Reference No. 6

DRAFT

EVALUATION OF FACTORS POTENTIALLY LIMITING AQUATIC SPECIES ABUNDANCE AND DISTRIBUTION IN THE SAN FRANCISCO BAY/SACRAMENTO - SAN JOAQUIN ESTUARY

Prepared for

The California Urban Water Agencies
Sacramento, California

By

R2 Resource Consultants, Inc.
Dudley W. Reiser, Ph.D,
Ed Connor,
and Karee Oliver

March 7, 1994

NOTICE

This draft report was prepared as a technical document for reference use by California Urban Water Agencies and others in preparing their comments to the US Environmental Protection agency on "Water Quality Standards for Surface Waters of the Sacramento River, San Joaquin River, and San Francisco Bay and Delta of the State of California, January 6, 1994." This draft technical report is not part of the CUWA formal comment to EPA.

EXECUTIVE SUMMARY

Since the inception of the Bay-Delta Project in 1986 and the formal recognition of the San Francisco Estuary Project (SFEP) in 1987, several detailed assessments have identified a number of factors that have a major influence on the biological health of the Bay and Delta. Recognizing that no single factor controls the existing populations of aquatic organisms, or is singly responsible for apparent declines in historic populations, the SFEP participants identified five broad issues and prepared detailed summary documents that described the status and trends of each of these major factors. These reports serve to describe a myriad of factors, both man-induced and natural that shape the biological, physical, chemical and hydrological characteristics of the Bay and Delta.

Because of the complexity of the Bay-Delta ecosystem, there was no attempt as part of those studies to apportion specific resource injuries or impacts ascribable to a given factor. Thus, although the reviews identified ongoing problems, there was no quantitative assessment of the relative impact each factor has on the aquatic resources in the Bay and Delta. Moyle (1992), in written testimony before the State Water Resources Control Board, classified potential factors causing the decline in Delta biota into 12 categories. These included: outside factors, natural factors, increased water clarity, decreased nutrients from sewage, pollution from toxic compounds, decreased reproductive ability, exploitation, predation, invasions by introduced species, entrainment in power plants, entrainment in diversions with the Delta, and removal of fresh water by SWP and CVP operations. In short, the Bay and Delta have been and continue to be subjected to an ever changing set of conditions, some transitory (e.g., water quality) and some permanent or semi-permanent (reservoir developments, wetland losses), which collectively operate on the aquatic ecosystem. In space and time, such conditions may favor one assemblage of organisms over another, resulting in changes in species abundance and composition.

It is unreasonable to place the entire burden for protecting or restoring the Bay-Delta system on one user group, when other factors influence resource conditions. This document serves to review and discuss a variety of factors other than fresh water diversions that may currently influence or in some way affect the aquatic resources in the Bay-Delta. The review was completed to address the underlying question of the likelihood that the proposed EPA salinity standard would or would not achieve the stated objective of restoring habitat conditions and species abundances to late 1960s-early 1970s levels.

Based on our evaluation, we have concluded that there are other factors (e.g., introduced species, upstream effects) which will continue to impact the populations of Bay-Delta species even with the X2 standard imposed. These, either singly or in combination, may prevent or limit the biological responses achievable through the manipulation of salinity. Because of the high water costs associated with meeting the standard, a more detailed analysis is recommended to evaluate the overall benefits to the resource attainable through its promulgation.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Since the inception of the Bay-Delta Project in 1986 and the formal recognition of the San Francisco Estuary Project in 1987 (as part of the National Estuary Program developed by the EPA), there have been a number of detailed assessments completed focused on various factors identified as having a major influence on the health of the Bay and Delta. These assessments were consistent with the overall objectives of the SFEP which were to:

* *Develop a comprehensive understanding of environmental and public health values;*

* *Achieve effective, united, and ongoing management of the Bay and Delta;*

* *Develop a Comprehensive Conservation and Management Plan to restore and maintain the chemical, physical, and biological integrity of the Bay and Delta focused on restoration of shellfish, fish, and wildlife and maintenance of recreational activities; and*

* *Recommend priority corrective actions and compliance schedules addressing point and non-point sources of pollution, to include short- and long-term components based on best scientific information available (Monroe and Kelly, 1992).*

Recognizing that no single factor was controlling the existing populations of aquatic biota, or was singly responsible for apparent declines in historic populations, the SFEP participants identified five broad issues which they believed the program should address (Monroe and Kelly 1992). These included: 1) intensified land use; 2) decline of biological resources; 3) freshwater diversion and altered flow regime; 4) increased pollutants; and 5) increased dredging and waterway modification. In response, the SFEP prepared the following detailed summary documents which described the status and trends of each of these major factors:

- Status and Trends Report on Land Use and Population: The Geomorphology, Climate, Land Use and Population Patterns in the San Francisco Bay, Delta and Central Valley Drainage Basins (Perkins et al. 1991)

- Status and Trends Report on Aquatic Resources in the San Francisco Estuary (Herbold et al. 1992)

- Status and Trends Report on Pollutants in San Francisco Estuary (Davis et al. 1991)

- Status and Trends Report on Wetlands and Related Habitats in the San Francisco Estuary (Meiorin et al. 1991)

- Status and Trends Report on Dredging and Waterway Modification in the San Francisco Estuary (Gunther et al. 1990)

These reports served to describe the myriad of factors, both man-induced and natural that have served to shape the existing biological, physical, chemical and hydrological characteristics of the Bay and Delta. These were summarized by Monroe and Kelly (1992) in their report:

- State of the Estuary, a Report on Conditions and Problems in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary.

Because of the complexity of the ecosystem, there was no attempt as part of those studies to apportion specific resource injuries ascribable to a given factor. Thus, even though the Status and Trends reviews identified ongoing problems, there was no quantitative assessment of the relative impact each of the factors was having on the aquatic resources in the Bay and Delta. This is unfortunate since it is just this kind of apportionment process that is needed so that all parties responsible for the existing conditions can be identified and ultimately share in the costs of restoring the ecosystem to an acceptable baseline condition. It is unreasonable to place the entire burden for protecting or restoring the system on one user group, when other factors are known to be influencing the resource condition. This is especially true if the constraints imposed are founded on data which are equivocal relative to the relationships they profess to show (See R2 1994a). Figure 1 depicts some of the factors and processes that are presently influencing the health and productivity of the Bay-Delta aquatic ecosystem. Some of these are interdependent such as hydrologic regime, outflow, and salinity; some are independent such as introduced species and fishing exploitation.

This document summarizes the impacts most often cited by agencies and researchers as being contributory to the overall condition of the Bay-Delta ecosystem. It is not the intent of this document to provide a comprehensive statistical analysis of these factors or to define their relationship to the abundance of aquatic biota in the system. Rather, the materials are presented to illustrate that other factors unrelated to flow exports are indeed operating in the Bay and Delta. Some statistical correlations are presented in Section 13, where data were available over comparable time periods as fish species abundance information. These serve to demonstrate that certain factors can explain some of the variability in the trends in species abundance.

