green) the author has frequently traversed by boat during radio and acoustic fish telemetry studies within the past 15 years.
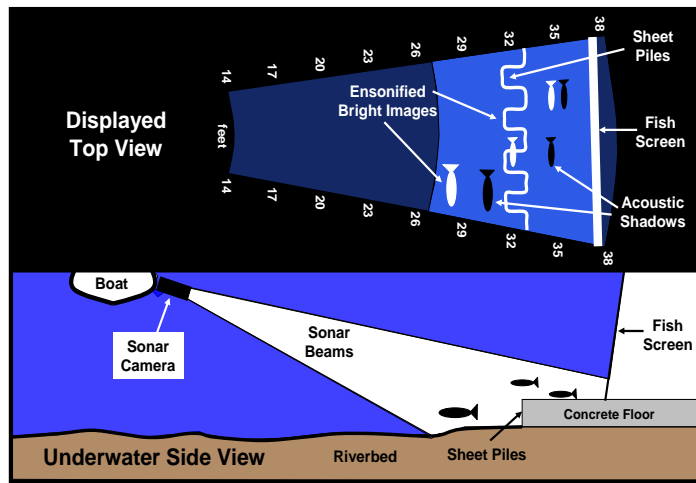
Figure 60. Schematics of DIDSON^TM imaging at the base of a flat-plate fish screen. Bottom diagram shows orientation of sonar beams from the acoustic camera off the side of a boat and submerged objects at the fish screens. Top diagram shows the resultant corresponding sonar imaging of objects ensonified with acoustic shadows from the objects. (from Vogel 2008b)

From 1996 through 2010, Natural Resource Scientists, Inc. conducted 22 separate research projects on juvenile salmon (including four studies of predatory fish) in the Delta using acoustic or radio telemetry as a means to gain an improved understanding of fish movements and mortality (Vogel 2010a). The reason juvenile salmon telemetry studies were initiated in the Delta was to acquire detailed data on fish behavior, fish route selection through complex channels, and estimate fish survival in discrete reaches. Past efforts using traditional coded-wire tagging could not answer those critically important questions. Research findings from the telemetry investigations indicate that smolt survival assumptions and models must incorporate these new conclusions to avoid misinterpretation of data and improve quantitative estimates of fish survival and movements (Vogel 2010a).

The first successful use of telemetry on juvenile salmon in the Central Valley was conducted by Natural Resource Scientists, Inc. on behalf of EBMUD in 1996 and 1997. At that time, the specific behavior of juvenile salmon in the Delta was largely unknown. The initial studies quickly determined that the fish did not move as a school, but instead, dispersed, exhibiting a wide range in migratory behaviors in the complex Delta environment. Salmon moved many miles back and forth each day with the ebb and flood tides and the side channels (where flow was minimal) were largely unused. Site-specific hydrodynamic conditions present at flow splits when the fish arrived had a major affect in initial route selection. Importantly, some of the salmon were believed to have been preyed upon based on very unusual behavior patterns (Vogel 2010a).

Subsequent, additional juvenile salmon telemetry studies were conducted by Natural Resource Scientists Inc. on behalf of the USFWS and CALFED in the north Delta (Vogel 2001, Vogel 2004). Triangulating radio-tagged fish locations in real time (Figure 61) clearly demonstrated

how juvenile salmon move long distances with the tides and were advected into regions with very large tidal prisms, such as upstream into Cache Slough and into the flooded Prospect and Liberty Islands (Figure 62). During the studies, it was determined that some radio-tagged salmon were eaten by predatory fish in northern Cache Slough, near the levee breaches into flooded islands (discussed below). Also, monitoring telemetered fish revealed that higher predation occurred in Georgiana Slough as compared to the lower Sacramento River (Figure 63). As discussed previously, past coded-wire tagging studies found that salmon released into northern Georgiana Slough were found to have a higher mortality rate than fish released downstream of the slough in the Sacramento River (Brandes and McLain 2001).

Figure 61. Left picture, mobile telemetry conducted in the north Delta. Photo by Dave Vogel.
Figure 62. Right picture, telemetered locations of approximately 100 radio-tagged salmon smolts released in the lower Sacramento River near Ryde (data from Vogel 2001 and Vogel 2004).
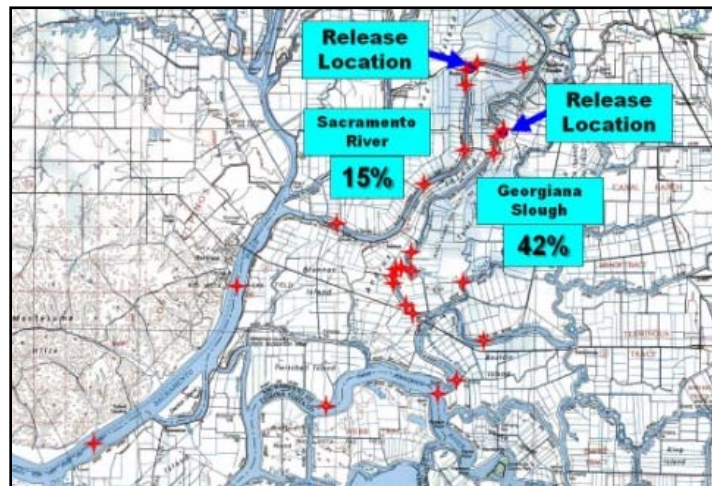
Figure 63. Estimated mortality rate for groups of radio-tagged salmon released at two locations in the north Delta and locations where radio-tagged salmon smolts were detected to have been preyed upon (Vogel 2001, Vogel 2004).

More recently, a 2007 study conducted by releasing acoustic-tagged juvenile salmon in the San Joaquin River found 116 motionless juvenile salmon transmitters in the lower San Joaquin River near the Stockton Waste Water Treatment Plant and a nearby bridge (Figure 64) (Vogel 2007b). This was an all-time record for the largest number of dead radio- or acoustic-telemetered juvenile

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salmon verified at one location. The cause of death of these fish, which were released far upstream and at different times and locations, was never established. Representatives of the Central Valley Regional Water Quality Control Board attributed the mortality to "a predation event" near the bridge. Although numerous bridges are positioned within many Delta channels where anadromous fish migrate, the magnitude of mortality at the Stockton site has never been observed elsewhere among more than a dozen fish telemetry studies. The finding amply demonstrated that fish mortality in the Delta can be high at very localized areas ("hot spots"[14]).

Figure 64. Location of 116 motionless juvenile salmon acoustic transmitters found in the lower San Joaquin River in 2007 (Vogel 2007).

A similar study conducted in 2009 found 173 acoustic transmitters from dead juvenile salmon believed to have been preyed upon (Figure 65). Often, the transmitters were located in sharp channel bends, deep scour holes, and near pump station structures (Figure 66) (Vogel 2010b).

