Annotated Bibliography on Aquatic Fish Resources in the Sacramento San-Joaquin Bay-Delta in reference to Export Limit objectives, Delta outflow objectives, and River Flow Objectives at Rio Vista

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Introduction

This annotated bibliography summarizes a broad range of literature relevant to aquatic resources in the Sacramento-San Joaquin Bay-Delta with emphasis on environmental factors controlling species abundance and distribution. Sources include scientific journals and reports, agency reports and agency plans. Summaries include either the original abstracts or relevant sections for each source. References were included in 5 objectives of the 1995 Bay Delta Plan: 1) Export limit objectives, 2) delta outflow objectives, 3) Rio Vista flow objectives, 4) Vernalis flow objectives and 5) Vernalis day pulse flow objective. Any given reference may be included in one or several objectives, depending on its content. An asterisk in front of the first author's name denotes that such reference was not available as a PDF file. The term "et al." follows the first author's name in studies involving more than two authors.

1. Export Limit Objectives

Arthur, J.F. et al. 1996. Summary of federal and state water project environmental impacts in the San Francisco Bay-Delta estuary, California. In: pages 445-495. J.T. Hollibaugh (ed.) The San Francisco Bay: The ecosystem. Further investigations into the natural history of San Francisco Bay and Delta with reference to the influence of man. Friesen Printers, Altona, Manitoba.

This review summarizes the early and post Federal and State water project development and the major changes in physical, chemical, and biological constituents that have occurred as a result of direct water transfer throughout the Delta (fresh-brackish water portion of the San Francisco Bay Delta estuary. Transfer of increasing amounts of Sacramento River water across the Delta channels to the Federal and State water project export pumps in the South Delta over the last 45 years has resulted in several major environmental impacts. The increase in fresh water in many delta channels during the summer and fall comes from water released from reservoirs to reduce salinity intrusion into the Delta and protect water quality. Most of the negative project-related impacts result from transferring large quantities of water across the Delta in existing channels. The ever increasing demand for project export water has resulted in net flow reversals during most months of the year in the Central and Southern Delta. Flow reversals has resulted in: the recycling of large quantities of salt from the San Joaquin Valley back into the Valley, scouring of Delta channels; increase in trihalomethane (THM) precursors from Delta sources in export water designated for municipal use; flushing of Delta aquatic habitat resulting from decreased residence times, and entrainment of plankton and various life stages of fish in the project intakes.

*** Bennett, W. A. and P.B. Moyle. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin Estuary. In pages 519-542. J.T. Hollibaugh (ed.) The San Francisco Bay: The ecosystem. Further investigations into the natural history of San Francisco Bay and Delta with reference to the influence of man. Friesen Printers, Altona, Manitoba.**

Fish populations have declined markedly in the Sacramento-San Joaquin estuary. Evidence of factors contributing to the declining abundance of fishes is reviewed in the context of six pathways by which alteration of freshwater outflow to the estuary affects the survival of larval and juvenile fishes. Specific pathways include: 1) transport and entrainment, 2) retention in and/or advection from preferred habitats, 3) success and effects of invading species, 4) primary production and food web dynamics, 5) dilution and/or flushing of toxic compounds, and 6) the quantity and quality of shallow-water spawning/rearing habitat. Clearly, ameliorating the effects of various factors (e.g., reducing entrainment, toxic runoff, and improving shallow water habitat) will improve conditions for fish. The current lack of life history information and on several of the most affected species and the need to prevent extinctions suggests that the most pragmatic and promising solution is to ensure adequate outflow to the estuary. The simultaneous declines of so many species with different habitat requirements and life history strategies is an indication of broad problems with the estuarine environment, especially in the Delta.

Brandes, P.L, and J.S. McLain. 2001. Juvenile Chinook salmon abundance, distribution, and survival in the Sacramento-San Joaquin Estuary. In R.L. Brown (ed.) Contributions to the Biology of Central Valley Salmonids. California Department of Fish and Game. Fish Bulletin 179(2):39-136.

All four races of juvenile Central Valley Chinook salmon migrate through and many rear in the Sacramento-San Joaquin Delta and Estuary. Delta residence and migration is considered important in determining adult production, as it is generally believed that density dependent effects are minimal after this life stage. Populations of winter run and spring run are presently listed as endangered and threatened species, while the remaining populations in the Central Valley are candidate species. Actions in the Delta to improve survival are likely important in the recovery of these depressed populations. The tidally influenced freshwater Delta also is an important area for water management in California, as it is where the Central Valley and State Water Project pump large volumes of water to southern California, the San Joaquin Valley and the Bay area. To document the effect of these various water management activities in the Delta on juvenile salmon, monitoring and special studies have been conducted since the early 1970s to the present. Changes in abundance in the Delta and estuary appear related to flow; high flows increase the use of the Delta and San Francisco Bay by fry. Relative survival of fry appears greater in the upper Sacramento River than in the Delta or bay, especially in the wetter years. Survival appears lower in the Central Delta relative to that in the North Delta in drier years for both fry and smolts. Fall-run smolt and late-fall-run yearling survival studies have found that diversion into the Central Delta via the Delta Cross Channel or Georgiana Slough reduces survival through the Delta. Experiments in the San Joaquin Delta have shown that survival appears greater for smolts that migrate down the mainstem San Joaquin River rather than through upper Old River. A temporary barrier in upper Old River was tested and found to improve survival for smolts originating in the San Joaquin basin. These specific experiments have identified management actions that could improve juvenile salmon survival through the Delta. In addition, indices of annual survival provide a way to compare survival through the Delta and could be used to assess restoration and management actions. This work demonstrates How long-term scientific studies can be applied to address management and restoration issues.

Brown, R., S.A. et al. 1996. An evaluation of the effectiveness of fish salvage operations at the intake to the California Aquaduct, 1979-1993. In pages 497-518. J.T. Hollibaugh (ed.) The San Francisco Bay: The ecosystem. Further investigations into the natural history of San Francisco Bay and Delta with reference to the influence of man. Friesen Printers, Altona, Manitoba.

The results of 14 years of operation of the Skinner Fish Protective Facility at the intake to the California Aquaduct are described. The Department of Water Resources constructed a behavioral barrier (louver) system in the late 1960's for a maximum flow of about 180 m^3. The facilities have been modified and the capacity has been increased to about 290 m^3/s. At least 47 species of fish have been entrained in the diversion. Chinook salmon screening efficiency ranges from 70 to 80 percent for juvenile salmon about 100 mm in length. Significant prescreen losses appear to be caused by subadult striped bass predation in a forebay in front of the fish facility. Small additional losses occur due to handling in the salvage process and when trucking the salvaged fish to Delta release sites about 40 km from the intake. Possible actions to reduce impacts on salmon maintaining existing intakes include: 1) Close the Delta Cross Channel from February 1 through May 20 each year, 2) Install an acoustical barrier at the Head of Georgiana Slough during the outmigration, 3) install a physical barrier at the head of Old River in the Spring to help keep San Joaquin Basin smolts from leaving the river and winding up at the State Water Project and Central Valley Project pumps, 4) pump in accordance with the export/inflow ratios in the Delta agreement and the 1995 Water Quality Control Plan for the estuary, and 5) Continue to truck much of hatchery production to San Pablo Bay. An alternative approach requiring to move the California Aqueduct intake from the Southern Delta to the Sacramento River near Hood has also been considered.

Brown, L.R. 2000. Fish communities and their associations with environmental variables, lower San Joaquin River drainage, California. Environmental Biology of Fishes 57: 251-269.

Twenty sites in the lower San Joaquin River drainage, California, were sampled from 1993 to 1995 to characterize fish communities and their associations with measures of water quality and habitat quality. The feasibility of developing an Index of Biotic Integrity was assessed by evaluating four fish community metrics, including percentages of native fish, omnivorous fish, fish intolerant of environmental degradation, and fish with external anomalies. Of the thirty-one taxa of fish captured during the study, only 10 taxa were native to the drainage. Multivariate analyses of percentage data identified four site groups characterized by different groups of species. The distributions of fish species were related to specific conductance, gradient, and mean depth; however, specific conductance acted as a surrogate variable for a large group of correlated variables. Two of the fish community metrics – percentage of introduced fish and percentage of intolerant fish – appeared to be responsive to environmental quality but the responses of the other two metrics – percentage of omnivorous fish and percentage of fish with anomalies – were less direct. The conclusion of the study is that fish communities are responsive to environmental conditions, including conditions associated with human-caused disturbances, particularly agriculture and water development. The results suggest that changes in water management and water quality could result in changes in species distributions. Balancing the costs and benefits of such changes poses a considerable challenge to resource managers.

The following is a quote from page 267:

"Differences in stream discharge among years is the most likely reason that species communities in 1995 were so different from those in the other years. Stream discharge in the lower San Joaquin drainage was much higher in water year 1995 (October 1 of previous year to September 30) compared to 1993 and 1994 (Mullen et al.6, Anderson et al.7, Hayes et al.8). Annual mean daily stream discharges ($m^3 s^{-1}$) in water years 1993 to 1995 were 66.6, 47.7, and 246.5, respectively, at the San Joaquin River near Vernalis (SJ1), 14.2, 8.4, and 42.6, respectively, at the Merced River at River Road (MR1), and 13.9, 10.4, and 93.5, respectively, at the Tuolumne River in Modesto (TR2). The exception was the Stanislaus River near Ripon (SR2), where stream discharge was relatively unchanged with values of 13.2, 12.7, and 16.5$m^3 s^{-1}$ in 1993, 1994, and 1995, respectively. Stream discharge at the time of sampling followed the same pattern."

Estuarine Ecology Team. 1997. An assessment of the likely mechanisms underlying the "Fish-X2" relationships. Interagency Ecological Program for the San Francisco Bay/Delta Estuary. Technical Report 52.

The effect of X2 on delta smelt entrainment losses are very well documented. In low outflow years, delta smelt may exhibit a higher probability of entrainment mortality of larvae, juveniles and adults at SWP, CVP, PG&E and agricultural diversions. Other less well documented, yet presumably important effects of X2 on delta smelt, include: 1) increase spawning habitat. The amount of flooded vegetation increases with increasing outflow, 2) increased co-occurrence of young delta smelt with food organisms. There is a significant relationship between delta smelt year-class strength and the amount of time during spring X2 is located in Siusun Bay. Other factors may be operating in some years as well, 3) more suitable habitat for larvae and juveniles may occur when X2 is located downstream in Siusun Bay, which supplies substantially more shallow water habitat than the river channels upstream, 4) reduced probability of encounter with predators. Annual delta smelt year classes exhibit a significant negative association with the abundance of the non-native predator inland silverside in years when X2 is located upstream during spring, 5) entrapment zone (EZ) residence time. Overall, food for larval and juvenile delta smelt is higher near the upstream end of the EZ. When X2 is positioned in Siusun Bay, a higher proportion of the larval population occurs in the EZ, 6) delta smelt may also reside longer in Siusun Bay if they are transported there earlier by higher flows and 7) higher production of food. The abundance of many food organisms for delta smelt larvae and juveniles is affected by mean X2 during spring. Thus, overall growth and condition of delta smelt may be better in higher outflow years.

Mesick, C. 2001. The effects of the San Joaquin River flows and Delta export rates during October on the number of adult San Joaquin Chinook salmon that Stray. In: R.L. Brown (ed.) Contributions to the Biology of Central Valley Salmonids. California Department of Fish and Game. Fish Bulletin 179(2): 139-162.

This report describes a two-part investigation of the effects of fall make-up pumping on straying of adult San Joaquin Chinook salmon. The first part is a reevaluation of 1964 to 1967 data collected by Hallock and others (1970) on the migratory behavior of tagged and untagged adult San Joaquin salmon in the Delta. The second part is an evaluation of the recovery of adult salmon that were released in the San Joaquin basin as coded-wire tagged juveniles reared at the Merced River Fish Facility. First, adult salmon are found migrating throughout the San Joaquin Delta near Prisoners Point primarily during October, the period when they are probably most susceptible to low flows and high exports. Second, the fish migrate slowly and do not arrive in San Joaquin tributaries until about four weeks after they pass Prisoners Point, even when flows, exports, and dissolved oxygen concentrations near Stockton are suitable for migration and third, migration rates of adult salmon are substantially higher when Vernalis flows exceed about 3,000 cfs and total exports are less than 100% of Vernalis flows. CWT recovery data suggest that: 1) straying rates of salmon increased as the percentage of San Joaquin flow exported by the CVP and SWP pumping facilities increased and 2) the critical period is October 1-21. Pulse flows from the San Joaquin tributaries, or a reduction of Delta exports that result in no more than a 300% export rate of San Joaquin flows at Vernalis for eight to 12 days in mid-October, are sufficient to keep straying rates below 3%. When more than 300% of Vernalis flow is exported over a ten-day period in mid-October, adult San Joaquin Chinook salmon stray to the Sacramento and eastside basins. Further tests are needed to support the conclusions derived from existing data.

Moyle, P.B. and B. Herbold. 1989. Status of the delta smelt, *Hypomesus transpacificus*. Final Report to U.S. Fish and Wildlife Service. Department of Wildlife and Fisheries Biology, University of California, Davis: 1-19 + Appendix.