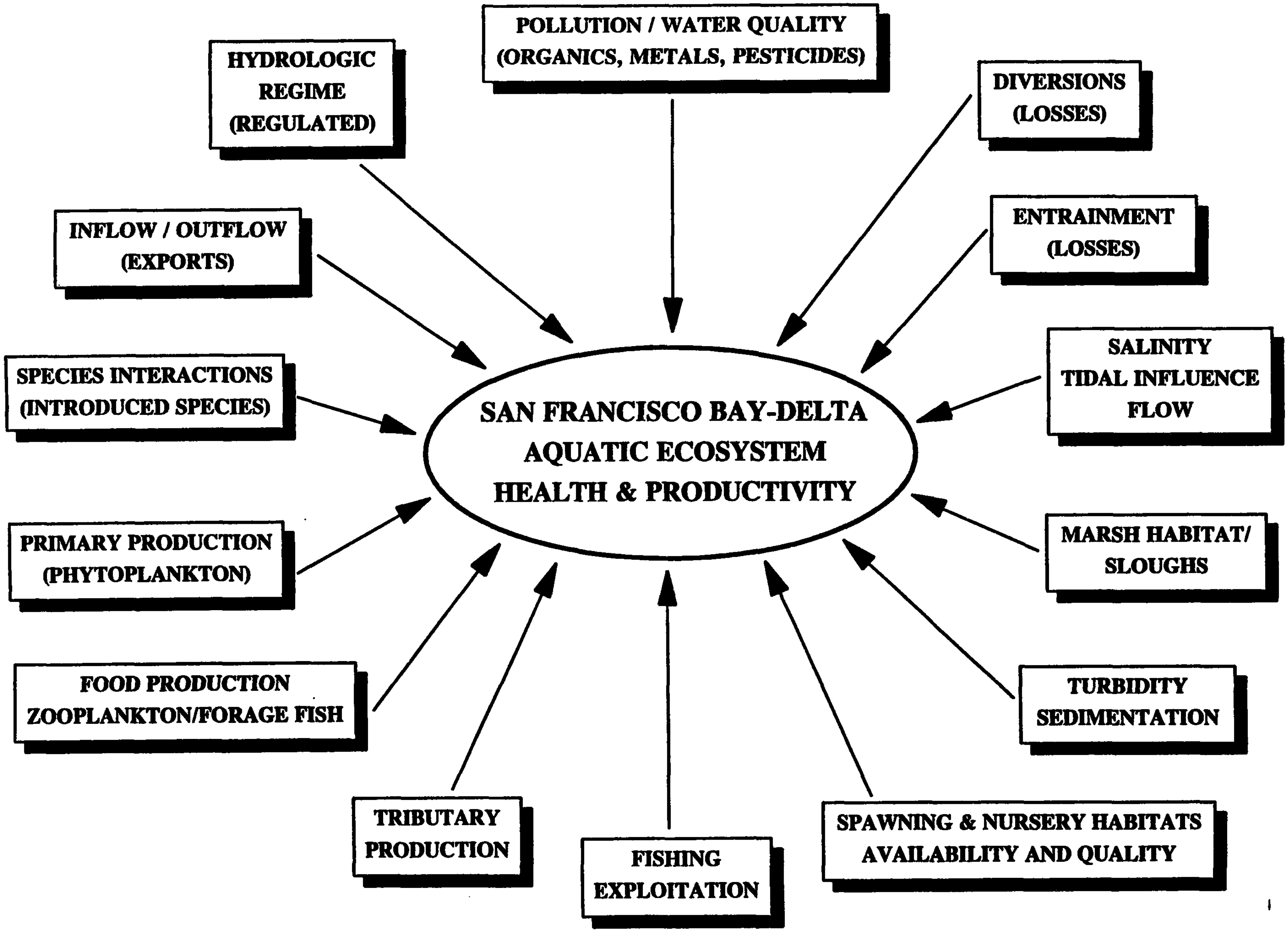


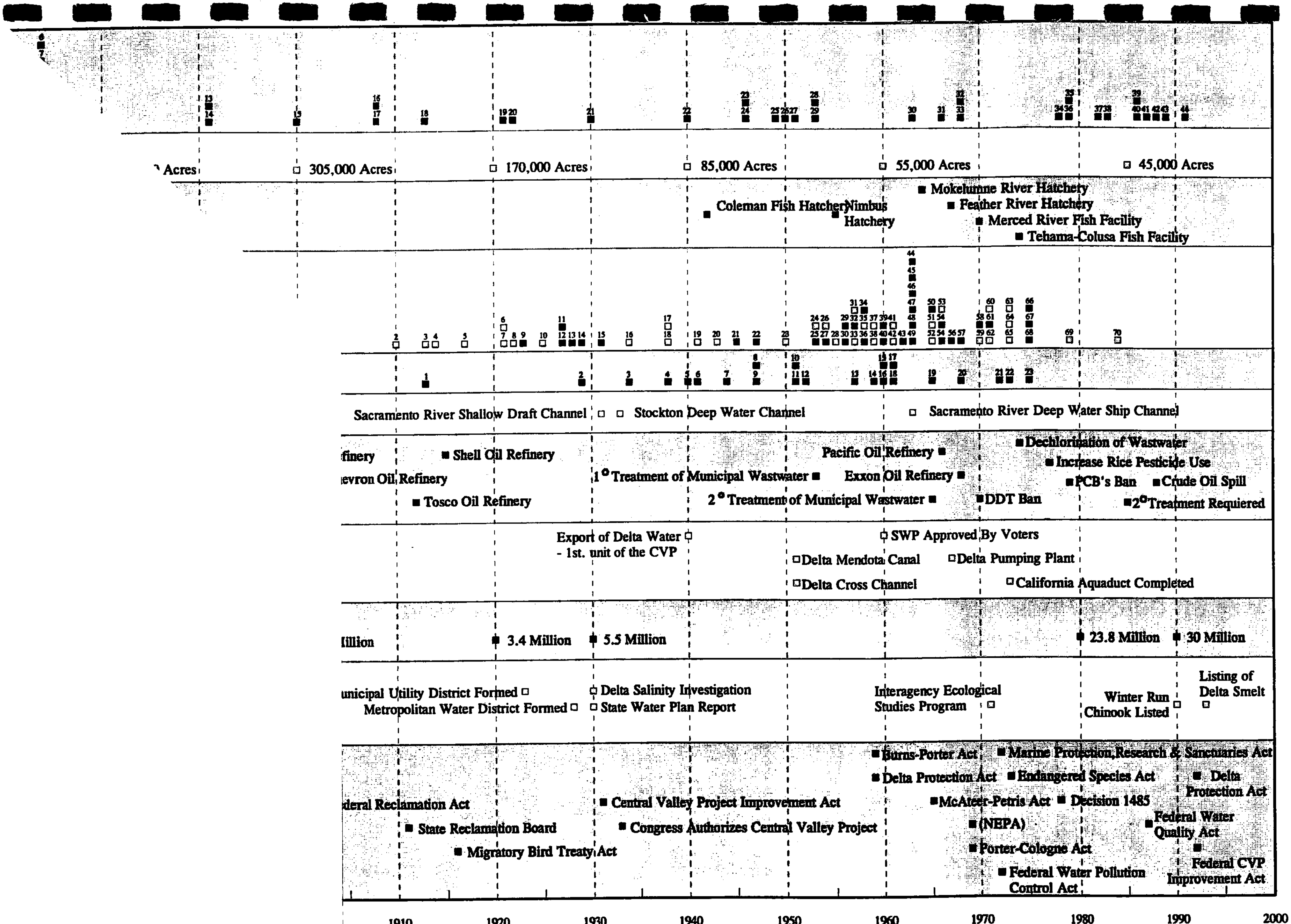
Figure 1. Factors and processes affecting the biological resources of the San Francisco/Sacramento-San Joaquin Estuary.

Moyle (1992), in written testimony before the State Water Resources Control Board classified potential factors causing the decline in Delta biota into 12 categories. These included: outside factors, natural factors, increased water clarity, decreased nutrients from sewage, pollution from toxic compounds, decreased reproductive ability, exploitation, predation, invasions by introduced species, entrainment in power plants, entrainment in diversions with the Delta, and removal of fresh water by SWP and CVP operations. These are discussed in this report, although several have been combined into a single category, e.g., sewage and toxic compounds are discussed in a single section - Pollution.

2.0 LEGISLATION AND ENVIRONMENTAL PROTECTION

Figure 2 depicts a timeline of developments, legislative actions and Bay/Delta characteristics since the mid-1800s. This provides a means for evaluating relatively recent biological changes in the Bay (within the last 30 years) within the context of historical development. Apparent in this figure is the general absence of any regulatory control to protect and preserve the ecosystem during the early 1900s. Indeed, the initial legislative record during these periods promoted development rather than protection of land and water resources (e.g., Federal Reclamation Act, Central Valley Project Improvement Act). Not until the passage of the National Environmental Policy Act of 1969 (NEPA), and subsequent passage of the Federal Water Pollution Control Act, Endangered Species Act (ESA), the Clean Water Act, and complementary State passed legislation during the 1970s and 1980s was full consideration given to the preservation and mitigation of impacts to important environmental resources.

As a result, little or no consideration was given to environmental protection during the initial development of land and water resources in the Bay and Delta. Consequently, the majority of land reclamation (wetlands destruction) and losses of habitat in and around the Bay and Delta had occurred by 1950. During this period, the biological resources were being subjected to an ever changing set of water quality and quantity conditions, and a general shrinkage in physical habitats. Construction of several major dams (e.g., Shasta Dam on the upper Sacramento River, Friant Dam on the San Joaquin) essentially removed hundreds of miles of riverine habitat from production, habitats which included important spawning areas for anadromous runs of chinook salmon (*Oncorhynchus tshawytscha)* and steelhead trout *(O. mykis)*. Hydraulic mining, which occurred in the upper reaches of the Sacramento River drainage in the late 1800s resulted in the introduction of hundreds of thousands of tons of fine sediments and sands to the river systems. These same waters were being used by salmon and trout for spawning, the success of which is dependent on having spawning gravels which are clean of fine sediments and silts (to allow water to freely flow through the gravel interstitial spaces and reach the incubating eggs). Through time, much of this material has been transported downstream and into the Bay and Delta. Urban developments were also increasing during this time, and resulted in the introduction of raw sewage into receiving waters. The biological consequences of this organic enrichment likely resulted in increased production of algae and certain pollution tolerant invertebrate species, and shifts in fish assemblages from water quality sensitive species to those more pollution tolerant and opportunistic relative to a changing food base.



that have influenced the condition of the San Francisco/Sacramento-San Jaoquin Estuary.

From 1950-1980, even with the passage of certain major environmental legislation (e.g., NEPA of 1969), the Bay and Delta areas continued to be developed. This period marked the development and construction of the majority of dams and reservoirs within the Sacramento and San Joaquin drainages, as well as construction of several major aqueducts (Figure 2). Industrial developments were likewise increasing during this period, including the construction and operation of major refineries near Suisun Bay.