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[14] One of the most significant early findings from the telemetry studies was the determination of locations of where high salmon mortality had occurred, a location the author had termed "hot spots" many years ago during science symposia on Delta research programs. The term has become popular in recent documents (e.g., BDCP). Prior studies over the past several decades, because of design and technology limitations, were unable to determine these problem areas in the Delta.

Figure 65. Left picture, locations of 173 acoustic tags detected in 2009 believed to be dead acoustic-tagged salmon or tags defecated by predatory fish (Vogel 2010b).

Figure 66. Right picture, locations of acoustic tags (showing designated transmitter codes) detected in the lower Joaquin River in 2009 believed to be dead acoustic-tagged salmon or tags defecated by predatory fish (Vogel 2010b).

As demonstrated by mobile telemetry studies (some discussed above), predation on juvenile anadromous fish is unlikely to be uniform throughout the Delta, and instead, is likely to be concentrated in limited areas where unique site-specific conditions favor predation. The following are just several examples where predation on salmon may be an ongoing concern and warrant close examination.

A large pipe partially buried in the riverbed perpendicularly across the river channel adjacent to the Freeport Waste Water Treatment Plant outfall in the Sacramento River (Figure 67) (Freeport Pipeline) appears to provide favorable conditions for predatory fish. This particular area is highly popular with sport fishermen who are frequently seen anchoring and fishing at the site. DIDSON^{TM} sonar camera footage and angling at the pipeline revealed that the fish species at the time of the survey were striped bass and white catfish: Predatory Fish Near Freeport Pipeline Depending on seasonal timing, downstream migrating juvenile anadromous fish near the riverbed at this location would be expected to be highly prone to predation.
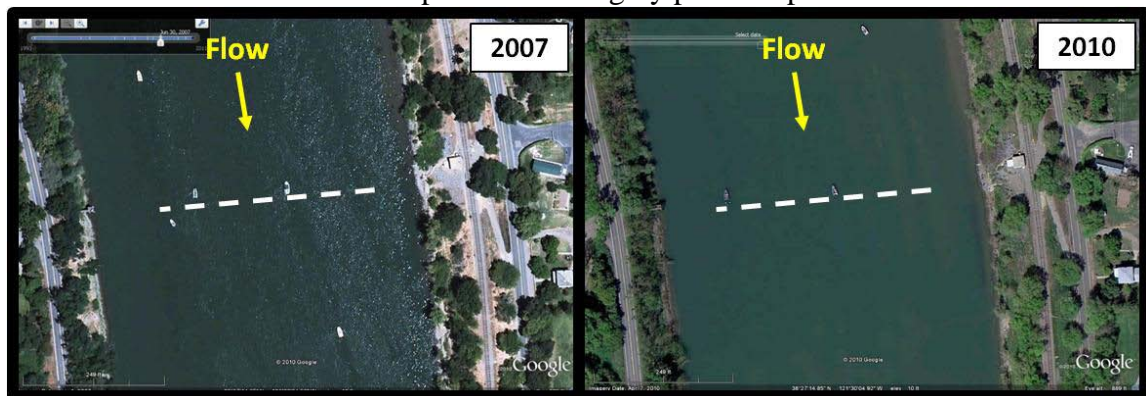
Figure 67. The lower Sacramento River showing the approximate location of a pipeline partially buried on top of the riverbed (dotted line). Sport anglers commonly anchor and fish at the site.

Although fish entrainment at in-Delta diversions may not be a significant problem for anadromous fish (previously discussed), the structures positioned year-round in flowing water in reaches where juvenile fish migrate could pose significant hazards during non-irrigation seasons. Predatory fish such as striped bass, largemouth bass, and white catfish are known to often be present near these water diversion facilities (*e.g.*, Striped Bass near Delta Ag. Diversion). Also, numerous agricultural drains (Figure 68) may similarly attract high concentrations of predatory fish particularly when water is discharged off of agricultural lands into the Delta (*e.g.*, Striped Bass near Delta Ag. Drain). Individually, the predation impacts in the vicinity of these in-channel structures could be low, but remain unquantified. Cumulatively, given the large number of artificial structures attracting predators within fish migration pathways, the adverse effects could be large.
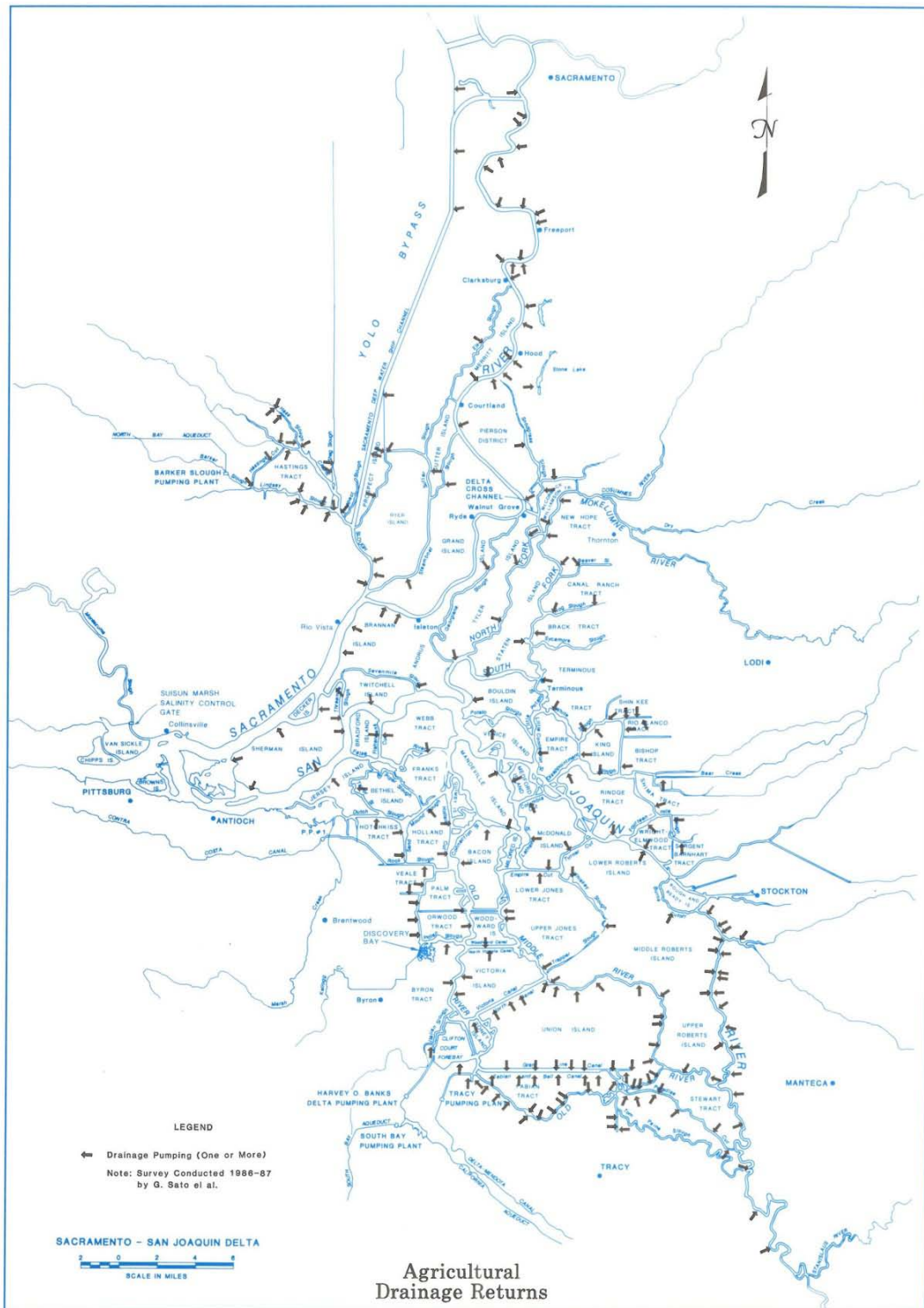
Figure 68. Location of irrigation drains in the Delta (from DWR's Delta Atlas) (not to be confused with Figure 43).