Delta smelt was once one of the commonest pelagic fish in the upper Sacramento-San Joaquin estuary. Since 1982 the population is at its lowest level ever recorded. Reasons for its decline are probably multiple and synergistic, including: 1) reduction of outflows resulting from increased water diversions in the Sacramento and San Joaquin rivers and tributaries, particularly in years of low runoff, 2) high outflows occurring in years of unusually wet years which put the entrapment zone in San Pablo and/or San Francisco bays, 3) entrainment losses to water diversions that result in large numbers of delta smelt pumped through the CVP and SWP plants and reduced population size, 4) changes in food organisms that could increase the potential of larval starvation, 5) toxic substances which could be detrimental but for which there is limited information and 6) loss of genetic integrity due to potential introgression and/or direct competition with the introduced the smelt wakasagi. Data analyses suggested that water flow sets an upper limit on recruitment of smelt each year. The cumulative number of days of reverse flows in the San Joaquin River during spring was always associated with low abundance of delta smelt in Siusun Bay in the fall. Higher outflows favored the development of higher biomasses at all trophic levels in the late spring and led to larger adult populations of smelt in the fall.

Moyle, P.B. et al. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society. 121:67-77.

The delta smelt *Hypomesus transpacificus* is endemic to the upper Sacramento-San Joaquin estuary. It is closely associated with the freshwater-saltwater mixing zone except when it spawns in fresh water. The delta smelt feeds on zooplankton, principally copepods. Its dominant prey was the native copepod *Eurytemora affinis* in 1972-1974 but the exotic copepod *Pseudodiaptomus forbesi* in 1988. Because the delta smelt has a 1-year life cycle and low fecundity, it is particularly sensitive to changes in estuarine conditions. Tow-net and midwater trawl samples showed wide year-to-year fluctuations in population densities. Surveys of different areas showed declines in different years between 1980 and 1983. After 1983, however, all populations remained at very low densities throughout most of the range. The recent decline of delta smelt coincides with an increase in the diversion of inflowing water during a period of extended drought. These conditions have restricted the mixing zone to a relatively small area of deep river channels and, presumably, have increased the entrainment of delta smelt into water diversions.

Nobriga, M. et al. 2000. Environmental factors influencing the distribution and salvage of young delta smelt: A comparison of factors occurring in 1996 and 1999. Interagency Ecological Program 13(2):55-65.

The incidental take of delta smelt is estimated as a part of the ongoing Central Valley Project and State Water Project. Salvage levels of young delta smelt have exceeded incidental take levels every spring and summer since 1994, except in the high spring outflow years 1995 and 1998. The San Joaquin River hydrographs for 1996 and 1999 were unlike the other years examined. In these years, San Joaquin River inflow to the Delta generally ranged over intermediate values (about 4,940 cfs to 15,000 cfs) from late January through late May. In both of these years many adult delta smelt were found in the San Joaquin River but few in the Sacramento River. It is hypothesized that the occurrence of intermediate flows on the San Joaquin River in late winter provided attractive conditions for adult delta smelt moving upstream to spawn. Maintenance of moderate flow levels through spring then provided favorable spawning and juvenile rearing conditions in the central and south Delta. Despite the similar flow pattern between 1996 and 1999, May-August salvage levels at the Delta facilities were significantly higher in 1999 (152,631) than in 1996 (39,712). The protracted spawning and recruitment period in 1999 partly explained the difference in salvage between these years. The rapid warming of delta waters may have caused cessation of spawning or may have greatly reduced egg and larval survival.

Nobriga, M. et al. 2001. Spring 2000 Delta smelt salvage and delta hydrodynamics and an introduction to the Delta smelt decision tree. Interagency Ecological Program. Newsletter Spring 2001 14(2):42-46.

San Joaquin River flows during winter and early spring 2000 were similar to other years hypothesized by Nobriga et al. (2000) to attract spawning delta smelt into the Central Delta. Delta smelt salvage quickly exceeded red light levels following the VAMP in 2000 as it has in most recent years. This lends additional support to the hypothesis that the VAMP results in suitable larval rearing conditions within the Central and South Delta as suggested by high subsequent salvage when CVP and SWP exports ramp up after the VAMP. Because delta smelt begins to be counted in salvage statistics when fish reach sizes of about 25 mm, it is conceivable that more fish were entrained as larvae in years prior to VAMP and thus, would not have survived to be reported in salvage statistics.

Periodic Review of the 1995 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary, September 30, 2004. State Water Resources Control Board, California Environmental Protection Agency.

"A review of the 1995 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary to address changes to the water quality compliance and baseline monitoring program, Delta cross channel gate closures, salmon protection, chloride objectives, Delta outflow, export limits, river flow at Rio Vista and Vernalis (for two periods), and southern Delta electrical conductivity. "This report describes the actions taken by the SWRCB to date for the periodic review of the 1995 Plan and includes staff's recommendations for future actions." Page 10.

***Raquel, P.F. 1988. Estimated entrainment of striped bass eggs and larvae at the State Water Project and Central Valley Project facilities in the Sacramento-San Joaquin Delta, 1987. Interagency Ecological Study Program for the Sacramento San Joaquin Estuary. Technical Report 15.**

A striped bass (*Morone saxatilis*) egg and larval sampling program was conducted in the southern Delta near the intakes of the State Water Project (SWP) and Central Valley Project (CVP) during spring 1987. Estimates of striped bass egg entrained were 2.1 million by the SWP and 6.8 million by the CVP. Estimates of striped bass larvae (fish less than 21 mm) entrained were 92.2 million by the SWP and 131.7 million by the CVP. Highest entrainment was for 3-6 mm larvae. Striped bass yearling equivalent losses were 41,726 for the state facility and 68,479 for the federal facility.

***Reynolds, F.L. et al. 1990. Central Valley Salmon and Steelhead Restoration and Enhancement Plan. Inland Fisheries Division, California Department of Fish and Game.**

The section pertaining to the Delta discusses the history of exports, the increases in exports, and the effects of exports; 1) if there is sufficient flow in the San Joaquin River, 2) if there is a deficiency in exports, and 3) if export and internal uses are greater than combined inflows from the San Joaquin River and the eastern streams combined with Georgiana Slough and Delta Cross Channel flows. Salmon and steelhead resources are discussed in terms of past and present, and the fisheries.

Sacramento Fish and Wildlife Office. 2004. 5-year review. *Hypomesus transpacificus* (delta smelt). Notice: Federal Register 68(148):45270-45271 on August 1, 2003.

The current U.S. Fish and Wildlife Service (Service) Recovery Plan (1996) for delta smelt assigned a recovery potential of 2C. A listed species is assigned a recovery priority number from 1 (highest) to 18 (lowest) according to the degree of threats, recovery potential and taxonomic distinctness. In addition, a species' rank may be elevated by adding a C designation to its numerical rank to indicate that there is some degree of conflict between the species' conservation efforts and economic development associated with its recovery. Recovery priority numbers are based on criteria published the Federal Register Notice (48 FR 43098; September 21, 1983). At the time of listing, Delta smelt was under a high degree of threat from the severe 1987-1992 California drought. The species persisted in small numbers and rebounded to pre-decline levels in 1993, suggesting that its recovery potential is fairly high. The subsequent decline in 1994, a critical water year, to a then all-time low annual abundance index of 102 (Fall Midwater Trawl Survey (FMWT)), however, illustrates the high degree of threat that neutralizes gains in abundance that result from good water years. More recent abundance indices have varied, but overall, the trend is still negative.

Sweetnam, D.A. and D.E. Stevens. 1993. Report to the Fish and Game Commission: A status review of the delta smelt (*Hypomesus transpacificus*) in California. State of California, The Resources Agency.

This report reviews evidence on a petition to the Fish and Game Commission by the Department of Fish and Game to list delta smelt (*Hypomesus transpacificus*) under the authority of the California Endangered Species Act. Key conclusions are: 1) whether or not water diversions are directly responsible for the delta smelt population decline, their drain on the population may be a significant factor inhibiting recovery, 2) delta smelt are threatened by habitat modifications which include changes in the character and position of the salinity gradient, 3) the decline of the copepod *Eurytemora affinis*, a major component of the delta smelt diet must be considered as a potential threat to the smelt's recovery unless other food resources compensate or *E. affinis* recovers to its former abundance, 4) the presence of exotic fish and invertebrates in the Sacramento-San Joaquin Estuary may inhibit smelt's recovery, 5) low spawning stock levels may inhibit potential population recovery, 6) the years of the delta smelt decline coincided with outflows that were either too low or exceptionally high, 7) the wakasagi, an introduced fish, could potentially compete with delta smelt and/or hybridize with it and dilute its gene pool; 8) effect of toxic substances, diseases and parasites, competition and predation on delta smelt population cannot be ruled out. Yet, several potential competitors or predators showed signs of population decline approximately coinciding with or preceding the decline of delta smelt, and 9) the most prudent action is to list the species as threatened.

USFWS. 1995. Biological Opinion for Delta Smelt. March 6, 1995. U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office. Sacramento, CA.

The following are selected quotes from page 18:

"March through June protections-- During March through June, exports shall be no greater than 35 percent of Delta inflow, subject to the flexibility provisions described below."

"July through January-- During July through January, exports shall be no greater than 65 percent of Delta inflow, subject to the flexibility provisions described below. The criteria will be developed by the Ops Group."

USFWS. 1995A. Working paper on restoration needs: Habitat restoration actions to double natural production of anadromous fish in the Central Valley of California. Volumes 1,2,3. May 9, 1995. Prepared for the U.S. Fish and Wildlife Service under the direction of the anadromous Fish Restoration Program. Stockton, CA.

Volumes 1 and 3 summarize the production goals, limiting factors, flows and other restoration actions that AFRP technical teams found necessary to double production of the anadromous fish stocks. Volume 2 identifies historical and existing conditions for anadromous fish and identifies roles of state and federal agencies in managing anadromous fish.

USFWS. 1995B. Sacramento-San Joaquin Delta Native Fishes Recovery Plan. U.S. Fish and Wildlife Service, Portland, Oregon.

Eight fish species are included in the Sacramento-San Joaquin Delta Native Fishes Recovery Plan. Delta smelt is listed as threatened species. The Sacramento splittail was proposed as a threatened species in 1994. This recovery plan recommends restoration criteria should the species be listed. Longfin smelt, green sturgeon, spring-run, late fall-run, and San Joaquin fall-run Chinook salmon are species of concern for which restoration criteria are recommended. Information is also included on Sacramento perch, a species believed to be extirpated from the Delta at this time. The eight species included in this recovery plan depend on the Sacramento-San Joaquin Delta for a significant segment of their life history. Threats to these species include loss of habitat due to increased freshwater exports resulting in increased salinity, loss of shallow-water habitat due to dredging, diking and filling, introduced species, and entrainment (movement of fish by currents produced by diversions) in state, federal and private water diversions. State and federal diversions have also changed the pattern and timing of flows through the Delta. Recovery criteria are quantifiable and species specific and can be used to 1) monitor effectiveness of recovery actions, 2) determine when a species has recovered to a secure level (stabilized), and 3) determine when a species qualifies for delisting. In many cases, criteria are based on two independent measures: population abundance and geographical distribution. Actions needed are: 1) enhance and restore aquatic and wetland habitat in the estuary, 2) reduce effects of commercial and recreational harvest, 3) reduce effects of introduced aquatic species on Delta native fishes, 4) change and improve enforcement of regulatory mechanisms, 5) monitor and investigate fish biology and management requirements, 6) assess recovery management actions and re-assess prioritization of actions, 7) increase public awareness of importance of Delta native fishes.

USFWS. 2001. 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. Prepared for the U.S. Fish and Wildlife Service under the direction of the anadromous Fish Restoration Program. Stockton, CA.

A number of specific flow and non-flow actions and evaluations deemed necessary to achieve doubling of anadromous fishes in the Sacramento-San Joaquin watershed are summarized.

USFWS. 2005. Operational Criteria and Plan, Biological Opinion for Delta Smelt. February 16, 2005. U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office. Sacramento, CA.

In-stream flow requirements for the Vernalis from February to June are discussed. Table 5 (p. 59) lists water year class and flows at Vernalis for the February-June period. The VAMP is pulse flow period is discussed with regards to flow objectives and export restrictions (p. 62-63).

The distribution of delta smelt may not always be regulated by X2 since food availability may influence their distribution (p.116). Further, "In addition to the degradation and loss of estuarine habitat, delta smelt have been increasingly subject to entrainment, upstream or reverse flows of waters in the Delta and San Joaquin river, and constriction of low salinity habitat to deep-water channels of the interior Delta (Moyle et al. 1992) (p.120). "For a large part of its annual life span, this species is associated with the freshwater edge of the mixing zone, where the salinity is approximately 2 ppt. (also described as X2) (Ganssle 1966, Moyle et al. 1992, Sweetnam and Stevens 1993). The relationship between the portion of the smelt population west of the Del;ta as sampled in the summer townet survey and the natural logarithm of Delta outflow from 1959 to 1988, indicates the summer townet index increased dramatically when outflow was between 34,000 and 48,000 cubic feet per second, placing X2 between Chipps and roe islands (DWR and Reclamation 1994)." (p.120).