In short, the Bay and Delta have been and are continuing to be subjected to an ever changing set of conditions, some transitory (e.g., water quality) and some permanent or semi-permanent (reservoir developments, wetlands losses), which collectively operate on the aquatic ecosystem. In space and time, such conditions may favor one assemblage of organisms over another resulting in changes in species abundance and composition. As conditions change, other shifts in species dominance and abundance will occur commensurate with factors which govern the density of each. This is an important consideration relative to setting a collective goal of restoration for fish species in the Bay and Delta; environmental changes will not affect all species equally or in the same fashion.

3.0 NATURAL FACTORS

In this report, natural factors are defined as those for which man has no or limited control over. Such factors are largely climatic and represent the extremes of the normal ranges of certain variables. For the Bay and Delta, these have included: periods of extended low snow pack and precipitation – drought; periods of high intensity rainstorm events – floods; and alternating periods of drought and flood. The San Francisco Bay and Delta areas have been subjected to these types of conditions in a sustained fashion over the last 20 years. Depending on particular habitat affinities, these conditions would be expected to have variable impacts to fish and invertebrate populations, even absent all other developments.

Because these factors have been operating in a sustained fashion for two decades, it is important to determine the extent to which they may be independently controlling or governing existing fish assemblages in the Bay. The majority of data cited by the EPA as justification for the X2 standard were collected during this same period. Thus, the question remains whether the observed trends were imposed by natural conditions, positions of X2 as determined by delta exports, or combinations of both.

3.1 DROUGHT IMPACTS

Monroe and Kelly (1992) reported five periods of extended drought in the region; 1917-1920, 1923-1924, 1928-1934, 1976-1977, and 1987-1992. Of these, a biological record is only available for the last two. From 1987 to 1992, the water year classifications for the San Joaquin drainage were considered critically dry. For the Sacramento River drainage, four of the last six years were considered critically dry, two were classified as dry (SWRCB, 1993). Eleven of the last 23 years (through 1992) were below the long-term average of the Sacramento River index, a measure of unimpaired runoff in the valley; the last six years represented extreme drought (DWR 1993). For the Sacramento and San Joaquin systems, critical and dry year types have occurred 30% and 32% of the time (based on period of record 1906-1990), respectively (Monroe and Kelly, 1992; data from SWRCB, 1991).

From an ecological perspective, drought and low flow conditions can have wide ranging impacts, depending on species and life stage habitat preferences. For riverine species, drought conditions can translate into reductions in available physical habitat, elevated water temperatures, reductions in food base, increased susceptibility to predation, and alterations in general water quality characteristics. Some estuarine species (e.g., striped bass) are anadromous and would therefore be subjected to similar types of impacts as noted above, during residency in riverine habitats. For other estuarine species (e.g., delta smelt, longfin smelt), drought conditions result in reduced inflows of freshwater, which may influence location of spawning and rearing habitats and production potential. Freshwater inflow also affects primary and secondary production of important food organisms for estuarine species (e.g., Neomysis sp., Crangon sp.).

For the period 1950 to present, the effects of sustained drought and low flow conditions on fish in the Bay and Delta must be considered in the context of ongoing operations of the Central Valley Project (CVP) and State Water Project (SWP), and other consumptive users in the basin. As reported by Monroe and Kelly (1992), in wet years diversions reduce outflow from the Delta by 10-30 percent, while in dry years Delta outflow is often reduced by more than 50 percent (Figure 3 and Figure 4). The most recent drought conditions have resulted in reductions of outflow by about 65 percent. During drought years, the percentage of total flow diverted as exports is higher than during normal or wet years, with 1977 serving as a good example of this (Figure 3).

Another phenomenon that is associated with the operation of the CVP and SWP is that of reverse flows. This typically occurs during periods of high pumping and low delta outflow, which results in a net movement of water upstream from the delta confluence toward the pumps. The occurrence of this is a function of delta inflow. Thus, under conditions of drought and low flow, there is a greater percentage of time that reverse flow conditions occur (Figure 5). Ecologically, reverse flows reportedly disorient anadromous fish species (striped bass *(Morone saxatalis)* and chinook salmon) as they migrate upstream to spawning grounds (Monroe and Kelly, 1992), and as juvenile fish (smolts) migrate downstream. For the latter, the USFWS (1992) has reported a weak relationship between QWEST, a measure of reverse flow conditions, and salmon smolt survival. Reverse flows may also influence the number of fish lost via entrainment into the CVP and SWP pumping plants; Wendt (1987) presented an inverse relationship between QWEST and number of juvenile striped bass salvaged at one of the pumping plants in June and July. Thus, the effects of reverse flows may be transitory, depending on species and life history stages present at any given time. Thus, the potential effects of drought conditions are exacerbated by the Delta exports. However, the incremental impacts associated with the exports (above those which would occur naturally) have not been determined.

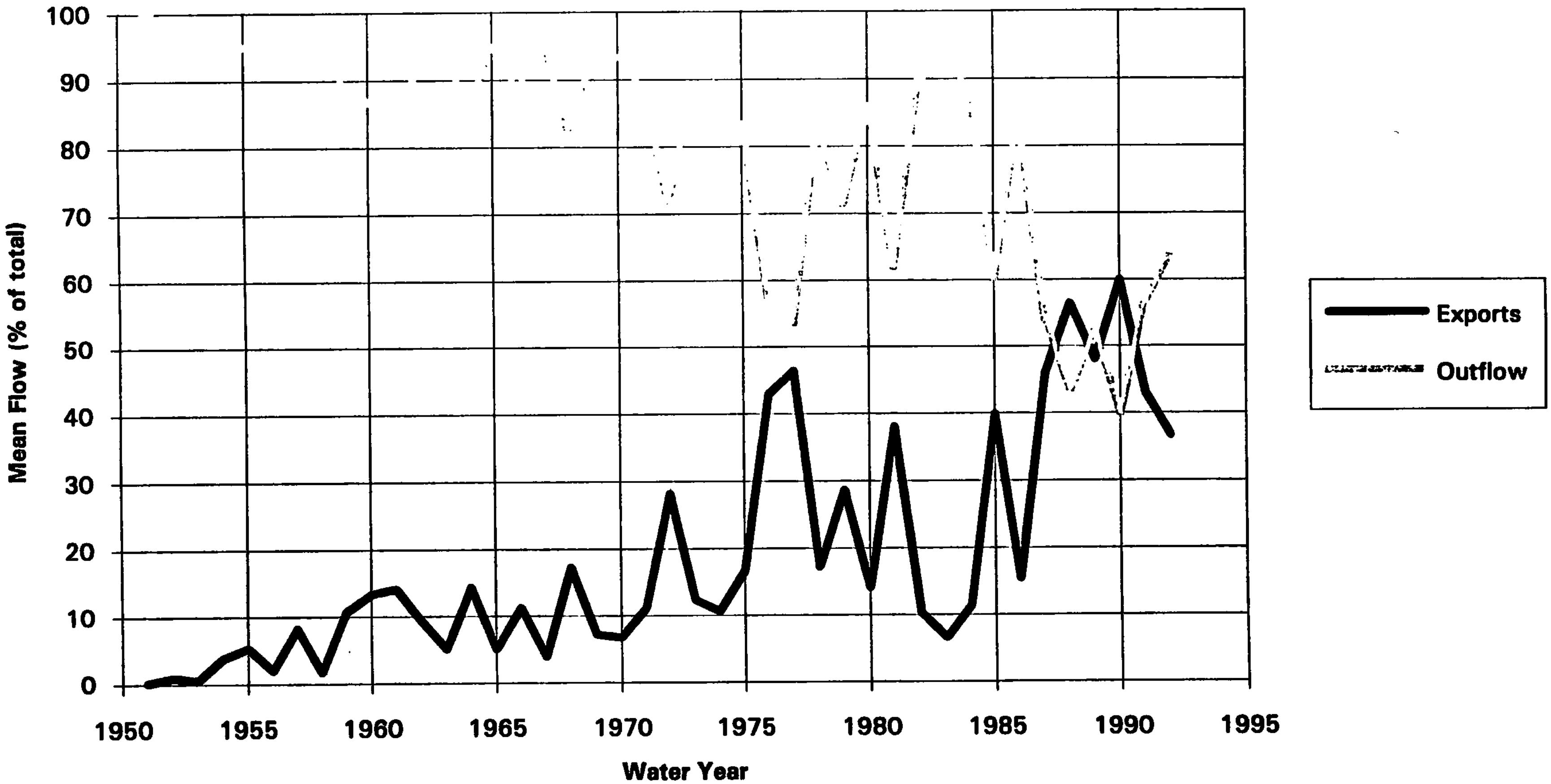


Figure 3. Chronology of exports and outflow expressed as a percentage of total inflow to the Sacramento-San Joaquin Delta. (Source DAYFLOW).