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Installation of new boat docks and marinas in the Delta has not been adequately studied to quantify potential increased predator concentrations (*e.g.*, largemouth bass). The overall impact of these facilities on juvenile anadromous fish migrating through the area is unknown. Surprisingly, the relevance of the issue has not been evaluated even though it is generally assumed that predatory fish can be concentrated in those areas. Construction of boat docks and marinas within flowing water where salmon must migrate creates ideal conditions for predation. Invariably, marina structures require vertical posts driven in the channel bed with supporting overhead structure (*e.g.*, docks, shade canopies, etc.). The potential problem may be particularly acute when the marina and dock structures are positioned over a considerable portion of the cross-sectional profile of the river channel where many salmon must transit. Large quantities of water move under these structures and juvenile anadromous fish moving with the flow under the structures are exposed to conditions considered as favorable predatory fish habitat. An added problem for the salmon in the Delta at these structures is created when tidal seiching may cause exposure to the predatory fish habitats not just once, but perhaps several times, as the fish move back and forth with the tides (*e.g.*, Figures 69 and 70). Similarly, numerous bridges across Delta waterways are known to attract predatory fish.

Figure 69. Lower Sacramento River at Walnut Grove showing locations of a new marina and boats docks.

Figure 70. Aerial photos of the lower Mokelumne River before and after new marina and dock installations.

In the north Delta, the lower Sacramento River near Sacramento also possesses numerous boating and waterway structures positioned within the cross-sectional area of the channel where

juvenile fish may migrate. Figure 71 shows some examples.
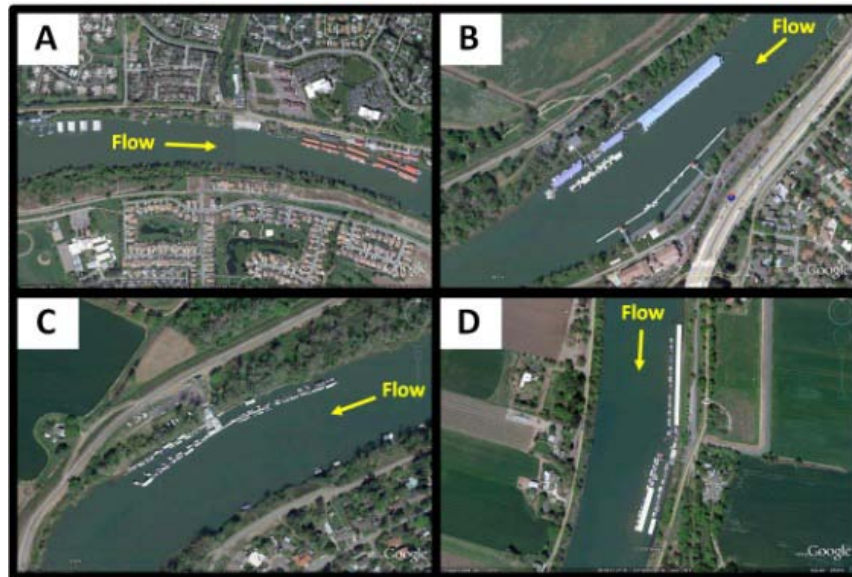
Figure 71. Boating and waterway facilities on the lower Sacramento River: (A) Just upstream of Sacramento; (B) just downstream of Sacramento; (C) downstream of Sacramento; and (D) near Freeport.

A variable which may affect predation on juvenile salmon in the lower river and Delta is water clarity. The feeding success of sight predators such as striped bass and largemouth bass (the latter being a Centrarchid fish species) is expected to be higher in clearer water conditions compared to turbid water. In recent decades, there has been an increase in water clarity in the Delta (DWR 1996, as cited by Grimaldo and Hymanson 1999).   Turner (1996), as cited by Shaffter (1998), reported the relatively small size of centrarchids in the Delta was likely due to the high turbidity in the region. During the 1980s, largemouth bass growth rates in the Delta were the slowest among low-elevation bass populations in California (Shaffter (1998). These conditions have now changed. Due to changes in land-use practices and water development, there was a rapid decline in sediment loads to the Delta during the first half of the 20th century followed by a gradual steady decline in the last half of the century (Shvidchenko *et al.* 2004). Data collected on suspended sediment in the lower Sacramento River near Sacramento and Freeport since 1960 has shown a downward trend (Oltmann 1996), with the exception of high flow years in 1996 – 1997 (Oltmann, *et al.* 1999). Suspended sediment and water clarity are strongly inversely correlated and the decline in suspended sediment entering the north Delta suggests that water clarity, over time, has increased.

Additionally, increased water clarity is also believed to be attributable to the introduction of the non-native Brazilian water weed (*Egeria densa*) in the Delta. Water clarity is higher in stands of *Egeria*, which is the dominant submerged vegetation in central Delta shallow waters, as compared to nearby shallow areas without vegetation (Grimaldo and Hymanson 1999). Nobriga *et al.* (2003) noted a positive correlation between higher densities of submerged aquatic

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vegetation at some sites in the Delta and water clarity. Increased water clarity for sight predators such as black bass and striped bass would presumably favor predatory fish over prey (*e.g.*, juvenile salmon). Fewer native fish species are found in *Egeria* stands compared to introduced fish species (Grimaldo and Hymanson 1999). Additionally, it has been hypothesized that high densities of *Egeria* in portions of the Delta may restrict juvenile salmon access to preferred habitats, forcing salmon to inhabit deep water or channel areas where predation risks may be higher (Grimaldo *et al.* 2000).