The Summary of the Five Year Review state that "In summary, the threats of the destruction, modification, or curtailment of its habitat or range resulting from extreme outflow conditions, the operations of the State and Federal water projects, and other water diversions as described in the original listing remain." (p.121)

Water Quality Control Plan. San Francisco Bay/Sacramento - San Joaquin Delta Estuary. 95-1WR. May 1995. Water Resources Control Board, State of California.

The following is quoted from the paper, page 14;

"C. Water Quality Objectives for Fish and Wildlife Beneficial Uses

The objectives for the protection of fish and wildlife beneficial uses are established for the following parameters: dissolved oxygen, salinity (expressed as electrical conductivity), Delta outflow, river flows, export limits, and Delta Cross Channel gate operation. Unlike water quality objectives for parameters such as dissolved oxygen, temperature, and toxic chemicals, which have threshold levels beyond which adverse impacts to the beneficial uses occur, there are no defined threshold conditions that can be used to set objectives for flows and project operations. Instead, the available information indicates that a continuum of protection exists. Higher flows and lower exports provide greater protection for the bulk of estuarine resources up to the limit of unimpaired conditions. Therefore, these objectives must be set based on a subjective determination of the reasonable needs of all of the consumptive and nonconsumptive demands on the waters of the Estuary. As the long-term planning process for the Estuary, cited in the Framework Agreement, is developed and implemented, these objectives will be evaluated and modified, as necessary, to provide a level of protection predicated on more optimal physical facilities and management actions."

Water Right Decision 1630. San Francisco Bay/Sacramento - San Joaquin Delta Estuary. April 1993. State Water Resources Control Board, California Environmental Protection Agency. Page 27-35.

Section II.C.1. discusses the Bay/Delta Estuary as highly modified, where flows that would be uncontrolled in the winter and spring are now regulated, and the outflow as reduced due to dam construction, upstream storage diversions and exports. The CVP and SWP export pumps cause a net reversal of flow, and when the Delta cross channel gates are open, substantial amounts of the Sacramento River water is diverted into the central Delta, much of the water for exports. "Under high export rates with reduced inflow, the lower San Joaquin River also experiences a net flow reversal, with net movement of water from the lower Sacramento river or Suisun Bay upstream into the central Delta."

In section II.C.1.b. the "public trust resources of the Estuary are in a state of decline" (p. 30). Fall-run and spring-run Chinook salmon numbers have declined, as well as delta smelt, striped bass, and two species of shrimp. High export rates from the pumping plants especially during April through June are related to substantial losses of juvenile fish. During dry or critically dry years, losses are particularly high. To reduce losses especially during the April through June period, it is recommended that exports be reduced. For winter-run Chinook salmon, the most effective method of protecting these juveniles is to prevent diversion from their migration route February through April.

Section IV.B. discusses fishery management measures in terms of long-term goals to insure that there are sufficient flows through the Delta to transport juvenile fish beyond the effects of the diversion pumping. The use of temporary hatcheries to boost populations where necessary, and upstream measures to ensure survival of salmon eggs, fry, and juvenile.

Section V. discussed the effects on salmon, striped bass, and other estuarine species. Table D lists a smolt survival index for the Sacramento River and the San Joaquin River with or without the barrier.

Water Right Decision 1641. March 15, 2000. State Water Resources Control Board, California Environmental Protection Agency.

Exports are referenced to 81 times in the document, particularly with regard to recirculation, the San Joaquin River, VMAP, and the CVP/SWP. The following are a few of the quotes:

"3. Recirculation could cause increased entrainment of fish at the southern Delta export facilities, particularly during the spring pulse flow period, due to the increase in exports for recirculation. (R.T. pp. 10401, 10404.) Species of primary concern include salmon, steelhead, delta smelt, Sacramento splittail, and longfin smelt. (R.T. p. 10406.)". Page 16.

"4. Increased exports due to recirculation might affect in-Delta hydrodynamics, which could affect the distribution of fish and their vulnerability to entrainment. (R.T. pp. 10404-10405.)". Page 16.

"6.3.1. The SJRA provides a mechanism for conducting the VAMP, an experiment to determine the relative impact of flow in the San Joaquin River and exports in the Delta on Chinook salmon in the lower San Joaquin River." Page 17.

Table 3; section dealing with export limits

TABLE 3 (continued)
WATER QUALITY OBJECTIVES FOR FISH AND WILDLIFE BENEFICIAL USES

COMPLIANCE LOCATION	INTERAGENCY STATION NUMBER(RKI 1[])	PARAMETER	DESCRIPTION (UNIT) [2]	WATER YEAR TYPE [3]	TIME PERIOD	VALUE
EXPORT LIMITS						
		Combined export rate[16]	*Maximum 3-dayrunning average(cfs) Maximum percent ofDelta inflow diverted [19] [20]*	*All All All*	*Apr 15-May 15 [17] Feb-Jun Jul-Jan*	*[18] 35% Delta inflow [21] 65% Delta inflow*

2. Delta Outflow Objectives

Aasen, G.A. 1999. Juvenile delta smelt use of shallow-water and channel habitats in California's Sacramento-San Joaquin Estuary. California Fish and Game 85(4):161-169.

Juvenile delta smelt, *Hypomesus transpacificus*, densities were significantly greater in shallow water in Honker Bay and Sherman Lake than in adjacent channels in 1993, indicating that they used shallow areas in bay and flooded island environments as nursery habitats. Densities and lengths were significantly greater on high than low tides in shallow water in Honker Bay, but not in the adjacent channel, suggesting that delta smelt moved tidally between Honker Bay and Grizzly bays. Delta smelt densities did not differ between shallow water and channels in the riverine environments of Montezuma Slough, the lower San Joaquin River, and Cache slough, presumably because shallow areas were smaller and no embayments existed to retain delta smelt. Delta smelt may be larger in shallow water in Honker Bay and Sherman Lake because: 1) Fish in shallow water were older and consequently larger or 2) residence time was longer and foraging success was better, resulting in increased growth rates. Availability of shallow habitats to delta smelt increases in high-outflow years when hydrodynamic transport locates the delta smelt population downstream in Siusun, Grizzly, and Honker bays.

***Bennett, W. A. and P.B. Moyle. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin Estuary. In pages 519-542. J.T. Hollibaugh (ed.) The San Francisco Bay: The ecosystem. Further investigations into the natural history of San Francisco Bay and Delta with reference to the influence of man. Friesen Printers, Altona, Manitoba.**

Fish populations have declined markedly in the Sacramento-San Joaquin estuary. Evidence of factors contributing to the declining abundance of fishes is reviewed in the context of six pathways by which alteration of freshwater outflow to the estuary affects the survival of larval and juvenile fishes. Specific pathways include: 1) transport and entrainment, 2) retention in and/or advection from preferred habitats, 3) success and effects of invading species, 4) primary production and food web dynamics, 5) dilution and/or flushing of toxic compounds, and 6) the quantity and quality of shallow-water spawning/rearing habitat. Clearly, ameliorating the effects of various factors (e.g., reducing entrainment, toxic runoff, and improving shallow water habitat) will improve conditions for fish. The current lack of life history information and on several of the most affected species and the need to prevent extinctions suggests that the most pragmatic and promising solution is to ensure adequate outflow to the estuary. The simultaneous declines of so many species with different habitat requirements and life history strategies is an indication of broad problems with the estuarine environment, especially in the Delta.

Brandes, P.L, and J.S. McLain. 2001. Juvenile Chinook salmon abundance, distribution, and survival in the Sacramento-San Joaquin Estuary. In R.L. Brown (ed.) Contributions to the Biology of Central Valley Salmonids. California Department of Fish and Game. Fish Bulletin 179(2):39-136.

All four races of juvenile Central Valley Chinook salmon migrate through and many rear in the Sacramento-San Joaquin Delta and Estuary. Delta residence and migration is considered important in determining adult production, as it is generally believed that density dependent effects are minimal after this life stage. Populations of winter run and spring run are presently listed as endangered and threatened species, while the remaining populations in the Central Valley are candidate species. Actions in the Delta to improve survival are likely important in the recovery of these depressed populations. The tidally influenced freshwater Delta also is an important area for water management in California, as it is where the Central Valley and State Water Project pump large volumes of water to southern California, the San Joaquin Valley and the Bay area. To document the effect of these various water management activities in the Delta on juvenile salmon, monitoring and special studies have been conducted since the early 1970s to the present. Changes in abundance in the Delta and estuary appear related to flow; high flows increase the use of the Delta and San Francisco Bay by fry. Relative survival of fry appears greater in the upper Sacramento River than in the Delta or bay, especially in the wetter years. Survival appears lower in the Central Delta relative to that in the North Delta in drier years for both fry and smolts. Fall-run smolt and late-fall-run yearling survival studies have found that diversion into the Central Delta via the Delta Cross Channel or Georgiana Slough reduces survival through the Delta. Experiments in the San Joaquin Delta have shown that survival appears greater for smolts that migrate down the mainstem San Joaquin River rather than through upper Old River. A temporary barrier in upper Old River was tested and found to improve survival for smolts originating in the San Joaquin basin. These specific experiments have identified management actions that could improve juvenile salmon survival through the Delta. In addition, indices of annual survival provide a way to compare survival through the Delta and could be used to assess restoration and management actions. This work demonstrates How long-term scientific studies can be applied to address management and restoration issues.

Brown, L.R. 2000. Fish communities and their associations with environmental variables, lower San Joaquin River drainage, California. Environmental Biology of Fishes 57: 251-269.

Twenty sites in the lower San Joaquin River drainage, California, were sampled from 1993 to 1995 to characterize fish communities and their associations with measures of water quality and habitat quality. The feasibility of developing an Index of Biotic Integrity was assessed by evaluating four fish community metrics, including percentages of native fish, omnivorous fish, fish intolerant of environmental degradation, and fish with external anomalies. Of the thirty-one taxa of fish captured during the study, only 10 taxa were native to the drainage. Multivariate analyses of percentage data identified four site groups characterized by different groups of species. The distributions of fish species were related to specific conductance, gradient, and mean depth; however, specific conductance acted as a surrogate variable for a large group of correlated variables. Two of the fish community metrics – percentage of introduced fish and percentage of intolerant fish – appeared to be responsive to environmental quality but the responses of the other two metrics – percentage of omnivorous fish and percentage of fish with anomalies – were less direct. The conclusion of the study is that fish communities are responsive to environmental conditions, including conditions associated with human-caused disturbances, particularly agriculture and water development. The results suggest that changes in water management and water quality could result in changes in species distributions. Balancing the costs and benefits of such changes poses a considerable challenge to resource managers.

The following is a quote from page 267:

“Differences in stream discharge among years is the most likely reason that species communities in 1995 were so different from those in the other years. Stream discharge in the lower San

Joaquin drainage was much higher in water year 1995 (October 1 of previous year to September 30) compared to 1993 and 1994 (Mullen et al.6, Anderson et al.7, Hayes et al.8). Annual mean daily stream discharges (m3 s−1) in water years 1993 to 1995 were 66.6, 47.7, and 246.5, respectively, at the San Joaquin River near Vernalis (SJ1), 14.2, 8.4, and 42.6, respectively, at the Merced River at River Road (MR1), and 13.9, 10.4, and 93.5, respectively, at the Tuolumne River in Modesto (TR2). The exception was the Stanislaus River near Ripon (SR2), where stream discharge was relatively unchanged with values of 13.2, 12.7, and 16.5m3 s−1 in 1993, 1994, and 1995, respectively. Stream discharge at the time of sampling followed the same pattern."

Dege, M. and L.R. Brown. 2004. Effect of outflow on spring and summertime distribution and abundance of larval and juvenile fishes in the upper San Francisco Estuary. American Fisheries Society Symposium 39:49–65.

Data on spring and summertime larval and juvenile fish distribution and abundance was analyzed in the upper San Francisco Estuary (SFE), California between 1995 and 2001. The upper SFE includes the tidal freshwater areas of the Sacramento–San Joaquin Delta downstream to the euryhaline environment of San Pablo Bay. The sampling period included years with a variety of outflow conditions. Fifty taxa were collected using a larval tow net. Two common native species, delta smelt *Hypomesus transpacificus* and longfin smelt *Spirinchus thaleichthys*, and four common alien taxa, striped bass *Morone saxatilis*, threadfin shad *Dorosoma petenense*, gobies of the genus *Tridentiger*, and yellowfin goby *Acanthogobius flavimanus*, were selected for detailed analysis. Outflow conditions had a strong influence on the geographic distribution of most of the species, but distribution with respect to the 2 psu isohaline (X2) was not affected. The distribution patterns of delta smelt, longfin smelt, and striped bass were consistent with larvae moving from upstream freshwater spawning areas to downstream estuarine rearing areas. There were no obvious relationships of outflow with annual abundance indices. Our results support the idea of using X2 as an organizing principle in understanding the ecology of larval fishes in the upper SFE. Additional years of sampling will likely lead to additional insights into the early life history of upper SFE fishes.