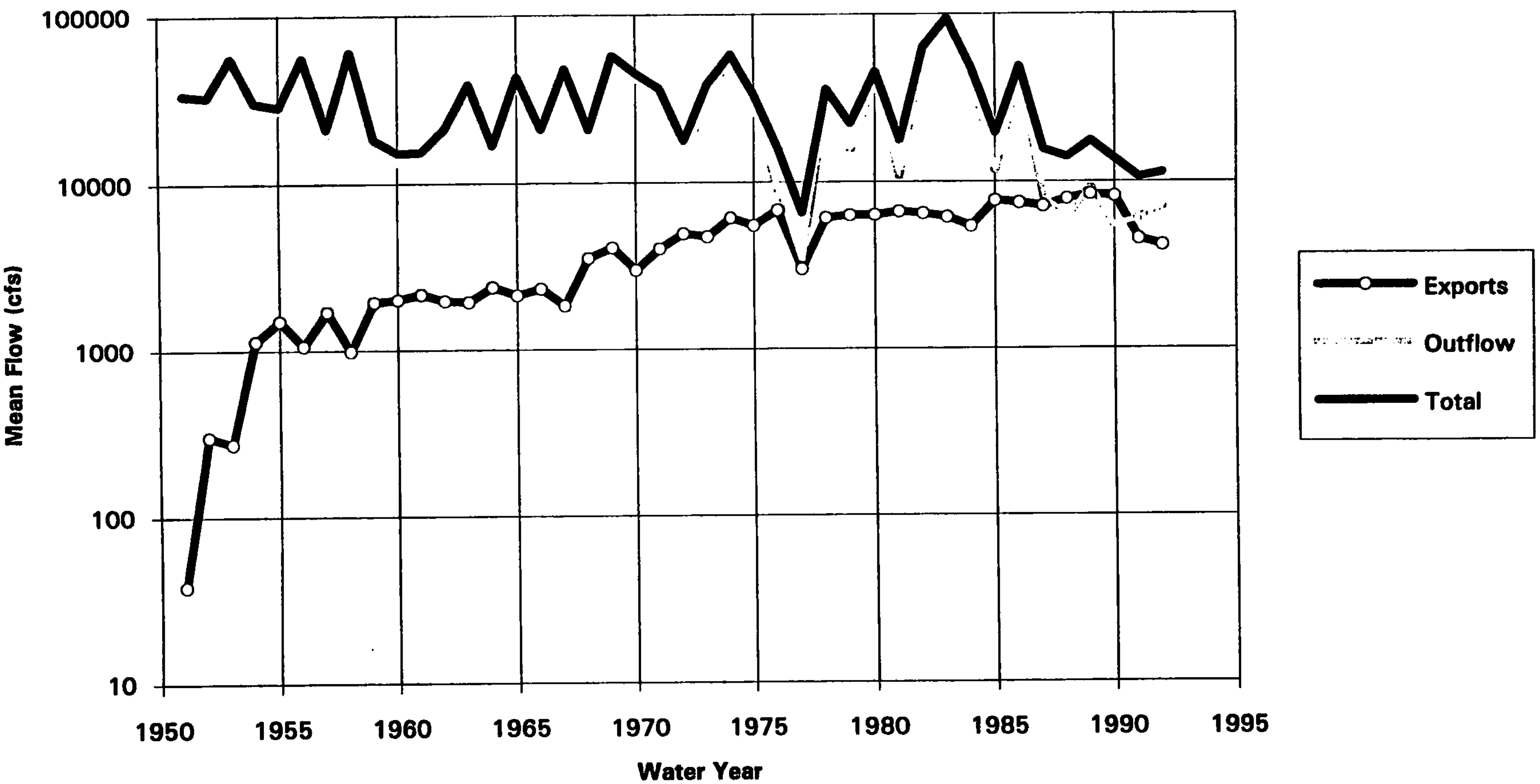


Figure 4. Chronology of exports and outflow as a function of total flow to the Sacramento -San Joaquin Delta. (Source: DAYFLOW).

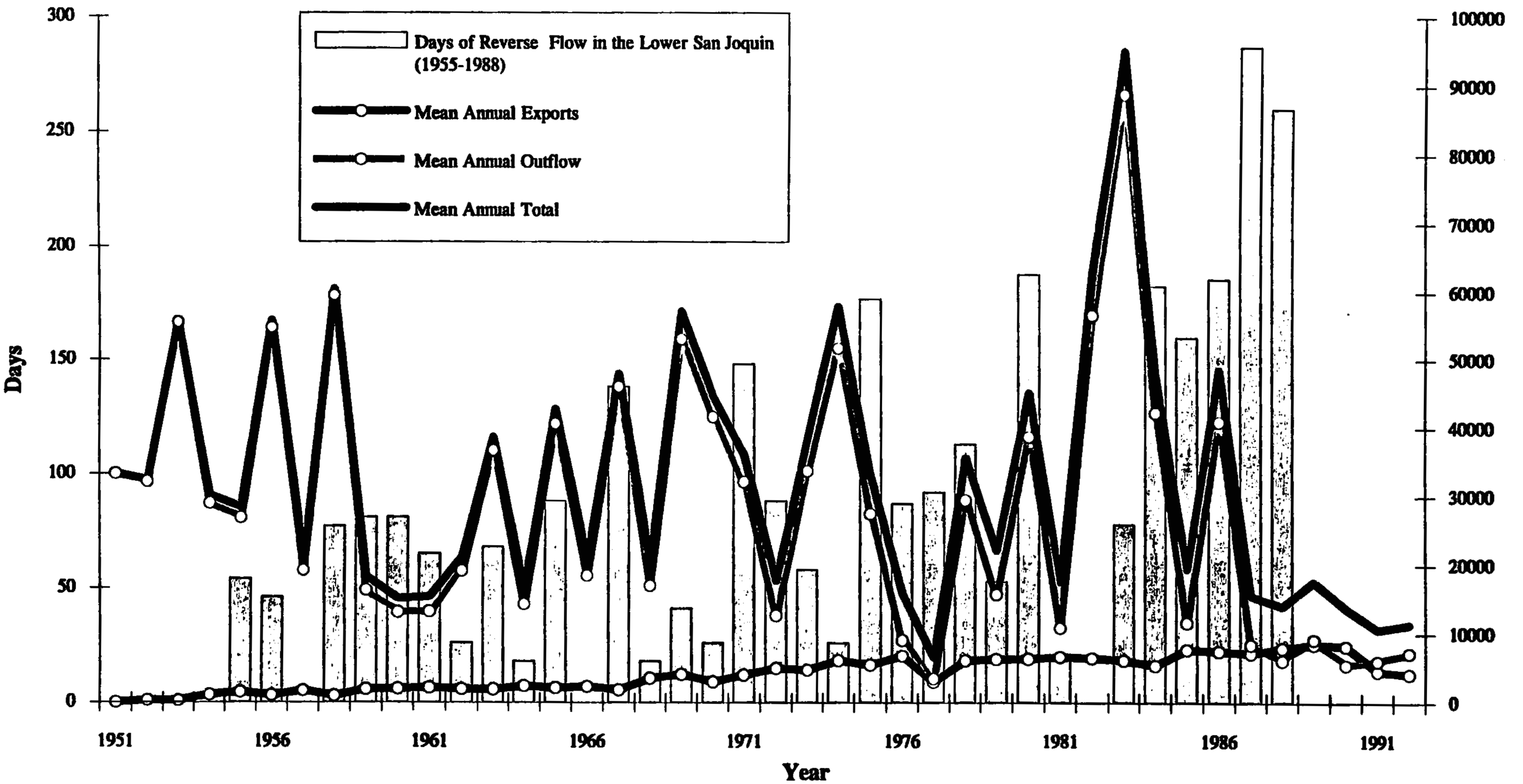


Figure 5. Frequency of reverse flows (days), mean annual exports, mean annual outflow, and total flow as a function of time (years) for the Sacramento-San Joaquin Delta. (Source: DAYFLOW).

A summary of potential impacts associated with, or caused by sustained drought, with consideration for CVP and SWP operations include:

- Increases in reverse flows in the central and south Delta (assuming no restrictions on exports) resulting in increased susceptibility to entrainment by water uptake facilities. Migration of fish into lower San Joaquin River from Suisun Bay during low flow periods, concentration of fish in more restricted habitat areas, and reverse flows in Delta increase potential for entrainment of fish in water uptake facilities of the SWP and CVP, as well as irrigation diversions for local agricultural water users. However, the DWR has examined relationships between number of days of reverse flows and Delta smelt (*Hypomesus transpacificus)* midwater trawl and tow-net indices and has not found a statistically significant relationship between reverse flow frequency and Delta smelt abundance indices.

- Reduced egg and larval survival due to reductions in either water quality or quantity, and proportionately greater entrainment of eggs and larvae in CVP and SWP operations;

- Increased concentration of toxics. Reduced streamflow and increased irrigation demands during drought periods would likely result in increased levels of pesticides and other toxins in the Delta. This could result in direct mortality to certain fish species and/or important forage organisms.

- Increased abundance of filter feeding invertebrates (including clams) which are more tolerance of high salinity conditions. Successive years of reduced freshwater inflow has historically resulted in the upstream colonization of clams (e.g., *Mya arenaria*) and other filter feeding organisms (Monroe and Kelly, 1992). Depending on the extent of population growth, these filter feeders have the potential for reducing available phytoplankton as food for planktivores fish and invertebrate species such as Delta smelt, opossum shrimp (*Neomysis mercedis*), and others. However, the recent introduction of the asiatic clam (*Potamocorbula amurensis*) has stemmed the normal return of these drought tolerant clams. This clam has a wide range of tolerance to salinity and as such has been able to successfully invade and maintain habitats subjected to widely varying shifts in salinity. However, its establishment and population boom within the Bay and Delta, and its ability to filter feed copious amounts of phytoplankton, may have its greatest impact during periods of extended drought.