During recent years, there has been an emphasis to reclaim or create shallow, tidal wetlands to assist in re-recreating the form and function of ecosystem processes in the Delta with the intent of benefitting native fish species (Simenstad *et al.* 1999). Among a variety of measures to create such wetlands, Delta island levees either have been breached purposefully or have remained unrepaired so the islands became flooded. A recent example is the flooding of Prospect Island which was implemented under the auspices of creating shallow water habitat to benefit native fish species such as anadromous fish (Christophel *et al.* 1999). Initial fish sampling of the habitat created in Prospect Island suggested the expected benefits may not have been realized due to an apparent dominance of non-native fish (Christophel *et al.* 1999). Importantly, a marked reduction of sediment load to the Delta in the past century (Shvidchenko *et al.* 2004) has implications in the long-term viability of natural conversion of deep water habitats on flooded Delta islands into shallow, tidal wetlands. The very low rates of sediment accretion on flooded Delta islands indicate it would take many years to convert the present-day habitats to intertidal elevations which has potentially serious implications for fish restoration (Nobriga and Chotkowski (2000) due to likely favorable conditions for non-salmonid fish species that can prey on juvenile salmon. Studies of the shallow water habitats at flooded Delta islands showed that striped bass and largemouth bass represented 88 percent of the individuals among 20 fish species sampled (Nobriga *et al.* 2003).

There have likely been significant adverse, unintended consequences of breaching levees in the Delta. There is a high probability that site-specific conditions at the breaches have resulted in hazards for juvenile anadromous fish through the creation of favorable predator habitats. The breaches have changed the tidal prisms in the Delta and can change the degree in which juvenile fish are advected back and forth with the tides (Figure 61; previously discussed). Additionally, many of the breaches were narrow which have created deep scour holes favoring predatory fish. Sport anglers are often seen fishing at these sites during flood or ebb tides. Breaching the levees at Liberty Island is an example (Figure 72 and 73). Recent acoustic-tagging of striped bass in this vicinity confirmed a high presence of striped bass (Figure 74, D. Vogel, unpub. data).

Figure 72. Liberty Island in the north Delta before and after flooding.

Figure 73. Liberty Island in the north Delta before and after flooding showing locations of narrow breaches in the levee.

Figure 74. Locations (squares) where predatory striped bass were acoustic-tagged with transmitters during the winter of 2008 – 2009 in the north Delta near Liberty Island (D. Vogel, unpublished data).

Another example is Mildred Island, flooded many years ago (Figure 75). The levee breach at the north-east portion of the island has created a very deep scour hole known to harbor large numbers of fish. Another example is in False River where the author has frequently caught striped bass (Figure 76). Additionally, artificially created scour holes within Delta channels can create ideal habitats for predatory fish (*e.g.*, Scour Hole) Many other examples are present in the Delta.

Figure 75. Mildred Island (flooded) in the central Delta showing location of a deep scour hole. Adapted and modified from dsm2bathymetry.

Figure 76. Breaches in an old levee along False River.

Many of these levee breaches have been present for numerous years, but nevertheless still pose significant hazards for juvenile anadromous fish.

Fish produced in the upper watersheds have survived all the density-dependent and density-independent mortality factors at earlier stages in the life cycle (*i.e.*, egg incubation, fry and juvenile rearing, outmigration from the upper rivers and streams) and must ultimately migrate through the channels in the Delta. As compared to the earlier life phases, the fish reaching the Delta are the least numerous. The impacts of these sites in the Delta have never been evaluated

but, cumulatively, the predation mortality could, and likely does, have a major adverse impact on juvenile anadromous fish.

5.5.4 Conclusions on Fry and Juvenile Outmigration

- Factors such as unscreened diversions, predation, Delta water exports and others have been cited over decades as having been major problems for fish but each of those factors have evolved in various degrees, in some cases dramatically, up to the present day in terms of positive or negative importance to fish survival.

- Although riverine diversions were identified as a major problem for salmonids before and after large dam construction, the site-specific effects were more significant for fall-run Chinook than other anadromous salmonids. This is attributable to the fact that the timing and location of diversions in relation to the seasonal presence of juveniles on their rearing grounds and outmigration timing do not coincide well for most anadromous salmonids.

- The majority of water diverted from the Sacramento River and its tributaries have now been screened to prevent fish entrainment. The cost of recently completed screens and screens soon-to-be completed is nearly $574,000,000. The maximum flow screened by these diversions is nearly 13,000 cfs. A program is currently underway to determine the highest priority remaining sites where entrainment could be a problem.

- The construction and historical operations of RBDD strongly correlates to the timing of fish population declines. Historically, prior to the present practice of raising the RBDD gates during the non-irrigation season, the location, timing, and magnitude of impacts of RBDD on anadromous fish coincided with the presence of the majority of anadromous fish.

- The high entrainment of juvenile fish into the Tehama-Colusa Canal and Corning Canals was resolved with the installation of the angled, rotary drum screens in 1990.

- Year-round removal of the RBDD gates in 2012 is anticipated to solve the remaining fish passage problems.

- The declines in spring-run Chinook in tributaries downstream of RBDD suggest that there are factors other than RBDD also causing major impacts on some fish populations.

- Increased flows could benefit outmigrant anadromous fish, depending on timing, magnitude, and duration, but those specific thresholds necessary to provide increased survival for anadromous fish have yet to be determined.

- There is the high risk that improper increased flows such as recommended by SWRCB (2010) and DFG (2010) under the auspices of improving fish outmigration in the Delta

could severely adversely impact cold-water storage in upstream reservoirs critically necessary for reproduction of some anadromous fish.

- The causal effects of flow/survival relationships have been difficult to determine because of complex inter-relationships with numerous variables associated with flow. Little progress has been made on parsing out the various and most important factors related to flow that may influence fish survival.

- Past and present studies solely oriented toward estimating "global" fish mortality in the Delta under limited environmental test conditions are not leading to solutions. Furthermore, conditions in the Delta are changing so rapidly, that the traditional native anadromous fish studies that have been, and continue to be conducted are unlikely to yield information relevant years later.

- The timing and magnitude of CVP/SWP exports during recent years corresponds to the seasonal presence of the majority of juvenile anadromous fish in the Delta. Additionally, the annual increase in south Delta exports since the mid-1960s corresponds with the significant decline of some anadromous fish populations.