Dettman, D.H. et al. 1987. The influence of flow on Central Valley salmon. D.W. Kelley & Associates. Newcastle, CA. Prepared for the California Department of Water Resources.

A review on juvenile salmon survival experiments conducted by the U.S. Fish and Wildlife Service and the California Department of Fish and Game showed that survival increase in direct proportion to Sacramento River flow up to levels of about 30,000 cfs at I street (Sacramento, CA). An index of spawning returns was positively correlated with June flows in the Sacramento river and with both June and July outflows from the Delta. There has been a major reduction in the upper Sacramento spawning runs, but the Feather and American River runs have increased, probably due to the hatchery operations. Both juvenile salmon survival and adult population size has broken down in recent years, which is attributed to the Department of Fish and Game policy of planting large numbers of salmon smolts directly into the estuary.

Estuarine Ecology Team. 1997. An assessment of the likely mechanisms underlying the "Fish-X2" relationships. Interagency Ecological Program for the San Francisco Bay/Delta Estuary. Technical Report 52.

The effect of X2 on delta smelt entrainment losses are very well documented. In low outflow years, delta smelt may exhibit a higher probability of entrainment mortality of larvae, juveniles and adults at SWP, CVP, PG&E and agricultural diversions. Other less well documented, yet presumably important effects of X2 on delta smelt, include: 1) increase spawning habitat. The amount of flooded vegetation increases with increasing outflow, 2) increased co-occurrence of young delta smelt with food organisms. There is a significant relationship between delta smelt year-class strength and the amount of time during spring X2 is located in Siusun Bay. Other factors may be operating in some years as well, 3) more suitable habitat for larvae and juveniles may occur when X2 is located downstream in Siusun Bay, which supplies substantially more shallow water habitat than the river channels upstream, 4) reduced probability of encounter with predators. Annual delta smelt year classes exhibit a significant negative association with the abundance of the non-native predator inland silverside in years when X2 is located upstream during spring, 5) entrapment zone (EZ) residence time. Overall, food for larval and juvenile delta smelt is higher near the upstream end of the EZ. When X2 is positioned in Siusun Bay, a higher proportion of the larval population occurs in the EZ, 6) delta smelt may also reside longer in Siusun Bay if they are transported there earlier by higher flows and 7) higher production of food. The abundance of many food organisms for delta smelt larvae and juveniles is affected by mean X2 during spring. Thus, overall growth and condition of delta smelt may be better in higher outflow years.

Feyrer, F. and M.P. Healey 2002. Structure, sampling gear and environmental associations, and historical changes in the fish assemblage of the Southern Sacramento San Joaquin Delta. California Fish and Game 88(3):126-138.

Fishes were sampled at 11 fixed sites monthly from January 1993 through December 1994 in the Southern Sacramento-San Joaquin Delta. After accounting for the effect of gear type, flow and temperature had the strongest effect on fish assemblage structure. The native species (splittail, tule perch and Sacramento sucker) were associated with high river flow relative to other species. The delta fish assemblage has greatly changed since it was first described 30 years prior to this study. Two native species have apparently been extirpated and at least eight non-native fish have invaded the South Delta. Native species represented only 27% of the species and 1% of the total number of fishes collected. This study supports the hypothesis that highly altered habitats are vulnerable to the invasion and establishment of alien species.

Feyrer, F. and M.P. Healey. 2003. Fish community structure and environmental correlates in the highly altered southern Sacramento-San Joaquin Delta. Environmental Biology of Fishes 66:123-132.

Eleven sites were sampled in the southern Sacramento –San Joaquin Delta from 1992-1999, to characterize fish communities and their associations with environmental variables. Only eight of the 33 different taxa collected were native and none of the native species comprised more than 0.5% of the total number of individuals collected. Abundance of native species peaked during high outflow periods despite being consistently low. The majority of non-native species were associated with either warm water or low river flows. Fish communities at each river location were consistently different each year and were correlated with river flow and turbidity. It is predicted that fish communities will remain numerically dominated by non-native species if the observed environmental conditions persist in the future.

Feyrer, F. 2004. Ecological segregation of native and alien larval fish assemblages in the Southern Sacramento-San Joaquin Delta. American Fisheries Society Symposium 39:67-79.

Fish larvae were sampled at multiple fixed sites from late winter to early summer over six years (1990-1995) in the southern Sacramento-San Joaquin Delta. The two most numerically dominant species were non-native (Shimofuri goby 71% and threadfin shad 15%), followed by the native prickly sculpin (12%). Native species, including delta smelt, and splittail, tended to be associated with early season conditions of cool water temperature and high river flow. Non-native species were associated with late season conditions of relatively warm water temperature and low river flow. Although native species dominated the assemblage February March, while non-native species dominated May-July, the peak of seasonal abundance for non-native species was typically five times greater than that of native species

Jassby, A. et al. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5:272-289.

Populations of native and introduced aquatic organisms in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary ("Bay/Delta") have undergone significant declines over the past two decades. Decreased river inflow due to drought and increased freshwater diversion have contributed to the decline of at least some populations. Effective management of the estuary's biological resources requires a sensitive indicator of the response to freshwater inflow that has ecological significance, can be measured accurately and easily, and could be used as a "policy" variable to set standards for managing freshwater inflow. Positioning of the 2ppt (grams of salt per kilogram of seawater) bottom salinity value along the axis of the estuary was examined for this purpose. The 2ppt bottom salinity position (denoted by X2) has simple and significant statistical relationships with annual measures of many estuarine resources, including the supply of phytoplankton and phytoplankton-derived detritus from local production and river loading; benthic macroinvertebrates (molluscs); mysids and shrimp; larval fish survival; and the abundance of planktivorous, piscivorous, and bottom-foraging fish. The actual mechanisms are understood for only a few of these populations. X2 also satisfies other recognized requirements for a habitat indicator and probably can be measured with greater accuracy and precision than alternative habitat indicators such as net freshwater inflow into the estuary. The 2ppt value may not have special ecological significance for other estuaries (in the Bay/Delta, it marks the locations of an estuarine turbidity maximum and peaks in the abundance of several estuarine organisms), but the concept of using near-bottom isohaline position as a habitat indicator should be widely applicable. Although X2 is a sensitive index of the estuarine community's response to net freshwater inflow, other hydraulic features of the estuary also determine population abundances and resource levels. In particular, diversion of water for export from or consumption within the estuary can have a direct effect on population abundance independent of its effect on X2. The need to consider diversion, in addition to X2, for managing certain estuarine resources is illustrated using striped bass survival as an example. The striped bass survival data were also used to illustrate a related important point: incorporating additional explanatory variables may decrease the prediction error for a population or process, but it can increase the uncertainty in parameter estimates and management strategies based on these estimates. Even in cases where the uncertainty is currently too large to guide management decisions, an uncertainty analysis can identify the most practical direction for future data acquisition. Although delta smelt distribution is determined by X2, a delta smelt abundance index based on the fall mid water trawl did not exhibit a statistical verifiable relation with X2 and an effect of X2 position on the abundance of delta smelt was not ruled out. X2 role may simply be masked by the effect of additional mechanisms or delta smelt respond to other function of X2, rather than the April-July averaging period used.

Kimmerer, W.J. 2002A. Effect of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Marine Ecology Progress Series 243: 39-55.

All ecosystems are influenced by physical forcing. Estuarine ecosystems respond most strongly on an interannual timescale to variability in freshwater flow. Several mechanisms for positive or negative flow effects on biological populations in estuaries have been proposed; however, positive effects appear to operate mainly through stimulation of primary production with effects propagating up the food web. In the northern San Francisco Estuary, abundance or survival of several common species of fish and shrimp varied positively with flow-in data through 1992. I re-examined these relationships and those of several additional taxa in an analysis of long-term (20 to 40 yr) monitoring data. The spread of the introduced clam *Potamocorbula amurensis* in 1987 provided an opportunity to examine simultaneously the responses of estuarine species to flow and to changes in the food web. I separated variability into a flow response, a step change after 1987 and other sources of variability. Responses of fish and shrimp contrasted with those of lower trophic levels. All but 1 species of nekton responded positively to flow, only 2 had clear declines after 1987, and none of the relationships changed in slope after 1987. In contrast with the higher trophic levels, chlorophyll *a* (chl *a*) and several species of zooplankton declined markedly after 1987, and had either weak responses to flow or responses that changed after 1987. Thus, the food web appears strongly coupled between benthos and plankton, and weakly coupled between zooplankton and fish, as has been found in other systems. More importantly, the variation with freshwater flow of abundance or survival of organisms in higher trophic levels apparently did not occur through upward trophic transfer, since a similar relationship was lacking in most of the data on lower trophic levels. Rather, this variation may occur through attributes of physical habitat that vary with flow.

Kimmerer, W. J. 2002B. Physical, biological, and management responses to variable freshwater flow into the San Francisco Estuary. Estuaries 25, 6B:1275–1290.

Freshwater flow is the principal cause of physical variability in estuaries and a focus of conflict in estuaries where a substantial fraction of the freshwater is diverted. Variation in freshwater flow can have many effects: inundation of flood plains, increase loading and advective transport of materials and organisms, dilution or mobilization of contaminants, compression of the estuarine salinity field and density gradient, increase in stratification, and decrease in residence time for water while increasing it for some particles and biota. In the San Francisco Estuary, freshwater flow is highly variable, and has been altered by shifts in seasonal patterns of river flow and increases in diversions from tidal and nontidal regions, entraining fish of several species of concern. Abundance or survival of several estuarine-dependent species also increases with freshwater outflow. These relationships to flow may be due to several potential mechanisms, each with its own locus and period of effectiveness, but no mechanism has been conclusively shown to underlie the flow relationship of any species. Several flow-based management actions were established in the mid-1990s, including a salinity standard based on these flow effects, as well as reductions in diversion pumping during critical periods for listed species of fish. The effectiveness of these actions has not been established. To make the salinity standard more effective and more applicable to future estuarine conditions will require investigation to determine the underlying mechanisms. Effects of entrainment at diversion facilities are more straightforward conceptually but difficult to quantify, and resolving these may require experimental manipulations of diversion flow.

Kimmerer, W. 2004. Open Water Processes of the San Francisco Estuary: From Physical Forcing to Biological Responses San Francisco Estuary & Watershed Science 2(1): 142 p.

This paper reviews the current state of knowledge of the open waters of the San Francisco Estuary. This estuary is well known for the extent to which it has been altered through loss of wetlands, changes in hydrography, and the introduction of chemical and biological contaminants. It is also one of the most studied estuaries in the world, with much of the recent research effort aimed at supporting restoration efforts. The conceptual foundations for our current understanding of estuarine dynamics are emphasized, particularly those aspects relevant to restoration. Four themes run throughout this paper. 1) the critical role physical dynamics play in setting the stage for chemical and biological responses. Physical forcing by the tides and by variation in freshwater input combine to control the movement of the salinity field, and to establish stratification, mixing, and dilution patterns throughout the estuary. Many aspects of estuarine dynamics respond to interannual variation in freshwater flow; in particular, abundance of several estuarine-dependent species of fish and shrimp varies positively with flow, although the mechanisms behind these relationships are largely unknown. 2) the importance of time scales in determining the degree of interaction between dynamic processes. Physical effects tend to dominate when they operate at shorter time scales than biological processes; when the two time scales are similar, important interactions can arise between physical and biological variability. These interactions can be seen, for example, in the response of phytoplankton blooms, with characteristic time scales of days, to stratification events occurring during neap tides, 3) the key role of introduced species in all estuarine habitats; particularly noteworthy are introduced waterweeds and fishes in the tidal freshwater reaches of the estuary, and introduced clams there and in brackish water, and 4) the rather heterogeneous set of results from monitoring and research in the estuary. For example, some topics have been subjects of intense activity both in research and monitoring (e.g., physical dynamics of the upper estuary, phytoplankton blooms), while others have received little attention (e.g., microzooplankton). In addition, both research and monitoring have emphasized some regions of the estuary (e.g., the Sacramento-San Joaquin Delta) over others (e.g., San Pablo Bay). In addition, ecological modeling and synthesis has emphasized lower trophic levels over higher. Opportunities for restoration in the open waters of the estuary are somewhat limited by the lack of scientific basis for restoration, and the difficulty in detecting ecosystem responses in the context of high natural variability.

***Kjelson, M.A. and P.F. Raquel. 1981. The life history of fall run juvenile Chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento-San Joaquin Estuary of California. Estuaries 4(3):285.**

Juvenile salmon studies emphasize the significance of estuarine rearing, analysis of water development project impacts, and identification of salmon water quality and flow needs. Young Chinook utilize San Francisco Bay and the upper estuary (Delta) for both rearing and seaward migration. Major recruitment of fry (30 to 50 mm) to the estuary begins in January with peak abundance in March and rearing occurs between January and June. Growth rate ranges from 0.5 to 1.3 mm per day. The timing and quantity of inflow to the Delta appears to determine the distribution and number of fry reared in the estuary and the survival of smolts. Peak migration of smolts (70 to 80 mm) occurs in May and June. Smolt migration rates range from 8 to 24 km per day. Major food items observed in juvenile Chinook vary between the freshwater (cladocera, diptera) and saline (copepods, amphipods, fish larvae) portions of the estuary.