- Decreased influx of organic carbon (phytoplankton and associated breakdown products resulting from decomposition) due to reduced delta inflow and reverse currents in southern Delta (organic carbon entrained into agricultural, SWP and CVP diversions). The effects of this reduction may be exacerbated by the high densities of filter feeding clams in the Delta region.

- Increased parasite infections (loads) and resulting mortality and lowered fecundity may affect the abundance of fish such as striped bass during drought periods. These increased infestations/loads may result from the reduction in suitable habitat area during drought periods and the subsequent concentration of fish, which promotes spreading of parasites. Increased vulnerability due to other forms of stress, including changes in water temperature, food availability, and increased toxic contaminant concentrations may also influence parasite loads.

- Reduced access to and habitat quality (e.g., elevated water temperatures) and quantity within river systems for anadromous fish which pass through the Delta. Severe reductions in chinook salmon populations during the drought may be due to extreme reductions in natural flows in Central Valley rivers and streams. Depending on required flow releases from impoundments, there is also a greater potential for stranding of juveniles/smolts, and straying of adults during upstream migrations (due to reduced flow olfactory ques).

- Increased water temperatures resulting from reduced volumes and increased retention time of water in the Delta.

- Increased vulnerability to predation. For example, rapid increases in silverside abundance occurred concurrently with reductions in striped bass and Delta smelt in 1980s. Increased concentration of larvae and eggs in Delta areas (due to reductions in inflows) may increase susceptibility to predation by fish such as silverside.

- Increased water transparency due to decreased inflows and reduced sediment recruitment. This may be partially due to the increased abundance of the asiatic clam and the filtering of phytoplankton from the water column. Biological effects of this increased transparency are largely unknown, although if it is related to phytoplankton reductions, then reductions in food base for planktivores fish may be one impact. From a fish sampling perspective, increased transparency would likely reduce gear efficiency since the fish would be able to see and avoid the sample nets/trawls.

With respect to the setting of an X2 standard, the impacts to fish occurring during drought conditions, including flow reversals in the central and southern regions of the delta and subsequent entrainment into water diversions, may be reduced by the greater total delta inflows required to maintain the location of X2 in the Bay and Delta. However, impacts from drought on certain fish species would likely occur regardless of the X2 standard. Consequently, benefits derived from the implementation of X2 may be offset or reduced during periods of extended drought. The EPA apparently recognizes this, and has proposed different X2 criteria depending on water year type. Nevertheless, *the effects of extended drought have not been evaluated independent of flow exports*. This is important for determining the degree to which natural versus man-induced effects may be influencing the Bay and Delta fish populations, and to what extent the proposed standards will achieve their stated purpose.

3.2 FLOODING AND PEAK FLOWS

Variation in flow to the Bay and Delta is the most commonly cited control on the abundance, distribution, and reproductive success of many species of fish in the Sacramento-San Joaquin estuary and delta. However, it is not evident after reviewing temporal trends for several "key" fish species (e.g., Delta smelt) whether declines in abundance were caused by flood conditions or by drought conditions. It is possible that low population levels of many species observed in the late 1980s resulted from a record high flow event which occurred in February 1986, which was followed by extreme drought conditions which prevented species from recovering from this flood.

The volume of water flowing into the Delta have been extremely variable from year to year. The past 15 years have encompassed the wettest year on record (1983), as well as two of the longest and driest droughts on record (1976-1977 and 1985-1992). In addition to year-to-year variations in flow, extreme fluctuations in Delta inflows have been observed on a seasonal basis. For example, during the drought year of 1990, the Central Valley experienced the wettest May on record. High flows may be responsible for declines in longfin smelt populations in 1986, as record high flows presumably flushed a high percentage of mature adults out of the estuary. The same could be true for other fish populations inhabiting the Delta; populations of Delta smelt (townet index) reached extremely low levels after 1965 and 1986, years having record high flows. The abundance of white sturgeon (*Acipenser transmontanus*) is likewise tied to spawning success in years of very high outflow. Some species, such as the Sacramento splittail (*Pogonichthys macrolepidotus*) spawn more successfully within flooded vegetation, which is more available in years of high outflow.

Contrary to high flow events, moderate Delta outflows are thought to support higher populations of American shad (*Alosa sapidissima*), longfin smelt (*Spirinchus thaleichthys*), and chinook salmon. These species migrate through or into the Delta to spawn and may benefit from increased passage survival provided by moderate flows (decreased downstream travel time for young fish, decreased predation risk). Increased discharge has also been thought to increase the total load of phytoplankton passing through the Delta. The importance of this is relatively unknown, but it could be great due to the importance of phytoplankton in the Delta food chain.

3.3 YEARLY VARIABILITY IN FLOW

Combinations of extremely wet and extremely dry years, as occurred during the 1980s were likely a contributing factor to declines in fish abundance. Poor habitat conditions in one year will likely result in reduced egg and fry survivals for that year, resulting in a poor year class (i.e., low production of fry). If conditions improve the following year, production would be expected to increase resulting in a strong year class. This type of yearly variability may partially explain the widely ranging fluctuations in fish populations (e.g., Delta smelt and striped bass) observed for different flow conditions (i.e., wet, normal, dry, critically dry).

4.0 WATER PROJECT DEVELOPMENT AND OPERATIONS

Figure 2 depicts the historical development of the major water projects in the Sacramento-San Joaquin drainages. Monroe and Kelly (1992) provided an excellent historical accounting of this development, portions of which are excerpted here.

The two largest water projects are the Central Valley Project which was authorized in 1933, and the State Water Project authorized in 1959. These two projects have diversion capacities of 4,600 cfs via CVP's Tracy pumping plant, and 6,400 cfs at the SWP's delta pumping plant. The region has more than 7,000 water right holders which allow diversion of water from these systems.

4.1 EXPORTS

Exports from the Delta commenced in 1940 with the opening of the Contra Costa Canal (Monroe and Kelly, 1992). Major diversions began in 1951, with the operation of CVP's Tracy pumping plant supplying water to the Delta-Mendota Canal. There has been an increasing amount of water exported from the Delta (Figure 5); CVP diversions averaged 700,000 acre-feet in the 1950s and were about 3 million acre-feet in 1989. The SWP has likewise increased the amount of exports annually since its operation (drought years excepted) with more than 3 million acre-feet being diverted in 1989.

4.2 TIMING OF FLOW DELIVERY

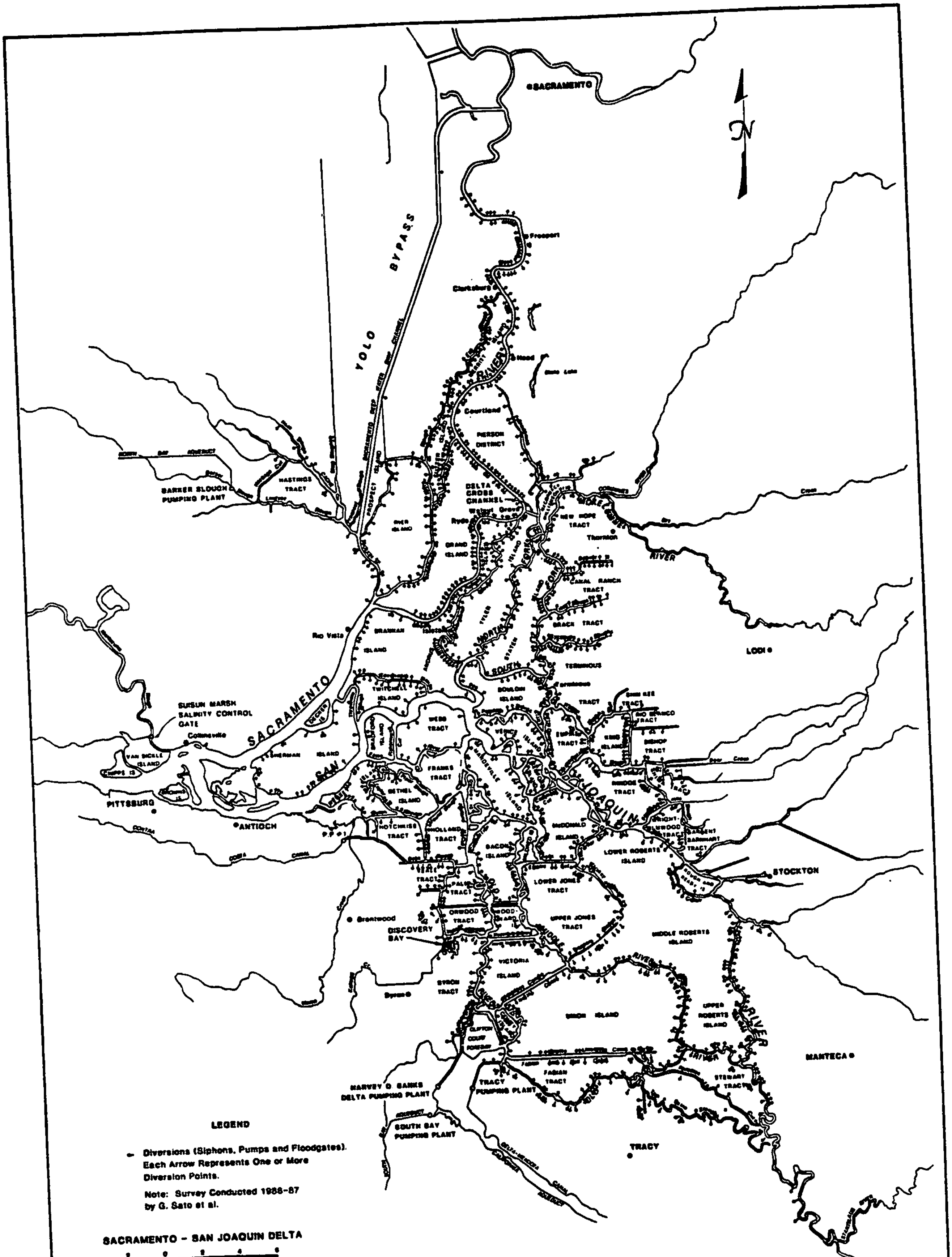
The operations of the SWP and CVP have altered the timing and amount of water delivered to the estuary, and have created conditions of reverse flows, whereby freshwater is essentially drawn upstream within the San Joaquin Delta as a result of the pumping plant operations (Figure 5). In general, the release of outflow water from upstream impoundments is timed to coincide with peak irrigation demands. This has resulted in a substantial decrease in outflows from April through June, with a slight increase in flows in other months (Peterson et al., 1989).