- The CVP/SWP impacts on fish may be very high, particularly when compared to other factors described in this report. However, the mechanisms of how south Delta exports affect fish migrating through the north Delta remain perplexing. The adverse impacts may be attributable to inferior rearing habitats in the Delta and the potentially severe indirect effects resulting from predation.

- With some exceptions in upstream areas, the greatest opportunities for increasing populations of anadromous fish remain in the Delta.

- Overall, predation is likely the highest source of mortality to anadromous fish in the Delta. Despite well-known problems of predation in the Delta at a variety of locations for many years, very little progress (in many instances, no progress) has been made on ameliorating those problems. Ironically, some measures implemented in the Delta under the auspices of improving fish habitats have likely increased predation of anadromous fish. The best available evidence indicates that the predation problems have gotten worse, not better, during recent decades.

- Despite the enormous, unprecedented actions to improve fish production in the upper watersheds, there has been remarkable lack of focus or progress to increase shallow-water rearing habitats and fix the serious predation mortality in the Delta, through which all fish must migrate. Until significant progress is made on correcting these in-Delta problems, it is likely that many of the benefits of upstream actions will continue to be negated in the Delta.

5.6 Ocean Rearing

5.6.1 Food Supply

Conditions in the ocean can affect the abundance of salmon due to effects on the food base during the ocean-rearing life phase. Between years, ocean conditions related to El Niños affect salmon in the California ocean current and changing ocean conditions appear to exert a strong effect on salmon populations. This circumstance is usually the primary source of unexplained variability in research on salmon in freshwater (Botsford 2002). Longer-term cyclical inter-annual warming and cooling trends in ocean conditions (Pacific Decadal Oscillation[15]) has occurred during the past century (Figure 77). Warmer or cooler ocean conditions off the northern California coast can be detrimental or beneficial, respectively, to the abundance of salmon food organisms.
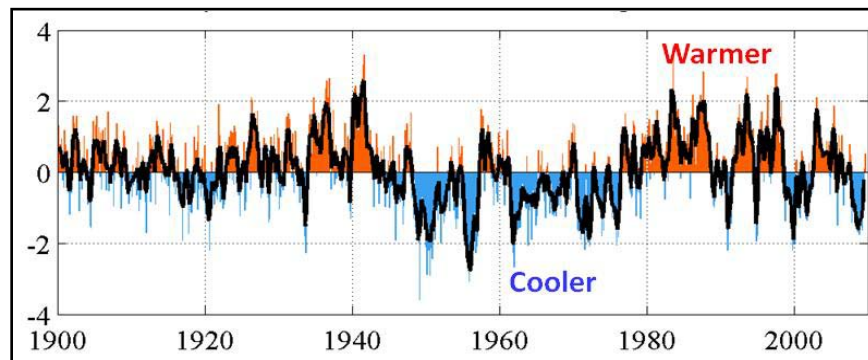
Figure 77. Monthly values for the Pacific Decadal Oscillation index: 1900 – September 2009 (from jisao.washington.edu)

One of the most robust and recent analyses of the potential profound effects of ocean food supply for salmon were conducted by Lindley *et al.* (2009). These authors provide a detailed account of the causal reasons for the poor production resulting from the 2004 and 2005 brood years of Sacramento River fall-run Chinook. They believed that anomalous ocean conditions in 2005 and 2006 were the primary factors contributing to the poor survival. Specifically, as young fish from those brood years entered the ocean, conditions exhibited weak upwelling, warm sea temperatures, and low densities of prey (Lindley *et al.* 2009).

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[15] *"The 'Pacific Decadal Oscillation' (PDO) is a long-lived El Niño-like pattern of Pacific climate variability. "The PDO Index is defined as the leading principal component of North Pacific monthly sea surface temperature variability." "Major changes in northeast Pacific marine ecosystems have been correlated with phase changes in the PDO; warm eras have seen enhanced coastal ocean biological productivity in Alaska and inhibited productivity off the west coast of the contiguous United States"* (source: jisao.washington.edu)

5.6.2 Predation

Predation on adult anadromous fish during the ocean rearing phase is a stressor that was previously not believed to be a significant factor affecting the species. However, more recent research on the topic indicates that predation on salmon can be significant, particularly by sea lions. Empirical evidence of the impacts has been difficult to obtain due to the difficulty in obtaining direct observations (Scordino 2010), although ocean sport anglers commonly complain about reeling in heads of salmon which had been eaten by sea lions after the fish are hooked. However, those instances may be attributable to hooked fish being more vulnerable to predation by sea lions. In 1999, Congress appropriated approximately $750,000 annually from 1998 to 2005 to study the impacts of California sea lions and Pacific harbor seals on salmonids and West Coast ecosystems. During that time, over 150 studies were performed to determine the impact of pinniped predation on salmonids in west coast rivers, estuaries and open water regions. After compiling the results, Scordino (2010) determined that pinnipeds (*e.g.*, Pacific harbor seals and California sea lions) can adversely affect the recovery of ESA-listed salmonid populations. Furthermore, "*In most areas, it appears that as adult salmon migrate into an area, some of the pinnipeds in that area will alter their foraging behavior to target salmonids.*" Some areas near northern California salmon ocean rearing grounds are known to harbor large concentrations of sea lions (*e.g.*, Figure 78). The population of California sea lions has increased dramatically since the 1970s (Scordino 2010). As recently as the fall of 2009, more than 1,500 sea lions were observed concentrated in San Francisco Bay[16] near where anadromous fish migrate and high numbers are commonly seen at Pier 39 in San Francisco Bay which is a popular tourist attraction (Figure 78). The problem of high predation on salmon by sea lions is obvious.

Figure 78. Left picture: California sea lions off the coast of northern California. Photo provided by Charles Ciancio. Right picture: sea lions on docks at Pier 39 in San Francisco Bay. Photo by David Ball.