Kjelson, M.A., et al. 1982. Life history of fall-run juvenile Chinook salmon, *Oncorhynchus tshawystscha* in the Sacramento-San Joaquin Estuary, California. In: pages 393-411. V.S. Kennedy(Ed.) Estuarine Comparisons. Academic Press Inc.

Fall-run Chinook salmon is the dominant run of this species in the Sacramento-San Joaquin Estuary and utilize the estuary for rearing and migration. Brackish water bays are used primarily as a migration corridor by smolts. Fry abundance and distribution in the estuary are influenced by the magnitude and timing of river flows. Survival during smolt outmigration is greater in the lower bays than in the Delta. Survival through the Delta in June is inversely related to water temperature and directly related to river flows which is consistent with observations in other northern estuaries. Alteration of the timing, magnitude and distribution of flow in the Sacramento San Joaquin Estuary has a major impact on juvenile Chinook salmon survival.

Kjelson, M.A. and P.L. Brandes. 1989. The use of smolt survival estimates to quantify the effects of habitat changes on salmonid stocks in the Sacramento-San Joaquin rivers, California. Canadian Special Publication. Fisheries and Aquatic Sciences. 105:100-115.

Mark-recapture studies of smolt survival in the Sacramento-San Joaquin Delta of California provides empirical data on the effects of water development on fall-run Chinook salmon. Recoveries of coded-wire tagged hatchery fish from the ocean troll fishery and estuarine trawling yielded two survival measures that were positively correlated ($r = 0.90$). Smolt survival from both measures were highly correlated to river flow, temperature, and percent diversion. Survival of fish exposed to diversion was about 50% less than those not exposed. Estuarine survival has decreased a minimum of 30% in the past 70 yr. Spawner escapements in the Central Valley are positively correlated to flow during their spring smolt outmigration suggesting that flow alteration in upstream and estuarine habitats at that time influences adult stock production.

Moyle, P.B. and B. Herbold. 1989. Status of the delta smelt, *Hypomesus transpacificus*. Final Report to U.S. Fish and Wildlife Service. Department of Wildlife and Fisheries Biology, University of California, Davis: 1-19 + Appendix.

Delta smelt was once one of the commonest pelagic fish in the upper Sacramento-San Joaquin estuary. Since 1982 the population is at its lowest level ever recorded. Reasons for its decline are probably multiple and synergistic, including: 1) reduction of outflows resulting from increased water diversions in the Sacramento and San Joaquin rivers and tributaries, particularly in years of low runoff, 2) high outflows occurring in years of unusually wet years which put the entrapment zone in San Pablo and/or San Francisco bays, 3) entrainment losses to water diversions that result in large numbers of delta smelt pumped through the CVP and SWP plants and reduced population size, 4) changes in food organisms that could increase the potential of larval starvation, 5) toxic substances which could be detrimental but for which there is limited information and 6) loss of genetic integrity due to potential introgression and/or direct competition with the introduced the smelt wakasagi. Data analyses suggested that water flow sets an upper limit on recruitment of smelt each year. The cumulative number of days of reverse flows in the San Joaquin River during spring was always associated with low abundance of delta smelt in Siusun Bay in the fall. Higher outflows favored the development of higher biomasses at all trophic levels in the late spring and led to larger adult populations of smelt in the fall.

Moyle, P.B. et al. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society. 121:67-77.

The delta smelt *Hypomesus transpacificus* is endemic to the upper Sacramento-San Joaquin estuary. It is closely associated with the freshwater-saltwater mixing zone except when it spawns in fresh water. The delta smelt feeds on zooplankton, principally copepods. Its dominant prey was the native copepod *Eurytemora affinis* in 1972-1974 but the exotic copepod *Pseudodiaptomus forbesi* in 1988. Because the delta smelt has a 1-year life cycle and low fecundity, it is particularly sensitive to changes in estuarine conditions. Tow-net and midwater trawl samples showed wide year-to-year fluctuations in population densities. Surveys of different areas showed declines in different years between 1980 and 1983. After 1983, however, all populations remained at very low densities throughout most of the range. The recent decline of delta smelt coincides with an increase in the diversion of inflowing water during a period of extended drought. These conditions have restricted the mixing zone to a relatively small area of deep river channels and, presumably, have increased the entrainment of delta smelt into water diversions.

Nobriga, M. et al. 2000. Environmental factors influencing the distribution and salvage of young delta smelt: A comparison of factors occurring in 1996 and 1999. Interagency Ecological Program 13(2):55-65.

The incidental take of delta smelt is estimated as a part of the ongoing Central Valley Project and State Water Project. Salvage levels of young delta smelt have exceeded incidental take levels every spring and summer since 1994, except in the high spring outflow years 1995 and 1998. The San Joaquin River hydrographs for 1996 and 1999 were unlike the other years examined. In these years, San Joaquin River inflow to the Delta generally ranged over intermediate values (about 4,940 cfs to 15,000 cfs) from late January through late May. In both of these years many adult delta smelt were found in the San Joaquin River but few in the Sacramento River. It is hypothesized that the occurrence of intermediate flows on the San Joaquin River in late winter provided attractive conditions for adult delta smelt moving upstream to spawn. Maintenance of moderate flow levels through spring then provided favorable spawning and juvenile rearing conditions in the central and south Delta. Despite the similar flow pattern between 1996 and 1999, May-August salvage levels at the Delta facilities were significantly higher in 1999 (152,631) than in 1996 (39,712). The protracted spawning and recruitment period in 1999 partly explained the difference in salvage between these years. The rapid warming of delta waters may have caused cessation of spawning or may have greatly reduced egg and larval survival.

Nobriga M. et al. 2001. Spring 2000 Delta smelt salvage and delta hydrodynamics and an introduction to the Delta smelt decision tree. Interagency Ecological Program. Newsletter Spring 2001 14(2):42-46.

San Joaquin River flows during winter and early spring 2000 were similar to other years hypothesized by Nobriga et al. (2000) to attract spawning delta smelt into the Central Delta. Delta smelt salvage quickly exceeded red light levels following the VAMP in 2000 as it has in most recent years. This lends additional support to the hypothesis that the VAMP results in suitable larval rearing conditions within the Central and South Delta as suggested by high subsequent salvage when CVP and SWP exports ramp up after the VAMP. Because delta smelt begins to be counted in salvage statistics when fish reach sizes of about 25 mm, it is conceivable that more fish were entrained as larvae in years prior to VAMP and thus, would not have survived to be reported in salvage statistics.

Periodic Review of the 1995 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary, September 30, 2004. State Water resources Control Board, California Environmental Protection Agency.

A review of the 1995 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary to address changes to the water quality compliance and baseline monitoring program, Delta cross channel gate closures, salmon protection, chloride objectives, Delta outflow, export limits, river flow at Rio Vista and Vernalis (for two periods), and southern Delta electrical conductivity. "This report describes the actions taken by the SWRCB to date for the periodic review of the 1995 Plan and includes staff's recommendations for future actions." (page 10).

Sacramento Fish and Wildlife Office. 2004. 5-year review. *Hypomesus transpacificus* (delta smelt). Notice: Federal Register 68(148):45270-45271 on August 1, 2003.

The current U.S. Fish and Wildlife Service (Service) Recovery Plan (1996) for delta smelt assigned a recovery potential of 2C. A listed species is assigned a recovery priority number from 1 (highest) to 18 (lowest) according to the degree of threats, recovery potential and taxonomic distinctness. In addition, a species' rank may be elevated by adding a C designation to its numerical rank to indicate that there is some degree of conflict between the species' conservation efforts and economic development associated with its recovery. Recovery priority numbers are based on criteria published the Federal Register Notice (48 FR 43098; September 21, 1983). At the time of listing, Delta smelt was under a high degree of threat from the severe 1987-1992 California drought. The species persisted in small numbers and rebounded to pre-decline levels in 1993, suggesting that its recovery potential is fairly high. The subsequent decline in 1994, a critical water year, to a then all-time low annual abundance index of 102 (Fall Midwater Trawl Survey (FMWT)), however, illustrates the high degree of threat that neutralizes gains in abundance that result from good water years. More recent abundance indices have varied, but overall, the trend is still negative.

***Sommer, T. et al. 1997. Resilience of splittail in the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society 126(6):961-976.**

Splittail *Pogonichthys macrolepidotus*, an endemic cyprinid of the Sacramento-San Joaquin Estuary, has been proposed for listing as threatened under the U.S. Endangered Species Act. Almost continuous low outflow conditions in the estuary from 1987 to 1994 led to reduced abundance of young splittails, but adult abundance did not decline consistently except in the downstream portion of the species' range. This range had decreased primarily as a result of historical levee and dam construction but did not appear to have changed substantially in the past 20 years. The distribution of young splittails appears to be relatively plastic on an interannual basis. Evidence of the resilience of the species was seen when high freshwater outflows in extremely wet years (such as 1982, 1983, 1986, and 1995) resulted in high numbers of young splittails. Splittail year-class strength was positively related to freshwater outflow during the spawning season. High outflow inundates the floodplain, which provides spawning, rearing, and foraging habitat. The relatively long life span, high reproductive capacity, and broad environmental tolerances of splittails are contrasted with delta smelt *Hypomesus transpacificus* and longfin smelt *Spirinchus thaleichthys*, other native species of special concern in the system.

***Stevens, D.E. 1977. Striped Bass (*Morone saxatilis*) year-class strength in relation to river flow in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society. 106(1):34-42.**

Striped bass, *M. saxatilis*, abundance indices were developed from 2 analyses of sport-fishing party boat catch statistics for the Sacramento-San Joaquin Estuary. These analyses cover the periods 1938-1954 and 1958-1972. The abundance indices provided evidence that the size of the fishable population fluctuated by a factor of 3.7 during the latter period and that river flows in the first summer of life affected recruitment during both periods.

***Stevens, D.E., Miller, L.W. 1983. Effects of river flow on abundance of young Chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin River System. North American Journal of Fisheries Management 4(4):425-437.**

Annual abundance indices for young fall-run Chinook salmon (*Oncorhynchus tshawytscha*), American shad (*Alosa sapidissima*) and longfin smelt (*Spirinchus thaleichthys*) increased directly with river flow rates during the spawning and nursery periods. Annual abundance of young delta smelt (*Hypomesus transpacificus*) did not vary with river flow.

***Swanson, C. et al. 2000. Comparative environmental tolerances of threatened delta smelt (*Hypomesus transpacificus*) and introduced wakasagi (*H. nipponensis*) in an altered California estuary. Oecologia 123(3):384-390.**

In California's Sacramento-San Joaquin estuary, environmental protection and habitat restoration efforts directed at a threatened native osmerid, the delta smelt (*Hypomesus transpacificus*), are complicated by the presence of a morphologically similar non-native congener, the wakasagi (*H. nipponensis*), transported to the estuary from upstream reservoirs. In order to better define delta smelt critical habitat and to evaluate the potential for habitat overlap by these two species, we compared the tolerances of the two species to temperature, salinity, and water velocity, environmental factors that vary spatially and temporally within the estuary. For fishes acclimated to 17 ^{o}C and fresh water (0 ppt), we measured critical thermal maxima and minima, chronic upper salinity tolerance limits, and critical swimming velocities. Wakasagi had higher critical thermal maxima (29.1 ^{o}C vs. 25.4 ^{o}C for delta smelt), lower critical thermal minima (2.3 ^{o}C vs. 7.5 ^{o}C for delta smelt), higher upper salinity tolerances (26.8 ppt vs. 19.1 ppt for delta smelt), and swam faster (for 6-6.9 cm SL fish, 43.3 cm s^{-1}) vs. 28.2 cm s^{-1} for delta smelt) than delta smelt. This suggests that the wide seasonal and year-to-year fluctuations in temperature, salinity, and flow typical in the estuary would not exclude wakasagi, although their eggs and larvae may be less tolerant. With respect to these factors, the native delta smelt may be at a physiological disadvantage, particularly in habitats with suboptimal environmental conditions, and may be excluded from shallow-water habitat restoration sites, which are characterized by poor circulation, low flows, and more environmentally extreme conditions. The low abundance of wakasagi in the estuary recorded to date may indicate that factors other than temperature, salinity, and flow determine wakasagi distribution.

Unger, P.A. 1994. Quantifying salinity habitat of estuarine species. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary. Newsletter autumn 1994. p.7-10.

Limits of optimal salinity ranges were determined for 10 estuarine species of fish and invertebrates. Optimal salinity was assumed to correspond to the 10th and 90th percentile of salinity distribution of all sampled larvae and juveniles Delta smelt exhibited the narrowest optimum salinity range (0.3-1.8 psu). Regressions of species abundance on optimum salinity area were significant (P= 0.05) or close to significant (P = 0.08) for all species whose limiting life stages inhabit relatively fresh or brackish water and included striped bass, delta smelt, longfin smelt, starry flounder and *Crangon franciscorum*. The optimal salinity habitat range of these species generally increased with increasing flows.

USFWS. 1995. Biological Opinion for Delta Smelt. March 6, 1995. U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office. Sacramento, CA.