4.3 ENTRAINMENT AND IMPINGEMENT

Associated with the diversion of water is the entrainment and loss of aquatic organisms (fish and invertebrates) into the CVP and SWP systems. Although screened to prevent losses of juvenile and adult fish, it is estimated that millions of eggs, larvae and smaller juvenile fish are entrained each year.

4.4 OTHER DIVERSIONS

In addition to losses into the SWP and CVP pumps, there are over 1,800 other diversions including siphons and pumps located throughout the Bay-Delta system (Figure 6). None of these are screened to prevent fish losses, presumably because there are no regulatory requirements to install such. Based on the shear number of these diversions, it seems likely that losses of fish could, at times be substantial. However, there has apparently been no comprehensive evaluation of the potential impacts of these diversions on the aquatic biota completed to date. This warrants immediate attention since measures can be engineered to prevent/minimize such losses.



Irrigation Diversions

Figure 6. Map depicting locations of unscreened diversions and pumps within the Sacramento-San Joaquin Delta. (CDWR, 1993)

5.0 LAND RECLAMATION

Based on the review of Meiorin et al. (1992) who described the status and trends of wetlands and land use in the Bay and Delta, one of the greatest visible changes that has occurred around the Delta pertains to land reclamation. The present condition and quantity of wetland habitats in the area bears little resemblance to the once extensive and expansive marsh and tidal wetlands that were described by early explorers. From the historical estimates of about 545,000 acres of wetlands, todays wetlands have been reduced to about 3 percent of this total, with most being reclaimed for agricultural use. This reclamation resulted in the loss or alteration of extensive areas of ecologically important habitats, habitats which were used by many of the same species which are listed or are being considered for listing under the ESA. Over 70% of the Delta is presently deep, open water habitat. Meiorin et al. (1992) provided a list of 97 animal and plant species that have been listed under state and federal ESA categories. Fish species listed included Delta smelt, Sacramento splittail, and Sacramento perch (*Archoplites interruptus*). According to Meiorin et al. (1992), wetland and habitat conversion and degradation are the major reasons for the decline of the species they listed. Two native Delta species, thicktail chub (*Gila crassicauda*) and Sacramento perch are believed to have become extinct due to the elimination of important wetlands and riparian habitats (Herbold et al., 1992).

Fundamentally, the loss of wetlands and marsh habitats effectively reduced the potential carrying capacity of the different fish, or the theoretical maximum population size (of a given species) that would occur if space were the only limiting factor. This would have its greatest impact on species that utilize shallow, back water habitats, sloughs, and intertidal zones during all or part of their life cycle. Theoretically, no impacts (related to marsh lands reclamation) would occur to such fish populations until all surplus quantities of habitat would be removed. Until such time, the fish populations were likely controlled by factors other than space and physical habitat. All other things remaining constant, the continued removal of marsh and wetland habitats would, after the surplus was expended, begin to have a direct impact on the potential carrying capacity and abundance of fish populations. This would occur through the elimination or reduction of certain critical habitats (e.g., spawning or nursery areas) to levels below those necessary to support the historical populations. Coincident with this, interspecific competition would then likely factor into the ultimate species mix and density sustainable under varying conditions.

Based on the data presented by Meiori et al. (1994), there was apparently the wholesale elimination of wetlands and marsh habitats during the early and mid-1900s so that the habitats remaining today, are but a fraction of what existed historically. With respect to native species that utilized these areas, the range and quantity of their habitats has been reduced to rather limited areas such as Suisun Bay and Marsh, in some cases to levels which may, when associated with climatological extremes (e.g., drought, flooding) limit the production potential of the species. This could occur through the seasonal loss of spawning, nursery or important rearing habitats. For example reclamation of marshlands habitat to farmland has likely resulted in the destruction of most of the potential spawning habitat of many native fish species, including Sacramento splittail, Sacramento Blackfish *(Orthodon microlepidotus)*, and perhaps longfin smelt and Delta smelt. Tule perch *(Hysterocarpus traski)* and Sacramento splittail have lost much of their original foraging habitat through losses of marshlands. The loss of these habitats has had a profound impact on the fish fauna in the Delta, and coupled with the introduction of non-native species (exotics) has resulted in major changes in the species composition. Moyle (1976) reported a 60% reduction in the number of native fish presently found in the San Joaquin River near Friant and attributed such shifts to problems of habitat change, introduced species and fishing.

Although the pace of land alteration has slowed in recent years, comparatively little remains of native delta marshlands. According to Madorne Assoc. (1980) as referenced in Meiorin et al. (1992), about 450,000 of the original 545,000 acres of tidal wetlands had been converted to agricultural production by 1930, of which today there are about 350,000 acres in active production. Much of this land is below sea level (due to subsidence) and must be maintained via drainage and pumping systems. This warrants a detailed assessment, since the future restoration of the Bay and Delta ecosystem, including the recovery of species presently listed as threatened or endangered, will likely depend on the creation of new or restoration of old habitats.

We believe that the losses of habitat that have occurred throughout the delta have reduced the resiliency of certain populations to respond to natural and man-induced perturbations, and that this has set the stage for the reported recent declines in certain species, including Delta smelt, Sacramento splittail, and to a lesser degree longfin smelt. As a consequence, marsh and wetlands habitat losses must be considered as one of the major factors that have served to shape and control existing populations. The EPA did not consider the potential losses of fish due to this factor during the formulation of the salinity standard. Indeed, an argument could be made that were it not for the loss of such habitats, the overall effects of shifts in salinity isohalines due to CVP and SWP operations would have far less (perhaps no) influence on existing fish populations; abundant marsh and wetland habitats would exist

6.0 NON-NATIVE SPECIES INTRODUCTIONS

Shafland (1986) listed four concerns relative to the introduction of exotic fishes into Florida's waters. These included:

- Potential for introduced fish to alter the natural energy flow through a system
- Unpredictable response following introduction
- Direct or indirect competition with native species
- Transmittal or vector of disease and parasites

These same concerns apply to essentially any water body where native species exist, and certainly to the Bay and Delta, where today, 27 of 55 fish species historically or presently residing in the system were introduced (Table 1) (Herbold and Moyle, 1989). Kohler and Courtenay (1986), in developing a position statement for the American Fisheries Society (AFS), listed five categories of potential impacts due to introduced species: 1) habitat alteration; 2) trophic alteration; 3) spatial alteration; 4) gene pool deterioration; and 5) introduction of diseases. This was followed by a series of recommendations designed to assist in the planning, regulation, implementation and monitoring of introductions into river and lake systems. Moyle (1976) considered three mechanisms in which introduced species could directly eliminate native ones: 1) direct competition for food or space (in limited supply); predation on native species; 2) habitat interference (i.e., actions of introduced species alter habitats of native species); and 3) hybridization between introduced and native species. The Sacramento perch may have been eliminated from its native habitat in the Sacramento-San Joaquin system through competition with the bluegill (Moyle, 1976).

Essentially all state resource agencies acknowledge the potential problems associated with introducing non-native species and most have specific regulations for controlling such. The federal government likewise has existing legislation (Lacey Act of 1900 (amended in 1981)) which is administered by the USFWS, specifically focused on controlling illegal introductions of aquatic organisms.