5.6.3 Harvest

As discussed earlier, the impacts of overharvest on northern California salmon stocks have been recognized for many decades, even pre-dating large dam construction. As described by DFG (1998), freshwater sport, ocean sport and commercial fishing for salmon are highly regulated to

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[16] Source: wordpress.com

protect fish for eventual return to the spawning grounds. The intent of fishery managers is to allow harvest of surplus fish while ensuring sufficient numbers escape in order to reproduce and continue a healthy propagation of the species. Ocean sport fishing and commercial regulations impose a variety of restrictions to limit overharvest, including in some instances, total prohibition on harvest. Fishing is closed in all marine protected areas. With limited entry restrictions, the number of commercial vessels declined from nearly 6,000 in 1982 to approximately 1,800 in 1999 (Boydstun (2001). Because of extremely depressed salmon runs, all ocean fishing was closed during several recent years. Prior to that time, the commercial fishery harvested about two-thirds of Chinook salmon off the coast of California. Commercial catches averaged 407,700 salmon during 1995 – 1999 compared to a sport harvest of 200,000 fish (Boydstun 2001). In 2010, with projections of improved salmon runs, ocean salmon sport fishing was open April 3rd to April 30th seven days per week. From May 1st through September 6th fishing was open Thursday through Monday only. The limit was two salmon per day (CFGC 2010c). The laws for commercial salmon fishing are not described here but, similar to freshwater regulations, they are also intended to allow harvest of surplus fish while ensuring sufficient numbers of returning spawners. However, because of the difficulty in calculating the numbers of fish in the ocean, over estimates can lead to overharvest, which has happened in the recent past (Lindley *et al.* 2009). Also, ocean harvest cannot discriminate between depressed and surplus stocks nor between endangered and non-endangered salmon runs. For example, DFG believes that the ocean fisheries may have had a significant impact on spring-run Chinook (DFG 1998). Research is underway to benefit future fish populations by developing new techniques to discern the differences between stocks.

Barbed hooks were used in the commercial troll fishery up until the 1980s. During that time, high numbers of "hook-scarred" salmon (*e.g.*, Figure 79) were noted passing through the fish ladders at RBDD. Hooked-scarred salmon are those which have received visible physical damage from being hooked by anglers and volitionally or non-volitionally released. Notably, USFWS SCUBA divers working inside the concrete pools of the RBDD ladders during the 1980s found large numbers of stainless-steel barbed hooks in the base of the ladders (D. Vogel, pers. observation). These hooks undoubtedly originated from salmon hooked in the ocean that escaped to return to the upper Sacramento River. The flow inside the fish ladders was the first high velocity water encountered by the returning salmon which broke the hooks loose from their mouths. By law, commercial fishermen must release sub-legal sized salmon even if the fish are wounded. It was believed that significant numbers of salmon were historically mortally wounded due to the difficulty in disengaging barbed hooks from the fish's mouth. These fish were termed "shakers" and the consequence of fish dying from physical damage from release was termed "shaker mortality". The level of shaker mortality prior to the ban in the 1980s on barbed hooks is unknown, but the ban undoubtedly reduced that mortality. However, in the present day, there remains a concern that the stress imposed by releasing sub-legal fish in the ocean fishery, even with barbless hooks, can cause a significant degree of mortality. Recently DFG estimated that hooking mortality of released salmon is about 30 percent in the commercial fishery and less than 24 percent in the sport fishery (Boydstun 2001).

Figure 79. Adult spring-run Chinook at the bottom of a deep pool in upper Mill Creek. Note the large hook scar under the eye. Picture taken prior to the ban on the use of barbed hooks in the ocean fishery. Underwater photo by Dave Vogel.

Besides the obvious direct effects of harvesting salmon and the resultant reduction of adult fish "escaping" back to freshwater spawning grounds, ocean harvest can also affect the age structure and fecundity of salmon stocks. This important adverse impact is commonly overlooked in fishery management and restoration plans. It has been documented that the age structure and population fecundity of west coast salmon stocks have declined from historical levels. This is believed to be primarily attributable to ocean fishing cropping off the older age groups because of their extended exposure to the fishery as compared to younger age groups. Scientific literature dealing with Chinook salmon produced in the Sacramento River basin shows that the average age of all mature stocks has decreased by 0.2 to 1 year from approximately the mid-1940s to the early 1970s. Fish maturing at age 5+ years historically were not uncommon (Ricker 1972). A 1948 U.S. Department of the Interior (USDOI) document states:

> "*Approximately 50 percent of the Sacramento-San Joaquin salmon return from the sea as adult salmon to spawn during their fourth year. The remainder return, in decreasing order of abundance, as five-year fish, three-year fish, and two-year fish.*" (USDOI 1948)

Even earlier, Clark (1929) reported that six-year-old fish were more abundant than two-year old salmon. This historical age structure represents a markedly different pattern from present-day Central Valley salmon stocks. DFG reported that, based on recoveries of coded-wire tagged salmon in the ocean fisheries during the late 1970s to early 1990s, the majority of fish caught were three-year-old fish, followed by two-year-old fish. The composition of four- and five-year-old fish in the sport and commercial catch was less than 10% (DFG 1998).

Ricker (1972) proposes two possible causes for explaining the decline in age of mature Chinook salmon:

> 1) *Trollers catch some Chinook salmon that would not have matured in the year that they were caught, as opposed to gill nets and seines that are used to capture salmon almost*

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exclusively during periods of spawning and capture almost exclusively mature fish. Fish maturing at age 3+ years are exposed to an additional year of harvest as opposed to those that mature at age 2+ years; subsequently, older fish become more scarce.

2) *The selection for larger (older) fish by fishing trollers may be changing the genetic structure of the salmon stocks to favor those that mature at a younger age.*

The net result of the ocean fisheries' impact on the age structure of Chinook salmon populations is a decrease in the number of larger, older fish. The ocean fishery crops off the older age groups because Chinook salmon that would mature at a later age (*i.e.*, stay out in the ocean for a longer period) experience extended (greater) exposure to the fishery as compared to younger age groups which mature earlier (*i.e.*, the younger fish spend less time in the ocean). The older fish are typically females, while the younger, smaller fish are disproportionately males. As a result of smaller, less-fecund fish returning to the rivers at a younger age, less freshwater salmonid production would be expected. Under such circumstances, the egg producers of the population become fewer and smaller, essentially causing a decrease in the fecundity of the stock (Ricker 1972). In his scientific report entitled "Fecundity and Mortality in Pacific Salmon", Neave (1948) points out the importance of this component to the overall health of salmon populations:

> "*Although the level of abundance of the whole population may change from time to time, any continued underproduction or overproduction of eggs by the average individual would quickly change the status of the species.*"

In addition, loss of the older age groups dramatically reduces the resilience of salmon populations to "bounce back" after natural disasters (*e.g.*, floods and droughts). The loss of historical, multiple-age-group composition causes salmon runs to be particularly vulnerable to consecutive years of adverse conditions. For this reason, a uniform age structure of Central Valley salmon stocks (*e.g.*, mostly 3-year-old fish) is not desirable. If dominated by one age group, a natural or man-made disaster impacting one year's spawning escapement can be evident for many future years. Using a simple example for illustration, if a salmon population is composed of mainly three-year-old fish and the reproductive success is extremely poor in one particular year, a low spawning escapement three years later could be expected. This phenomenon is a potential factor which could have significantly contributed to the decline in the winter-run Chinook salmon. These predominately three-year-old fish were severely impacted by lethally warm water temperatures in the 1976 and 1977 droughts. Consequently, the returns were very low every three years following both 1976 and 1977. Had there been a more substantial age-group overlap for this species (*e.g.*, more four-and five-year olds), the runs would have had more resilience to recover in years following the drought.