The following is a quote from page 26:

"In addition to the degradation and loss of estuarine habitat, the delta smelt has been increasingly subject to entrainment, upstream or reverse flows of waters in the Delta and San Joaquin River, and constriction of low salinity habitat to deep-water river channels of the interior Delta (Moyle ***et al.*** 1992). These adverse conditions are primarily a result of drought and the steadily increasing proportion of river flow being diverted from the Delta by the CVP and SWP (Monroe and Kelly 1992). Figure 4a shows the relationship between the portion of the delta smelt abundance west of the Delta as sampled in the summer townet survey and the natural logarithm of Delta outflow from 1959 to 1988 (DWR and Reclamation 1994). This relationship indicates that the percent of the summer townet index increased dramatically when outflow was between 34,000 and 48,000 cfs placing X2 between Chipps and Roe islands. Placement of X2 at Chipps and Roe islands would duplicate these favorable conditions of distribution into Suisun Bay."

USFWS. 1995A. Working paper on restoration needs: Habitat restoration actions to double natural production of anadromous fish in the Central Valley of California. Volumes 1, 2, 3. May 9, 1995. Prepared for the U.S. Fish and Wildlife Service under the direction of the anadromous Fish Restoration Program. Stockton, CA.

Volumes 1 and 3 summarize the production goals, limiting factors, flows and other restoration actions that AFRP technical teams found necessary to double production of the anadromous fish stocks. Volume 2 identifies historical and existing conditions for anadromous fish and identifies roles of state and federal agencies in managing anadromous fish.

USFWS. 2001. 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. Prepared for the U.S. Fish and Wildlife Service under the direction of the anadromous Fish Restoration Program. Stockton, CA.

A number of specific flow and non-flow actions and evaluations deemed necessary to achieve doubling of anadromous fishes in the Sacramento-San Joaquin watershed are summarized.

USFWS. 2005. Operational Criteria and Plan, Biological Opinion for Delta Smelt. February 16, 2005. U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office. Sacramento, CA.

In-stream flow requirements for the Vernalis from February to June are discussed. Table 5 (p. 59) lists water year class and flows at Vernalis for the February-June period. The VAMP is pulse flow period is discussed with regards to flow objectives and export restrictions (p. 62-63).

The distribution of delta smelt may not always be regulated by X2 since food availability may influence their distribution (p.116). Further, "In addition to the degradation and loss of estuarine habitat, delta smelt have been increasingly subject to entrainment, upstream or reverse flows of waters in the Delta and San Joaquin river, and constriction of low salinity habitat to deep-water channels of the interior Delta (Moyle et al. 1992) (p.120). "For a large part of its annual life span, this species is associated with the freshwater edge of the mixing zone, where the salinity is approximately 2 ppt. (also described as X2) (Ganssle 1966, Moyle et al. 1992, Sweetnam and Stevens 1993). The relationship between the portion of the smelt population west of the Del;ta as sampled in the summer townet survey and the natural logarithm of Delta outflow from 1959 to 1988, indicates the summer townet index increased dramatically when outflow was between 34,000 and 48,000 cubic feet per second, placing X2 between Chipps and roe islands (DWR and Reclamation 1994)." (p.120).

The Summary of the Five Year Review state that "In summary, the threats of the destruction, modification, or curtailment of its habitat or range resulting from extreme outflow conditions, the operations of the State and Federal water projects, and other water diversions as described in the original listing remain." (p.121)

Water Quality Control Plan for the San Francisco Bay/Sacramento - San Joaquin Delta Estuary. 91-15WR. May 1991. Water Resources Control Board, State of California. Page 5-15 through 5-26.

The following is quoted from the paper, page 15;

"Delta outflow objectives are included for the protection of estuarine habitat for anadromous fishes and other estuarine-dependent species. Sacramento and San Joaquin river flow objectives are included to provide attraction and transport flows and suitable habitat for various life stages of aquatic organisms, including delta smelt and Chinook salmon. A narrative objective for salmon protection is included to ensure increased natural production of salmon."

Water Right Decision 1630. San Francisco Bay/Sacramento - San Joaquin Delta Estuary. April 1993. State Water Resources Control Board, California Environmental Protection Agency. Page 27-35.

Section II.C.1. discusses the Bay/Delta Estuary as highly modified, where flows that would be uncontrolled in the winter and spring are now regulated, and the outflow as reduced due to dam construction, upstream storage diversions and exports. The CVP and SWP export pumps cause a net reversal of flow, and when the Delta cross channel gates are open, substantial amounts of the Sacramento River water is diverted into the central Delta, much of the water for exports. "Under high export rates with reduced inflow, the lower San Joaquin River also experiences a net flow reversal, with net movement of water from the lower Sacramento river or Suisun Bay upstream into the central Delta." (page 28).

In section II.C.1.b. the "public trust resources of the Estuary are in a state of decline" (page 30). Fall-run and spring-run Chinook salmon numbers have declined, as well as delta smelt, striped bass, and two species of shrimp. High export rates from the pumping plants especially during April through June are related to substantial losses of juvenile fish. During dry or critically dry years, losses are particularly high. To reduce losses especially during the April through June period, it is recommended that exports be reduced. For winter-run Chinook salmon, the most effective method of protecting these juveniles is to prevent diversion from their migration route February through April.

Section IV.B. discusses fishery management measures in terms of long-term goals to insure that there are sufficient flows through the Delta to transport juvenile fish beyond the effects of the diversion pumping. The use of temporary hatcheries to boost populations where necessary, and upstream measures to ensure survival of salmon eggs, fry, and juvenile.

Section V. discussed the effects on salmon, striped bass, and other estuarine species. Table D lists a smolt survival index for the Sacramento River and the San Joaquin River with or without the barrier.

Water Right Decision 1641. March 15, 2000. State Water Resources Control Board, California Environmental Protection Agency. Page 184.

Delta outflow is referenced to 31 times in the document, particularly with regard to recirculation, the San Joaquin River, VMAP, and the CVP/SWP. The following are a few of the quotes:

> "**11.7.2.3 EFFECTS OF CHANGES IN DELTA OUTFLOW**
> Delta outflow is expected to change with the implementation of the JPOD alternatives but the effects are not expected to be as significant as entrainment effects. Delta outflow generally decreases compared to operation under the D-1485 base case in October, December, and January and generally increases in all other months. (SWRCB 1e, pp. [XIII-64], [XIII-74].)" (page 113).
>
> "For longfin smelt, Sacramento splittail, starry flounder, and *Crangon franciscorum*, abundance indices show significant positive relationships with Delta outflow in the spring months. No significant differences were observed in the modeled abundance of these species between the JPOD alternatives and the D-1485 and 1995 Bay-Delta Plan alternatives. (SWRCB 1e, pp. [XIII-70]-[XIII-72].)" (page 113).
>
> "**13.2 Responsibility for Meeting Flow Objectives**
> The DWR and the USBR currently have the responsibility to meet all the flow-dependent objectives adopted by the SWRCB in the 1978 water quality control plan for the Delta and for Suisun Marsh. This responsibility is pursuant to D-1485 and, for the Vernalis salinity objective, D-1422. Interim SWRCB Order WR 95-6, followed by interim Order WR 98-09, requires the DWR and the USBR to meet some but not all of the changes in the flow-dependent objectives adopted by the SWRCB in the 1995 Bay-Delta Plan. As discussed above, the flow-dependent objectives are to be met through amendments to existing water rights. The DWR and the USBR are meeting the remaining objectives as part of their current obligation under the federal and state Endangered Species Acts. It is in the public interest that these objectives continue to be implemented while the SWRCB conducts further proceedings to reach a final determination as to the responsibilities of

parties to help meet these objectives. Meeting these objectives protects fish and wildlife in the Bay-Delta Estuary, and ensures that water users such as CCWD who divert water from the Delta continue to receive water of adequate quality and quantity. For example, meeting the objectives ensures that water users whose authorization to divert water is dependent on the position of X2 are not prevented from diverting water because of a failure to implement the Delta outflow objective." (page 131-132).

Table 3; section dealing with Delta outflow.

TABLE 3 (continued)
WATER QUALITY OBJECTIVES FOR FISH AND WILDLIFE BENEFICIAL USES

COMPLIANCE LOCATION	INTERAGENCY STATION NUMBER(RKI 1[])	PARAMETER	DESCRIPTION (UNIT) [2]	WATER YEAR TYPE [3]	TIME PERIOD	VALUE
DELTA OUTFLOW						
		Net Delta Outflow Index (NDOI) [7]	*Minimum monthlyaverage [8] NDOI(cfs)*	*All All W,AN*	*Jan Feb-Jun Jul*	*4,500 [9] [10]8,000*
				BN		*6,500*
				D		*5,000*
				C		*4,000*
				W,AN,BN D	*Aug*	*4,000 3,500*
				C		*3,000*
				All W,AN,BN,D	*SepOct*	*3,000 4,000*
				C		*3,000*
				W,AN,BN,D	*Nov-Dec*	*4,500*
				C		*3,500*

3. River Flow Objectives (Rio Vista)

Aasen, G.A. 1999.Juvenile delta smelt use of shallow-water and channel habitats in California's Sacramento-San Joaquin Estuary. California Fish and Game 85(4):161-169.

Juvenile delta smelt, *Hypomesus transpacificus*, densities were significantly greater in shallow water in Honker Bay and Sherman Lake than in adjacent channels in 1993, indicating that they used shallow areas in bay and flooded island environments as nursery habitats. Densities and lengths were significantly greater on high than low tides in shallow water in Honker Bay, but not in the adjacent channel, suggesting that delta smelt moved tidally between Honker Bay and Grizzly bays. Delta smelt densities did not differ between shallow water and channels in the riverine environments of Montezuma Slough, the lower San Joaquin River, and Cache slough, presumably because shallow areas were smaller and no embayments existed to retain delta smelt. Delta smelt may be larger in shallow water in Honker Bay and Sherman Lake because: 1) Fish in shallow water were older and consequently larger or 2) residence time was longer and foraging success was better, resulting in increased growth rates. Availability of shallow habitats to delta smelt increases in high-outflow years when hydrodynamic transport locates the delta smelt population downstream in Siusun, Grizzly, and Honker bays.

Brandes, P.L, and J.S. McLain. 2001. Juvenile Chinook salmon abundance, distribution, and survival in the Sacramento-San Joaquin Estuary. In R.L. Brown (ed.) Contributions to the Biology of Central Valley Salmonids. California Department of Fish and Game. Fish Bulletin 179(2):39-136.

All four races of juvenile Central Valley Chinook salmon migrate through and many rear in the Sacramento-San Joaquin Delta and Estuary. Delta residence and migration is considered important in determining adult production, as it is generally believed that density dependent effects are minimal after this life stage. Populations of winter run and spring run are presently listed as endangered and threatened species, while the remaining populations in the Central Valley are candidate species. Actions in the Delta to improve survival are likely important in the recovery of these depressed populations. The tidally influenced freshwater Delta also is an important area for water management in California, as it is where the Central Valley and State Water Project pump large volumes of water to southern California, the San Joaquin Valley and the Bay area. To document the effect of these various water management activities in the Delta on juvenile salmon, monitoring and special studies have been conducted since the early 1970s to the present. Changes in abundance in the Delta and estuary appear related to flow; high flows increase the use of the Delta and San Francisco Bay by fry. Relative survival of fry appears greater in the upper Sacramento River than in the Delta or bay, especially in the wetter years. Survival appears lower in the Central Delta relative to that in the North Delta in drier years for both fry and smolts. Fall-run smolt and late-fall-run yearling survival studies have found that diversion into the Central Delta via the Delta Cross Channel or Georgiana Slough reduces survival through the Delta. Experiments in the San Joaquin Delta have shown that survival appears greater for smolts that migrate down the mainstem San Joaquin River rather than through upper Old River. A temporary barrier in upper Old River was tested and found to improve survival for smolts originating in the San Joaquin basin. These specific experiments have identified management actions that could improve juvenile salmon survival through the Delta. In addition, indices of annual survival provide a way to compare survival through the Delta and could be used to assess restoration and management actions. This work demonstrates How long-term scientific studies can be applied to address management and restoration issues.

*** Bennett, W. A. and P.B. Moyle. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin Estuary. In pages 519-542. J.T. Hollibaugh (ed.) The San Francisco Bay: The ecosystem. Further investigations into the natural history of San Francisco Bay and Delta with reference to the influence of man. Friesen Printers, Altona, Manitoba.**

Fish populations have declined markedly in the Sacramento-San Joaquin estuary. Evidence of factors contributing to the declining abundance of fishes is reviewed in the context of six pathways by which alteration of freshwater outflow to the estuary affects the survival of larval and juvenile fishes. Specific pathways include: 1) transport and entrainment, 2) retention in and/or advection from preferred habitats, 3) success and effects of invading species, 4) primary production and food web dynamics, 5) dilution and/or flushing of toxic compounds, and 6) the quantity and quality of shallow-water spawning/rearing habitat. Clearly, ameliorating the effects of various factors (e.g., reducing entrainment, toxic runoff, and improving shallow water habitat) will improve conditions for fish. The current lack of life history information and on several of the most affected species and the need to prevent extinctions suggests that the most pragmatic and promising solution is to ensure adequate outflow to the estuary. The simultaneous declines of so many species with different habitat requirements and life history strategies is an indication of broad problems with the estuarine environment, especially in the Delta.