The introduction of exotic species can have and has had widespread ecological significance on aquatic ecosystems. Sigler and Sigler (1987) considered the introduction of exotics to waters of the Great Basin as one of the major factors (habitat degradation was the number one cited cause) contributing to the decline in native fish populations. Moyle (1976) similarly considered introduced species among the top three categories (habitat change and

Table 1. Listing of species that have been introduced (and dates of introduction) into the San Francisco/Sacramento-San Joaquin Estuary. (Brown, 1992; Herbold and Moyle, 1989)

Year	No.[1]	Common Name	Scientific Name
1850	1	Isopod	*Sphaeroma quoyanum*
1869	2	Eastern Oyster	*Crassostrea virginica*
1871	3	American Shad	*Alosa spadissima*
1872	4	Carp	*Cyprinus carpio*
1873	5	Gribbles	*Limnoria spp.*
1874	6	Black Bullhead	*Ictalurus melas*
1874	7	Brown Bullhead	*Ictalurus nebulosus*
1874	8	Largemouth Bass	*Micropterus salmoides*
1874	9	Soft Shell Clam	*Mya arenaria*
1874	10	White Catfish	*Ictalurus catus*
1874	11	Yellow Bullhead	*Ictalurus natalis*
1879	12	Striped Bass	*Morone saxatillis*
1891	13	Golden Shiner	*Notemigonus crysoleucas*
1891	14	Green Sunfish	*Lepomis cyanellus*
1900	15	Goldfish	*Carassius auratus*
1908	16	Black Crappie	*Pomoxis nigromaculatus*
1908	17	Bluegill	*Lepomis macrochirus*
1913	18	Shipworm	*Teredo navalis*
1921	19	Warmouth	*Lepomis gulosus*
1922	20	Mosquitofish	*Gambusia affinis*
1930	21	Japanese Oyster	*Crassostrea gigas*
1940	22	Channel Catfish	*Ictalurus punctatus*
1946	23	Asian Clam	*Corbicula fluminea*
1946	24	Japanese Littleneck	*Tapes japonica*
1949	25	Redear Sunfish	*Lepomis microlophus*
1950	26	Fathead Minnow	*Pimephales promelas*
1951	27	White Crappie	*Pomoxis annularis*
1953	28	Bigscale Logperch	*Percina macrolepida*
1953	29	Threadfin Shad	*Dorosoma petenense*
1963	30	Yellowfin Goby	*Acanthogobius flavimanus*
1966	31	Copepod	*Oithona davisae*
1968	32	Inland Silversides	*Menidia beryllina*
1968	33	Snail	*Littorina littorea*
1978	34	Copepod	*Sinocalanus doerrii*
1979	35	Blue Catfish	*Ictalurus furcatis*
1979	36	Copepod	*Limnoithona sinensis*
1982	37	Clam	*Theora fragilis*
1983	38	Amphipod	*Gammarus daiberi*
1986	39	Asian Clam	*Potomocorbula amurensis*
1986	40	Crustacean	*Hemileucon hinumennsis*
1986	41	Copepod	*Pseudodiaptomus marinus*
1987	42	Copepod	*Pseudodiaptomus forbesi*
1988	43	Snail	*Malanoides tuberculata*
1989	44	Polychaete	*Potamilla sp.*
1991	45	European Green Crab	*Carcinus maenas*
1991	46	Polychaete	*Spionid sp.*

[1] Numbers correspond to numbers on figure 2.

fishing were also cited) causing reductions in native fish fauna in California. The biological literature abounds with case after case of how both planned and unplanned introductions of organisms have had unpredictable, negative impacts on native (or previously established) fish and/or invertebrate communities. Examples include the introduction of common carp (*Cyprinus carpio*) throughout the United States, walleye (*Stizostedium vitreum*) (highly piscivores) into waters containing salmonids, the freshwater shrimp (*Mysis relicta)* into lakes in the Western U.S. to serve as a forage base for kokanee salmon *(Oncorhynchus nerka)* (Mysis can compete for food base (zooplankton) of juvenile kokanee), and major hatchery outplantings of salmonids (primarily rainbow and brown trout (*Salmo trutta)*) into waters containing native stocks of cutthroat *(Oncorhynchus clarki)*, bull *(Salvelinus confluentus)*, and rainbow trout. These latter introductions were widespread throughout the West during the early 1900s, with hatchery production still being used in most states to augment fishing opportunities in some rivers and lakes. In recent times, however, there has become an increased awareness of the problems (competition for space, behavior modification of native stocks, hybridization) associated with hatchery stocking in streams containing wild salmonid populations (Vincent, 1987). Consequently, many states now limit stocking of hatchery trout to lakes and reservoirs, with riverine populations being managed as wild stocks.

With respect to the Bay and Delta, Herbold et al. (1992) summarized the history of species introductions that have had a widespread effect on ecosystem structure and economics of the area. The introductions were either planned, with the intent of improving the local fish fauna by providing additional catch opportunity for anglers, or were accidental, occurring through inadvertent releases of container water transported from other locations. Sportsman and anglers likely contributed to the unplanned introductions, via introduction of a particular species of fish into a given water body, simply because they (the anglers) would like to fish for it locally. Regardless of the cause or mode of introduction, the fauna of the Bay and Delta have and are being constantly subjected to new organisms. Depending on the individual species tolerances to salinity and physical habitat characteristics, the introduced species may: 1) be quickly eliminated from the system (i.e., intolerant of conditions); 2) become established into the ecosystem (generally at the expense of some other fish species) (i.e., tolerant of conditions); and 3) demonstrate a dramatic and sudden increase in abundance (i.e., conditions favor the introduced species). An example of this latter situation is the introduction of the Asian clam (*Potamocorbula amurensis*) in 1986. Since then the clam has become quite invasive and, according to Monroe and Kelly (1992), Carlton et al. (1990) and Nichols et al. (1990), presently dominates most of the benthic communities in San Pablo Bay and Suisun Bay. Herbold et al. (1992) suggested that recent and continued introductions of new species into the system "contributes greatly to the instability of the

Estuary's biotic communities and increases the difficulty of managing it to favor desired species."

A listing of introduced species (invertebrates and fish) to the San Francisco Bay, including the reported year and potential economic or ecological effect of the introduction is presented in Table 1. Although an in-depth analysis of each species is beyond the scope of this report, summary discussions of selected species are warranted to illustrate the degree to which introduced species have influenced the ecosystem of the Bay and Delta. For this, summaries are presented for striped bass, inland silversides, and the Asian clam. These collectively represent two planned (the fish species) and one unplanned (the Asian clam) introduction to the system.

6.1 STRIPED BASS

The striped bass represents the best example of a planned introduction to the Delta which has proven successful. A native of the Atlantic coast of the U.S., striped bass were first introduced into the lower Sacramento-San Joaquin Delta in 1879 (McGinnis, 1984). Apparently able to capitalize on an abundant food base, utilize both fresh and salt water habitats, and maintain a high egg-fry survival rate, the striped bass populations increased rapidly, resulting in the development of a commercial fishery by 1890. The species is anadromous and utilizes portions of the Sacramento and San Joaquin Rivers for spawning; spawning occurs in the spring. Herbold et al. (1992), attributed the early success and increase in population size to the reproductive habits of the bass. Striped bass are extremely fecund (females contain from 500,000 to 4.5 million eggs (Hassler, 1988)) and the eggs are semi-buoyant. Consequently, they were not susceptible to the high concentrations of sediments and silts that prevailed during the early 1900s due to hydraulic mining operations. The commercial fishery lasted until 1935, when it was curtailed due to declining abundance and a shift toward management as a sport fishery (McGinnis, 1984). Herbold et al. (1992) suggested that these initial declines were likely attributed to overfishing, habitat degradation, or the "usual" declines in abundance following successful introduction of a species. Even after removal of the commercial fishery, the striped bass populations continued to drop as evidenced by decreases in catch per angler per year. With the passage of a water quality control plan in 1978, the State Water Resources Control Board recognized the importance of maintaining striped bass populations in the Bay-Delta. Using an index (Striped Bass Index - SBI) which gauges relative abundance of YOY striped bass ($\geq$ 38 mm length), the Board adopted the goal of maintaining the SBI at a long-term average of 79, which was the estimate of what the SBI would be, absent operations of the CVP and SWP. However, as noted in the EPA proposed standard, the highest the SBI has ever been since then has been in the 10s and 20s, with values of 1.2 and 2.2 reported in 1983 and 1985 respectively. The EPA has cited the failure to meet the SBI objectives as one of the reasons for its proposed salinity standard, with benefits being accrued to young striped bass feeding in nursery habitats of Suisun Bay.

Herbold et al. (1992) discussed four causes for the apparent continuing decline in striped bass abundance, including; toxic effects, larval starvation, increased entrainment, and declining egg abundance. Of these, the loss of eggs and larvae into the Central Delta was reported as the only documented mechanism which could explain continued reductions of striped bass. Herrgesell (1990) reported reductions of 73% and 84% from entrainment during dry years of 1985 and 1988. It was reasoned that with higher flows, a greater proportion of eggs and larvae are transported out of the Delta and out of the reach of entrainment. Herrgesell (1993) summarized the results of studies completed by the CDF&G focused specifically on striped bass abundance. A regression model was developed which indicated that outflow and water exports occurring during the initial year of life are the primary factors controlling adult striped bass abundance. While the most recent evidence suggests this may be the case, McGinnis (1984) presented information suggesting that in the late 1970s early 1980s, losses of striped bass were over two times greater due to entrainment within intake flows at Pacific Gas and Electric (PG&E) Company's Pittsburg and Contra Costa power plants in 1979; about 80 million fry lost via Tracy Pumps, compared to over 160 million via the power plants.