A reduction in the size and age of salmon spawners also can significantly alter their reproductive success. Healey and Heard (1984), as cited by Myers *et al.* (1998), reported that large body size in female Chinook salmon may be advantageous because of the success of larger fish in establishing, digging, and protecting their redds. In their studies on coho salmon, *Oncorhynchus kisutch*, van den Berghe and Gross (1984) stated:

> "*Nest depth was strongly correlated with female size in coho salmon (Oncorhynchus kisutch). Since nests of different-sized females are at different depths, they are differentially vulnerable to destruction by floods and to other females competing for the same nest sites.*" "*Managers of salmon populations should recognize that there is a selective advantage to larger bodied females resulting from their ability to dig nests deeper.*"

Central Valley rivers and streams are highly prone to substantial bed load movement during high flow events which scour the upper portion of salmon spawning grounds. Salmon eggs deposited deeper in the river gravels (by older, larger female salmon, such as a five-year old fish) would be expected to experience lower losses during flood events as compared to eggs deposited in shallower depths (by younger, smaller female salmon, such as a three-year old fish). Eggs deposited deeper in the river gravels during spawning activities would also be less susceptible to losses from subsequent salmon spawning activity in the same area (*i.e.*, spawning superimposition) as compared to eggs deposited in shallow gravel depths. However, large-sized salmon in the Sacramento River are now rare (Figure 80).

Figure 80. Chinook salmon carcass found in Battle Creek estimated to have weighed 88 pounds. Photo by DFG. Larger, older salmon within spawning runs can be expected to have higher reproductive success through the ability to move coarser riverbed substrate (cobbles) during redd construction; highly-fecund females laying eggs deeper in the gravels would also reduce impacts of riverbed scour during high flow events.

The problems with ocean harvest influencing fish reproduction at an earlier age and smaller size, spawning activity earlier in the season (Hard *et al*. 2008, as cited by Lindley *et al*. 2009), and a truncated age structure affecting variation in population abundance (Huusko and Hyv¨arinen 2005, Anderson *et al*. 2008, as cited by Lindley *et al*. 2009) have been recognized by others [reviewed by Hard *et al.* (2008)]. Without restoration of multiple age-group structures, and other remedial actions (*e.g.*, a more-terminal ocean harvest nearer to San Francisco Bay to selectively harvest the fish returning to spawn), boom-and-bust cycles will likely persist (even with significant habitat restoration efforts) and continue to plague salmon recoveries. Surprisingly, given the known adverse impacts of this major problem, corrective actions have not been pursued.

5.6.4 Conclusions on Ocean Rearing

- Recent management of the ocean fishery has demonstrated that regulatory measures, sometimes severe, can benefit resultant fish runs, but this has not always been the case in the past when overharvest occurred. Although measurable anthropogenic changes to ocean habitats to benefit the species are not feasible, fishery management measures such as harvest regulations or prohibitions can benefit the populations when fish runs are known to be depressed and surplus fish are unavailable.

- Ocean harvest and its effects on the reproductive success of the populations are indicators of a significant effect on recent salmon population declines. Smaller, less fecund fish returning to the rivers would be expected to result in less freshwater salmonid production. Also, the loss of historical, multiple-age-group composition in salmon populations allows the runs to be particularly vulnerable to consecutive years of adverse conditions. The reduction in average age of Sacramento River populations caused by ocean fishing has "carried through" to the present and has to be considered a significant factor contributing to recent population declines. This stressor to salmon stocks has gotten worse, not better, over time.

- Unless the historical age structure of Sacramento River basin salmon stocks is restored, the runs will always be subject to wide fluctuations caused by natural or anthropogenic conditions and continue to plague salmon restoration efforts.

- Predation by marine mammals such as sea lions is likely problematic for some salmon populations, but unless significant changes to the Marine Mammal Protection Act are made to control mammal populations in key areas where salmon may be concentrated (which is not likely), depressed anadromous salmonid populations will be continually subject to this stressor and reduce the resilience of fish populations.

- Unless major improvements in earlier freshwater fish survival are achieved (primarily in the Delta) to ensure fish populations remain sufficiently abundant in the ocean while concurrently providing for human harvest and forage by marine mammals, future low runs of fish can be expected.

6.0 Recommendations

6.1 Adult Fish Upstream Migration

- Research on the potentially serious problem with fish passage barriers in the Delta should be conducted or continued and, where warranted, remedial actions should be implemented as soon as possible to assist in restoring depressed fish populations. In each instance, engineering solutions or operational measures to correct the problem are likely

to be feasible. For example, short-duration pulses of relatively low-volume, but high-velocity flows can attract fish into bypasses. Elimination of these migration barriers through the installation of fish passage facilities or operational measures presents a significant restoration opportunity. (Fremont Weir: High Priority Action; Other Barriers: Medium Priority Study)

- There still remain additional opportunities to improve conditions for upstream migrating fish in some tributaries, particularly for spring-run Chinook. For example, sufficient spring flows in Mill and Deer creeks could be improved (particularly during drought years) to ensure unimpeded access and the migration of late-arriving fish to upstream holding and spawning areas. (High Priority Action)

- Some new fishways to provide access for spring-run Chinook to upper reaches of Big Chico Creek have yet to be constructed and should be implemented as soon as feasible. (High Priority Action)

- All existing fishways on important anadromous fish tributaries should be continually maintained and periodically examined to ensure conditions are optimal for fish passage. (High Priority Action)

- Government agencies should continue to work cooperatively with watershed groups in Butte, Mill, Deer, and Big Chico creeks (and other watershed organizations) to protect adult spring-run migrating up through lower reaches of those streams where the fish are highly vulnerable to illegal harvest. (Medium Priority Action)

- Because Butte, Mill, and Deer creeks likely possess the only true remaining wild spring-run in the entire Central Valley, both State and federal law enforcement presence in the watersheds should be maintained or increased as a deterrent for illegal harvest. Low-cost, digital infrared motion-detecting cameras could be installed at locations where adult fish are highly vulnerable to illegal harvest or human disturbance. (High Priority Action)

- There remain some flow and temperature problems in some small tributaries, particularly for spring-run Chinook, that should be closely examined to determine appropriate remedial measures to ensure the runs are protected. (High Priority Study)

6.2 Adult Fish Holding Habitat

- The relatively few and small holding areas where over-summering adult spring-run Chinook are exposed and highly vulnerable to human recreational activities in the summer months should be better protected. (High Priority Action)