Dege, M. and L.R. Brown. 2004. Effect of Outflow on spring and summertime distribution and abundance of larval and juvenile fishes in the upper San Francisco Estuary. American Fisheries Society Symposium 39:49–65.

Data on spring and summertime larval and juvenile fish distribution and abundance was analyzed in the upper San Francisco Estuary (SFE), California between 1995 and 2001. The upper SFE includes the tidal freshwater areas of the Sacramento–San Joaquin Delta downstream to the euryhaline environment of San Pablo Bay. The sampling period included years with a variety of outflow conditions. Fifty taxa were collected using a larval tow net. Two common native species, delta smelt *Hypomesus transpacificus* and longfin smelt *Spirinchus thaleichthys*, and four common alien taxa, striped bass *Morone saxatilis*, threadfin shad *Dorosoma petenense*, gobies of the genus *Tridentiger*, and yellowfin goby *Acanthogobius flavimanus*, were selected for detailed analysis. Outflow conditions had a strong influence on the geographic distribution of most of the species, but distribution with respect to the 2 psu isohaline (X2) was not affected. The distribution patterns of delta smelt, longfin smelt, and striped bass were consistent with larvae moving from upstream freshwater spawning areas to downstream estuarine rearing areas. There were no obvious relationships of outflow with annual abundance indices. Our results support the idea of using X2 as an organizing principle in understanding the ecology of larval fishes in the upper SFE. Additional years of sampling will likely lead to additional insights into the early life history of upper SFE fishes.

Estuarine Ecology Team. 1997. An assessment of the likely mechanisms underlying the “Fish-X2” relationships. Interagency Ecological Program for the San Francisco Bay/Delta Estuary. Technical Report 52.

The effect of X2 on delta smelt entrainment losses are very well documented. In low outflow years, delta smelt may exhibit a higher probability of entrainment mortality of larvae, juveniles and adults at SWP, CVP, PG&E and agricultural diversions. Other less well documented, yet presumably important effects of X2 on delta smelt, include: 1) increase spawning habitat. The amount of flooded vegetation increases with increasing outflow, 2) increased co-occurrence of young delta smelt with food organisms. There is a significant relationship between delta smelt year-class strength and the amount of time during spring X2 is located in Siusun Bay. Other factors may be operating in some years as well, 3) more suitable habitat for larvae and juveniles may occur when X2 is located downstream in Siusun Bay, which supplies substantially more shallow water habitat than the river channels upstream, 4) reduced probability of encounter with predators. Annual delta smelt year classes exhibit a significant negative association with the abundance of the non-native predator inland silverside in years when X2 is located upstream during spring, 5) entrapment zone (EZ) residence time. Overall, food for larval and juvenile delta smelt is higher near the upstream end of the EZ. When X2 is positioned in Siusun Bay, a higher proportion of the larval population occurs in the EZ, 6) delta smelt may also reside longer in Siusun Bay if they are transported there earlier by higher flows and 7) higher production of food. The abundance of many food organisms for delta smelt larvae and juveniles is affected by mean X2 during spring. Thus, overall growth and condition of delta smelt may be better in higher outflow years.

Jassby, A. et al. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5:272-289.

Populations of native and introduced aquatic organisms in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary ("Bay/Delta") have undergone significant declines over the past two decades. Decreased river inflow due to drought and increased freshwater diversion have contributed to the decline of at least some populations. Effective management of the estuary's biological resources requires a sensitive indicator of the response to freshwater inflow that has ecological significance, can be measured accurately and easily, and could be used as a "policy" variable to set standards for managing freshwater inflow. Positioning of the 2ppt (grams of salt per kilogram of seawater) bottom salinity value along the axis of the estuary was examined for this purpose. The 2ppt bottom salinity position (denoted by X2) has simple and significant statistical relationships with annual measures of many estuarine resources, including the supply of phytoplankton and phytoplankton-derived detritus from local production and river loading; benthic macroinvertebrates (molluscs); mysids and shrimp; larval fish survival; and the abundance of planktivorous, piscivorous, and bottom-foraging fish. The actual mechanisms are understood for only a few of these populations. X2 also satisfies other recognized requirements for a habitat indicator and probably can be measured with greater accuracy and precision than alternative habitat indicators such as net freshwater inflow into the estuary. The 2ppt value may not have special ecological significance for other estuaries (in the Bay/Delta, it marks the locations of an estuarine turbidity maximum and peaks in the abundance of several estuarine organisms), but the concept of using near-bottom isohaline position as a habitat indicator should be widely applicable. Although X2 is a sensitive index of the estuarine community's response to net freshwater inflow, other hydraulic features of the estuary also determine population abundances and resource levels. In particular, diversion of water for export from or consumption within the estuary can have a direct effect on population abundance independent of its effect on X2. The need to consider diversion, in addition to X2, for managing certain estuarine resources is illustrated using striped bass survival as an example. The striped bass survival data were also used to illustrate a related important point: incorporating additional explanatory variables may decrease the prediction error for a population or process, but it can increase the uncertainty in parameter estimates and management strategies based on these estimates. Even in cases where the uncertainty is currently too large to guide management decisions, an uncertainty analysis can identify the most practical direction for future data acquisition. Although delta smelt distribution is determined by X2, a delta smelt abundance index based on the fall mid water trawl did not exhibit a statistical verifiable relation with X2 and an effect of X2 position on the abundance of delta smelt was not ruled out. X2 role may simply be masked by the effect of additional mechanisms or delta smelt respond to other function of X2, rather than the April-July averaging period used.

***Herbold, B. and P.B. Moyle. 1989. Ecology of the Sacramento-San Joaquin Delta: A community profile. Biological Report. U.S. Fish and Wildlife Service. 120 pp.**

The report describes an ecosystem significantly different from other delta ecosystems in North America. The Sacramento-San Joaquin Delta is one of the 60 largest river deltas in the world and is the largest river delta on the west coast. As the hub of California's water system, the delta is of immense municipal, agricultural, and industrial importance. The amount of freshwater that flows through the delta controls the delta's productivity and regulates the life cycles of many of its organisms. The vast estuary of the Sacramento and San Joaquin Rivers is one of the most highly modified and intensively managed estuaries in the world.

Kimmerer, W.J. 2002A. Effect of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Marine Ecology Progress Series 243: 39-55.

All ecosystems are influenced by physical forcing. Estuarine ecosystems respond most strongly on an interannual timescale to variability in freshwater flow. Several mechanisms for positive or negative flow effects on biological populations in estuaries have been proposed; however, positive effects appear to operate mainly through stimulation of primary production with effects propagating up the food web. In the northern San Francisco Estuary, abundance or survival of several common species of fish and shrimp varied positively with flow-in data through 1992. I re-examined these relationships and those of several additional taxa in an analysis of long-term (20 to 40 yr) monitoring data. The spread of the introduced clam *Potamocorbula amurensis* in 1987 provided an opportunity to examine simultaneously the responses of estuarine species to flow and to changes in the food web. I separated variability into a flow response, a step change after 1987 and other sources of variability. Responses of fish and shrimp contrasted with those of lower trophic levels. All but 1 species of nekton responded positively to flow, only 2 had clear declines after 1987, and none of the relationships changed in slope after 1987. In contrast with the higher trophic levels, chlorophyll *a* (chl *a*) and several species of zooplankton declined markedly after 1987, and had either weak responses to flow or responses that changed after 1987. Thus, the food web appears strongly coupled between benthos and plankton, and weakly coupled between zooplankton and fish, as has been found in other systems. More importantly, the variation with freshwater flow of abundance or survival of organisms in higher trophic levels apparently did not occur through upward trophic transfer, since a similar relationship was lacking in most of the data on lower trophic levels. Rather, this variation may occur through attributes of physical habitat that vary with flow.

Kimmerer, W.J. 2002B. Physical, biological, and management responses to variable freshwater flow into the San Francisco Estuary. Estuaries 25, 6B:1275–1290.

Freshwater flow is the principal cause of physical variability in estuaries and a focus of conflict in estuaries where a substantial fraction of the freshwater is diverted. Variation in freshwater flow can have many effects: inundation of flood plains, increase loading and advective transport of materials and organisms, dilution or mobilization of contaminants, compression of the estuarine salinity field and density gradient, increase in stratification, and decrease in residence time for water while increasing it for some particles and biota. In the San Francisco Estuary, freshwater flow is highly variable, and has been altered by shifts in seasonal patterns of river flow and increases in diversions from tidal and nontidal regions, entraining fish of several species of concern. Abundance or survival of several estuarine-dependent species also increases with freshwater outflow. These relationships to flow may be due to several potential mechanisms, each with its own locus and period of effectiveness, but no mechanism has been conclusively shown to underlie the flow relationship of any species. Several flow-based management actions were established in the mid-1990s, including a salinity standard based on these flow effects, as well as reductions in diversion pumping during critical periods for listed species of fish. The effectiveness of these actions has not been established. To make the salinity standard more effective and more applicable to future estuarine conditions will require investigation to determine the underlying mechanisms. Effects of entrainment at diversion facilities are more straightforward conceptually but difficult to quantify, and resolving these may require experimental manipulations of diversion flow.

Kimmerer, W. 2004. Open Water Processes of the San Francisco Estuary: From Physical Forcing to Biological Responses. San Francisco Estuary & Watershed Science 2(1): 142 p.

This paper reviews the current state of knowledge of the open waters of the San Francisco Estuary. This estuary is well known for the extent to which it has been altered through loss of wetlands, changes in hydrography, and the introduction of chemical and biological contaminants. It is also one of the most studied estuaries in the world, with much of the recent research effort aimed at supporting restoration efforts. The conceptual foundations for our current understanding of estuarine dynamics are emphasized, particularly those aspects relevant to restoration. Four themes run throughout this paper. 1) the critical role physical dynamics play in setting the stage for chemical and biological responses. Physical forcing by the tides and by variation in freshwater input combine to control the movement of the salinity field, and to establish stratification, mixing, and dilution patterns throughout the estuary. Many aspects of estuarine dynamics respond to interannual variation in freshwater flow; in particular, abundance of several estuarine-dependent species of fish and shrimp varies positively with flow, although the mechanisms behind these relationships are largely unknown. 2) the importance of time scales in determining the degree of interaction between dynamic processes. Physical effects tend to dominate when they operate at shorter time scales than biological processes; when the two time scales are similar, important interactions can arise between physical and biological variability. These interactions can be seen, for example, in the response of phytoplankton blooms, with characteristic time scales of days, to stratification events occurring during neap tides, 3) the key role of introduced species in all estuarine habitats; particularly noteworthy are introduced waterweeds and fishes in the tidal freshwater reaches of the estuary, and introduced clams there and in brackish water, and 4) the rather heterogeneous set of results from monitoring and research in the estuary. For example, some topics have been subjects of intense activity both in research and monitoring (e.g., physical dynamics of the upper estuary, phytoplankton blooms), while others have received little attention (e.g., microzooplankton). In addition, both research and monitoring have emphasized some regions of the estuary (e.g., the Sacramento-San Joaquin Delta) over others (e.g., San Pablo Bay). In addition, ecological modeling and synthesis has emphasized lower trophic levels over higher. Opportunities for restoration in the open waters of the estuary are somewhat limited by the lack of scientific basis for restoration, and the difficulty in detecting ecosystem responses in the context of high natural variability.

***Kjelson, M.A. and P.F. Raquel. 1981. The life history of fall run juvenile Chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento-San Joaquin Estuary of California. Estuaries 4(3):285.**

Juvenile salmon studies emphasize the significance of estuarine rearing, analysis of water development project impacts, and identification of salmon water quality and flow needs. Young Chinook utilize San Francisco Bay and the upper estuary (Delta) for both rearing and seaward migration. Major recruitment of fry (30 to 50 mm) to the estuary begins in January with peak abundance in March and rearing occurs between January and June. Growth rate ranges from 0.5 to 1.3 mm per day. The timing and quantity of inflow to the Delta appears to determine the distribution and number of fry reared in the estuary and the survival of smolts. Peak migration of smolts (70 to 80 mm) occurs in May and June. Smolt migration rates range from 8 to 24 km per day. Major food items observed in juvenile Chinook vary between the freshwater (cladocera, diptera) and saline (copepods, amphipods, fish larvae) portions of the estuary.

Kjelson, M.A. et al. 1982. Life history of fall-run juvenile Chinook salmon, *Oncorhynchus tshawystscha* in the Sacramento-San Joaquin Estuary, California. In: pages 393-411. V.S. Kennedy (Ed.) Estuarine Comparisons. Academic Press Inc.

Fall-run Chinook salmon is the dominant run of this species in the Sacramento-San Joaquin Estuary and utilize the estuary for rearing and migration. Brackish water bays are used primarily as a migration corridor by smolts. Fry abundance and distribution in the estuary are influenced by the magnitude and timing of river flows. Survival during smolt outmigration is greater in the lower bays than in the Delta. Survival through the Delta in June is inversely related to water temperature and directly related to river flows which is consistent with observations in other northern estuaries. Alteration of the timing, magnitude and distribution of flow in the Sacramento San Joaquin Estuary has a major impact on juvenile Chinook salmon survival.

Kjelson, M.A. and P.L. Brandes. 1989. The use of smolt survival estimates to quantify the effects of habitat changes on salmonid stocks in the Sacramento-San Joaquin rivers, California. Canadian Special Publication. Fisheries and Aquatic Sciences. 105:100-115.

Mark-recapture studies of smolt survival in the Sacramento-San Joaquin Delta of California provides empirical data on the effects of water development on fall-run Chinook salmon. Recoveries of coded-wire tagged hatchery fish from the ocean troll fishery and estuarine trawling yielded two survival measures that were positively correlated (r = 0.90). Smolt survival from both measures were highly correlated to river flow, temperature, and percent diversion. Survival of fish exposed to diversion was about 50% less than those not exposed. Estuarine survival has decreased a minimum of 30% in the past 70 yr. Spawner escapements in the Central Valley are positively correlated to flow during their spring smolt outmigration suggesting that flow alteration in upstream and estuarine habitats at that time influences adult stock production.

***Meng, L et al. 1994. Changes in abundance and distribution of native and introduced fishes of Suisun Marsh. Transactions of the American Fisheries Society 123(4): 498-507.**

Overall fish abundance, abundance of introduced, native, and seasonal fish groups, and species diversity declined over a 14-year period in Suisun Marsh, a portion of the San Francisco Bay estuary, and were associated with decreases in freshwater outflow and increases in salinity.

Fish groups showed different patterns of abundance; large fluctuations in introduced and seasonal fish groups contrasted with a steady decline in native fish. Mixed groups of native and introduced species with similar freshwater and seasonal needs reflected effects of drought and increasing water diversions from the estuary. Chameleon goby and yellowfin goby, two introduced species, fluctuated greatly in abundance in recent years, whereas other species declined steadily. Changes in fish abundance in the marsh reflect estuary-wide changes and suggest that environmental disturbances coupled with introduced species are altering fish communities and hastening native fish declines.

***Meng, L. and P.B. Moyle. 1995. Status of splittail in the Sacramento-San Joaquin Estuary Transactions of the American Fisheries Society 124(4):538-549.**

Extensive fish surveys in the Sacramento-San Joaquin estuary indicated that splittail *Pogonichthys macrolepidotus*, endemic to the Central Valley of California, declined by 62% over a 13-year period. Splittails migrate into freshwater to spawn and river outflow carries juveniles into productive, shallow, low-salinity areas downstream. The high correlation of abundance of young with river outflow (average $r^2 = 0.60$) and a weak stock-recruitment relationship ($r^2 = 0.22$) indicate that spawning success depends on favorable environmental conditions created by high outflows, such as the number of days that lowland areas remain flooded in the spring. Splittails prefer shallow, low-salinity habitats. The reductions in splittail abundance and range and the movements and habitat preferences of splittail young and adults correspond to trends and habits of two other species characteristic of the estuary, delta smelt and longfin smelt. The largest threats to these three species are changes in water management and increases in water diversions that reduce spawning and rearing areas and other low-salinity habitats in Suisun Bay.

***Meng, L. and Matern, S.A. 2001. Native and introduced larval fishes of Suisun Marsh, California: The Effects of Freshwater Flow. Transactions of the American Fisheries Society 130(5):750-765.**

Fish larvae were sampled weekly in Suisun Marsh in the San Francisco Estuary from February to June each year from 1994 to1999. Catch was predominantly composed of the non-native shimofuri goby *Tridentiger bifasciatus* (60%) and the native prickly sculpin *Cottus asper* (33%). A group of native fishes (prickly sculpin, Sacramento sucker, threespine stickleback, longfin smelt, and splittail) were associated with the cool temperatures and higher outflows characterizing early-season conditions in Suisun Marsh. In contrast, a group of introduced species (shimofuri goby, inland silverside *Menidia beryllina*, striped bass *Morone saxatilis*, and threadfin shad) were associated with the warm temperatures and lower outflows that characterize late-season marsh conditions. Delta smelt catches overlapped temporally and spatially with catches of the introduced wakasagi. Sacramento splittail catches were confined mostly to 1995, a year when high flows peaked during their spawning season in March and April. Results suggest that temperature and interannual variations in freshwater flow are important for determining habitat quality for native and introduced larval fishes. Mimicking natural flow regimes in this highly regulated system is important for early life stages of native fishes.

Moyle, P.B. and B. Herbold. 1989. Status of the delta smelt, *Hypomesus transpacificus*. Final Report to U.S. Fish and Wildlife Service. Department of Wildlife and Fisheries Biology, University of California, Davis: 1-19 + Appendix.

Delta smelt was once one of the commonest pelagic fish in the upper Sacramento-San Joaquin estuary. Since 1982 the population is at its lowest level ever recorded. Reasons for its decline are probably multiple and synergistic, including: 1) reduction of outflows resulting from increased water diversions in the Sacramento and San Joaquin rivers and tributaries, particularly in years of low runoff, 2) high outflows occurring in years of unusually wet years which put the entrapment zone in San Pablo and/or San Francisco bays, 3) entrainment losses to water diversions that result in large numbers of delta smelt pumped through the CVP and SWP plants and reduced population size, 4) changes in food organisms that could increase the potential of larval starvation, 5) toxic substances which could be detrimental but for which there is limited information and 6) loss of genetic integrity due to potential introgression and/or direct competition with the introduced the smelt wakasagi. Data analyses suggested that water flow sets an upper limit on recruitment of smelt each year. The cumulative number of days of reverse flows in the San Joaquin River during spring was always associated with low abundance of delta smelt in Siusun Bay in the fall. Higher outflows favored the development of higher biomasses at all trophic levels in the late spring and led to larger adult populations of smelt in the fall.

Moyle, P.B. et al. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society. 121:67-77.

The delta smelt *Hypomesus transpacificus* is endemic to the upper Sacramento-San Joaquin estuary. It is closely associated with the freshwater-saltwater mixing zone except when it spawns in fresh water. The delta smelt feeds on zooplankton, principally copepods. Its dominant prey was the native copepod *Eurytemora affinis* in 1972-1974 but the exotic copepod *Pseudodiaptomus forbesi* in 1988. Because the delta smelt has a 1-year life cycle and low fecundity, it is particularly sensitive to changes in estuarine conditions. Tow-net and midwater trawl samples showed wide year-to-year fluctuations in population densities. Surveys of different areas showed declines in different years between 1980 and 1983. After 1983, however, all populations remained at very low densities throughout most of the range. The recent decline of delta smelt coincides with an increase in the diversion of inflowing water during a period of extended drought. These conditions have restricted the mixing zone to a relatively small area of deep river channels and, presumably, have increased the entrainment of delta smelt into water diversions.

Periodic Review of the 1995 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary, September 30, 2004. State Water resources Control Board, California Environmental Protection Agency.

A review of the 1995 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary to address changes to the water quality compliance and baseline monitoring program, Delta cross channel gate closures, salmon protection, chloride objectives, Delta outflow, export limits, river flow at Rio Vista and Vernalis (for two periods), and southern Delta electrical conductivity. “This report describes the actions taken by the SWRCB to date for the periodic review of the 1995 Plan and includes staff’s recommendations for future actions.”

Sacramento Fish and Wildlife Office. 2004. 5-year review. *Hypomesus transpacificus* (delta smelt). Notice: Federal Register 68(148):45270-45271 on August 1, 2003.

The current U.S. Fish and Wildlife Service (Service) Recovery Plan (1996) for delta smelt assigned a recovery potential of 2C. A listed species is assigned a recovery priority number from 1 (highest) to 18 (lowest) according to the degree of threats, recovery potential and taxonomic distinctness. In addition, a species' rank may be elevated by adding a C designation to its numerical rank to indicate that there is some degree of conflict between the species' conservation efforts and economic development associated with its recovery. Recovery priority numbers are based on criteria published the Federal Register Notice (48 FR 43098; September 21, 1983). At the time of listing, delta smelt was under a high degree of threat from the severe 1987-1992 California drought. The species persisted in small numbers and rebounded to pre-decline levels in 1993, suggesting that its recovery potential is fairly high. The subsequent decline in 1994, a critical water year, to a then all-time low annual abundance index of 102 (Fall Midwater Trawl Survey (FMWT)), however, illustrates the high degree of threat that neutralizes gains in abundance that result from good water years. More recent abundance indices have varied, but overall, the trend is still negative.

Unger, P.A. 1994. Quantifying salinity habitat of estuarine species. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary. Newsletter Autumn 1994. p.7-10.

Limits of optimal salinity ranges were determined for 10 estuarine species of fish and invertebrates. Optimal salinity was assumed to correspond to the 10th and 90th percentile of salinity distribution of all sampled larvae and juveniles Delta smelt exhibited the narrowest optimum salinity range (0.3-1.8 psu). Regressions of species abundance on optimum salinity area were significant ($P = 0.05$) or close to significant ($P = 0.08$) for all species whose limiting life stages inhabit relatively fresh or brackish water and included striped bass, delta smelt, longfin smelt, starry flounder and *Crangon franciscorum*. The optimal salinity habitat range of these species generally increased with increasing flows.

USFWS. 1995. Biological Opinion for Delta Smelt. March 6, 1995. U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office. Sacramento, CA.

The following quote is from page 12:

"Mitigation measures proposed by Reclamation and DWR to the Service (1993e) that were implemented to benefit the delta smelt included: (1) no reverse flow in the western Delta, based on the 14-day running average of the QWEST index, from May 1 through June 30; (2) the flow in the western Delta shall exceed negative 1,000 cfs from July 1 through July 31, and negative 2,000 cfs from December 1 through January 31; (3) springtime pulse flows were required from both the Sacramento and San Joaquin rivers to help transport larval delta smelt through the Delta and into Suisun Bay; (4) for Sacramento River at Freeport, Rio Vista, and Chipps Island, minimum daily flows were set for March through August and December through February 15; (5) CVP and SWP reduced combined Delta exports at Tracy and Banks to a daily average of not more than 1,500 cfs during the period April 26 through May 16, or coincident with the arrival of the San Joaquin pulse flows in the Delta; (6) for combined Delta pumping at Tracy, Banks and Contra Costa, the 14-day running average export rate was set from April through July; and (7) the CVP and SWP were operated to maintain the salinity regime in eastern Suisun Bay to provide a 14-day running average electro-conductivity (EC) of 3 mmhos per centimeter (mmhos/cm) at Mallard Slough from May 1 to June 30."

USFWS 1995A. Working paper on restoration needs: Habitat restoration actions to double natural production of anadromous fish in the Central Valley of California. Volumes 1-3. May 9, 1995. Prepared for the U.S. Fish and Wildlife Service under the direction of the anadromous Fish Restoration Program. Stockton, CA.

Volumes 1 and 3 summarize the production goals, limiting factors, flows and other restoration actions that AFRP technical teams found necessary to double production of the anadromous fish stocks. Volume 2 identifies historical and existing conditions for anadromous fish and identifies roles of state and federal agencies in managing anadromous fish.

USFWS. 2001. 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. Prepared for the U.S. Fish and Wildlife Service under the direction of the anadromous Fish Restoration Program. Stockton, CA.

A number of specific flow and non-flow actions and evaluations deemed necessary to achieve doubling of anadromous fishes in the Sacramento-San Joaquin watershed are summarized.

Water Right Decision 1641. March 15, 2000. State Water Resources Control Board, California Environmental Protection Agency. Page 184.

Therefore, on an interim basis, this decision requires that the DWR and the USBR meet all flow-dependent numeric objectives in the 1995 Bay-Delta Plan that are not assigned to other parties. This includes the Delta outflow objectives and the flow objectives at Rio Vista on the Sacramento River, and requires the USBR to meet the flow objectives at Vernalis except for the April/May pulse flows, which are addressed elsewhere in this decision.

Licensee/Permittee shall ensure that the water quality objectives for Delta outflow and for Sacramento River flow at Rio Vista for fish and wildlife beneficial uses as set forth in Table 3, attached, are met on an interim basis, not later than November 30, 2001, until the Board adopts a further decision in the Bay-Delta Water Rights Hearing assigning responsibility for meeting these objectives.

Table 3; section dealing with Rio Vista

TABLE 3 (continued)
WATER QUALITY OBJECTIVES FOR FISH AND WILDLIFE BENEFICIAL USES

COMPLIANCE LOCATION	INTERAGENCY STATION NUMBER(RKI 1[])	PARAMETER	DESCRIPTION (UNIT) [2]	WATER YEAR TYPE [3]	TIME PERIOD	VALUE
RIVER FLOWS						
Sacramento River at Rio Vista D-24 (RSAC101)		*Flow rate*	*Minimum monthlyaverage [11] flow rate (cfs)*	*All W,AN,BN,D C W,AN,BN,D*	*SepOct Nove-Dec*	*3,000 4,000 3,000 4,500*