- Greater scrutiny of snorkeling surveys in spring-run Chinook holding areas or development of alternative survey techniques should occur through the ESA 4(d) or

Section 10 research provisions to minimize and perhaps eliminate that risk to the populations. (Medium Priority Action)

- Because spring-run Chinook prefer shade and cover during over-summering in small tributary pools, greater protection of riparian corridors in holding areas should be provided. In some areas, such as in Butte Creek, adult spring run are highly exposed and could benefit from structural measures to provide shade and cover. (High Priority Action)

- Formal seasonal refuges at critical areas, akin to that historically provided for bald eagle nesting areas, should be provided to protect adult spring run and minimize human disturbance. (High Priority Action)

- Government agencies should continue to work cooperatively with watershed groups in Butte, Mill, Deer, and Big Chico creeks and other streams (*e.g.*, Battle Creek, Clear Creek) to protect adult spring-run and other species holding in the upper reaches of those streams where the fish are highly vulnerable to illegal harvest and human disturbance. (Medium Priority Action)

- Because Butte, Mill, and Deer creeks likely possess the only true remaining wild spring-run in the entire Central Valley, both State and federal law enforcement presence in the watersheds should be maintained or increased as a deterrent for illegal harvest. Low-cost, digital infrared motion-detecting cameras could be installed at holding locations where adult fish are highly vulnerable to illegal harvest or human disturbance. (High Priority Action)

6.3 Spawning and Incubation

- Because of the biological importance and high probability of success, spawning gravel introductions should continue and be significantly expanded downstream of all major dams. (High Priority Action)

- Gravel extraction on some tributaries should be closely examined to ensure adverse impacts to anadromous fish are not occurring. (Medium Priority Study)

- Detailed data on spawning habitat quantity and quality in many tributaries are limited, but because of their importance, those habitats should be examined to determine potential restoration measures; such studies are easy to conduct and relatively low in cost. Gravel replenishment projects in important spawning areas lacking sufficient natural gravel recruitment would undoubtedly benefit anadromous fish. (Medium Priority Study)

- Proposed plans to extract spring-run Chinook fertilized eggs from Mill or Deer Creek should be held in abeyance until the populations recover from currently depressed levels.

Butte Creek would be a more-appropriate egg source for a donor stock to be used elsewhere. (High Priority Action)

- Detailed modeling studies should be conducted of the effects of the high flow regimes contemplated by SWRCB (2010) to determine impacts to water supplies and the thermal regime as those factors affect anadromous fish spawning and incubation. (High Priority Study)

6.4 Fry and Juvenile Rearing

- Instream studies should be conducted to determine the quantity and quality of favorable rearing habitats. (High Priority Study)

- Projects to replenish coarse substrates (*i.e.*, gravels, boulders) and woody debris in the upper portion of the mainstem river in key locations should be implemented because of the high probability of improving and expanding mainstem rearing habitats. (High Priority Action)

- Pilot projects to create new rearing habitats should be conducted, and if found feasible, be expanded in reaches immediately downstream of dams. (High Priority Study)

- Modeling studies should be conducted of the impact of the high flow regimes contemplated by SWRCB (2010) to determine impacts to water supplies, the thermal regime, and the physical attributes of rearing habitats as those factors affect anadromous fish fry and juvenile rearing. (High Priority Study)

- Attempts to create anadromous fish rearing habitats in the lower Sacramento River through placement of woody debris structures and other measures should be closely scrutinized to determine if those efforts are inadvertently creating favorable predatory fish habitats at the expense of anadromous fish. (Medium Priority Study)

6.5 Fry and Juvenile Outmigration

- Instream studies of potential predation problems immediately downstream of Daguerre Point Dam on the Yuba River and ACID dam on the Sacramento River should be conducted; if necessary, remedial actions should be developed and implemented. The issue may be particularly important at the ACID dam because of the high concentration of winter-run fry in the vicinity during the period the diversion is in operation. (High Priority Study)

- A variety of solutions to the periodic reverse flow condition at Verona Dam have been contemplated and measures to correct this potentially serious problem should be implemented. (High Priority Action)

- New study approaches in the Delta should be designed and implemented to determine exactly where mortality is occurring in the Delta and how to ultimately fix the problems. (High Priority Study)

- Potential solutions to avoid predation at breached levees should be developed and implemented. For example, "feathering" back these levees over a much wider area instead of keeping the narrow channels would reduce high water velocities, reduce scour hole formation, and reduce predation opportunities as tides flood and ebb. (High Priority Study)

- Significant efforts should be implemented to re-create shallow-water rearing habitats for anadromous fish in the Delta. However, those restoration sites should designed to minimize predation. (High Priority Action)

- Studies should be conducted of the channel geometry at key locations in the Delta where predatory fish are concentrated and remedial actions, where warranted, should be developed and implemented to reduce predation losses of anadromous fish. (High Priority Study)

- An aggressive predator removal program at Clifton Court Forebay and Tracy Fish Facilities should be designed and implemented. The removal should be either lethal or relocation to waters not connected to the Delta. (High Priority Action)

- The technology is available to determine the presence of predatory fish and survival of juvenile anadromous fish moving with the flow under in-Delta structures (*e.g.*, telemetry, sonar camera). Depending on site-specific findings, measures to reduce predatory fish habitats or localized predatory fish control measures could be implemented. (High Priority Study)

- Plans for future structures, including habitat restoration projects, contemplated in the Delta should recognize and avoid the potential hazards for anadromous fish. (High Priority Action)

- Detailed modeling studies should be conducted of the impact of the high flow regimes contemplated by SWRCB (2010) for fish outmigration to determine impacts to water supplies and the thermal regime. (High Priority Study)

6.6 Harvest

- Early evaluation of oceanographic conditions that may be favorable or unfavorable for anadromous fish should be conducted so resource managers would have greater ability to adjust harvest regulations accordingly and prevent overharvest of depressed salmon

populations. (High Priority Action)

- An evaluation of alternative ways to harvest salmon to reduce adverse impacts on the species' fecundity should be conducted. Biologically important fishery management measures to increase the diversity of salmon age structure should be developed (absent total fishery closures). Doing would increase fish fecundity, increase natural production, improve freshwater survival, provide greater buffers against natural or anthropogenic disasters, and protect depressed fish stocks. (High Priority Study)

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Exhibit A

Sacramento River, San Joaquin River, and Delta technical reports
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(Sequential Listing)

Vogel, D.A. 2011. Evaluation of fish entrainment in seven unscreened Sacramento River diversions, 2010. Report prepared for the Anadromous Fish Screen Program, CALFED Ecosystem Restoration Program, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, NOAA Fisheries, and the California Department of Fish and Game. Natural Resource Scientists, Inc. February 2011. 77 p. plus appendices.

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