Surprisingly, the CDF&G (1989) as reported by Monroe and Kelly (1992) did not specifically list power plant entrainment as a factor contributing to the historic declines of striped bass. Factors that were considered included:

- Delta water diversions
- Reduced delta outflows
- Low San Joaquin River inflow
- Water pollution, toxic chemicals, trace elements
- Dredging and sediment disposal
- Wetland filling
- Illegal take and poaching
- Diseases and parasites
- Annual die-off of adult bass
- Commercial Bay shrimp fishery
- Exotic aquatic organisms

Many of these are discussed as factors acting on the entire Delta ecosystem as part of this report. The listing of the latter factor is somewhat ironic, in that the concern relates to the effects of one or more introduced organisms on populations of another, already established introduced species. Specific to striped bass is the concern of potential disruption of the existing food base used by fry and juvenile fish, due to the introduction of two new species of copepods. A further concern relates to potential competition for food by young striped bass with the introduced inland silverside (*Menidia beryliina)*. The placement of "exotic aquatic organisms" at the end of CDFG's list suggests it is viewed as one of the lessor factors contributing to the decline in striped bass abundance. Herbold et al. (1992) likewise downplayed its importance, in spite of laboratory feeding studies which indicated a relationship between food abundance and larval mortality. The laboratory results were apparently equivocal with field data which did not manifest anticipated effects in captured fry (e.g., no evidence of starvation, reduced growth, or histological change). The general belief presented by Herbold et al. (1992) is that the introduction of species likely had little effect on the declines in striped bass abundance, but they may factor into its restoration potential. Sufficient information has not been reviewed to lead us to the same conclusion.

6.2 INLAND SILVERSIDE

The inland silverside represents an interesting example of the planned introduction of a species into one location and, a subsequent illegal plant of the species into a second location which resulted in the widespread invasion into adjoining waters. Originally planted in 1967 in the Blue Lakes of Lake County to control nuisance gnats and midges, inland silversides were also illegally planted into Clear Lake that same year where it promptly underwent an "enormous population explosion" (McGinnis, 1984). Via irrigation ditches and canals, the species apparently was able to expand its range into the lower San Joaquin system and today is found throughout the Sacramento-San Joaquin Delta. The species feeds on zooplankton and benthic invertebrates, with a reported preference for the opossum shrimp (*Neomysis mercedis)*. This has ecological significance, since there are likewise a variety of Bay-Delta species which utilize Neomysis as food organisms, with the inland silverside further exploiting this food base. McGinnis (1984) suggested that the high abundance of inland silversides in the mid-San Joaquin system may be a contributing factor to the declines of striped bass. Citing competition for a common food base (opossum shrimp) between inland silversides and striped bass fry as the reason, he noted that the normal behavioral segregation of these two species (inland silversides are inshore feeders; striped bass are pelagic feeders) is absent in the San Joaquin system due to extensive channelization. Thus, food source and feeding sites overlap between the two species. McGinnis (1984) noted that because of the enormous populations of inland silversides in the system, it should be considered in the equation of factors potentially controlling striped bass populations. Surprisingly, inland silversides were not presented or discussed by either Herbold et al. (1992) or Moyle (1992) as being potentially problematic relative to striped bass and native fish populations. They were considered as a potential threat to Delta smelt by the BOR as part of their biological assessment of the operation of the SWP and CVP (BOR, 1993).

The introduction and population explosion of the inland silverside occurred concurrently with the early declines in Delta smelt abundance. Its observed overlap in feeding station and food habits with striped bass in the San Joaquin system suggests its role in influencing striped bass and perhaps other species abundance may be more than just secondary or passive. Indeed, patterns indicate that the silverside occurs in high abundance when small eggs and larval of fish are present in the Delta. Because they feed on zooplankton and benthic organisms, it is likely that predation on striped bass larvae and eggs, and perhaps Delta smelt larvae occurs, particularly during low flow periods when eggs and larvae would likely be concentrated in the water column. It would seem logical that if the inland silverside was thought to be a contributor to the declines of Delta fish abundance, studies of its ecology, distribution, and interrelationships with other species would have been completed. However, such studies were not referred to or referenced in any of the major source documents which formed the basis for the proposed EPA salinity standard, and we have concluded that research on the inland silverside is lacking.

6.3 INVERTEBRATE SPECIES: ASIAN CLAM AND TWO SPECIES OF COPEPODS

According to Nichols and Pamatmat (1988) as reported in Herbold et al. (1992), all but two of the common benthic mollusks are introduced species to the Bay and Delta. The dominant mollusc in the Delta is reportedly the Asiatic clam, *Corbicula fluminea*, the genera of which have been distributed widely throughout the United States. This species has a low tolerance to salinity while clams in the Bay, in particular the softshell clam *Mya arenaria*, are intolerant of freshwater. Moyle (1992) noted that the normal pattern of seasonal or drought induced shifts in salinity distributions in the Delta resulted in an increase in abundance of the softshell clam. This occurred in 1976-1977 in response to some of the lowest flow conditions on record.

In 1986 another introduced clam was identified near the Carquinez Strait. The species was another asiatic clam, *Potamorcorbula amurensis* and was presumably brought into the Bay via ballast water from a cargo ship (Monroe and Kelly, 1992). Unlike the other species of

Corbicula, Potamocorbula sp. apparently has a tolerance to a wide range of salinity conditions ranging from 1 to 33 ppt (Carlton et al., 1990; Herbold et al., 1992). Since its introduction, the species has spread rapidly and now dominates most of the benthic communities in Suisun and San Pablo bays; this has occurred within 7-8 year time frame. Densities of the Asian clam are reported as high as 25,000/m^2 and its ability to withstand changes in salinity has allowed it to persevere in the upper Bay even though drought conditions have created more saline conditions, which would normally result in the invasion of the softshell clam, *Mya sp.* Conversely, the species is thought to have prevented the normal recolonization of Suisun Bay by *Corbicula sp.* following the drought conditions in 1984-1985 and return to lower salinities. As noted by Monroe and Kelly (1992), there is great interest to see how the densities and distribution of *Potamorcorbula amurensis* will respond in 1994-1995 following the extended drought of 1987-1992.

The introduction and spread of the asian clam indicates that it has found the conditions of the Bay conducive to its propagation and growth and that it has an apparently wide niche partition. As a filter feeder, it is able to remove and process phytoplankton from all waters in which it inhabits. Studies have noted a dramatic reduction in phytoplankton and chlorophyll *a* densities since its introduction, with levels at some of the lowest values ever recorded (Herbold et al., 1992). This has ecological significance for a number of planktivores fish species in the Bay, which rely on both phytoplankton and zooplankton as their major food source. These include Delta smelt, longfin smelt, and larvae and fry of striped bass.

The introduction of two copepod species; *Sinocalanus doerii and Psuedodiaptomous forbesi*, has further complicated the food web of the system, inasmuch as they have apparently replaced the heretofore abundant *Eurytemora affinis*, which was the preferred food base of many of planktivores species. *Sinocalanus sp.* is considered by researchers to be more problematic to the system, in that larval fish have a harder time in capturing the organism.

It has been calculated that the densities of *Potamorcorbula amurensis* are so high, that the entire water column of San Pablo and Suisun bays can be filtered within a 24 hour period. As noted above, this has resulted in dramatic reductions in phytoplankton density throughout the Bay and shifts in particulate organic carbon (POC) loadings. For those species linked to phytoplankton abundance, including zooplankters and planktivores fish, such reductions are likely having a direct influence on population dynamics. The reduction in phytoplankton has likely resulted in conditions of greater water transparency during the summer and fall months when Delta inflows are generally at their lowest. For species which are negatively phototactic, this may result in altered feeding and patterns of migration.

Citing the date of introduction of the Asian clam as 1986, both Moyle (1992) and Herbold et al. (1992) suggest that it has had little influence on the recent declines in fish abundance (first noted in the early 1980s) in the Bay-Delta; the species became abundant after the biotic declines were well underway (Moyle, 1992). This may be the case for the asian clam, but the copepod Sinocalanus sp. was noted as early as 1978 (CDF&G, 1987), and reportedly resulted in major declines in abundance of *Eurytemora sp.* by 1979 and 1980. A comparison of density data over time for Eurytemora sp. in both the Sacramento and San Joaquin systems, compared to Delta smelt abundance suggests that some relationship may exist (Figure 7). The potential effects that the implementation of the proposed X2 standard may have on both native and introduced species, especially those cited as being of concern to the ecosystem, was completed by R2 Resource Consultants, Inc. (R2, 1994b).

6.4 DEGREE OF EFFECT ON EXISTING FISH SPECIES ABUNDANCE

There can be no question that the introduction of non-native species has influenced the existing species composition and population abundance in the Bay and Delta. However, Moyle (1992) considered "introduced species" as overall, a "minor contributing cause" to the declines of fish species (nine species reviewed) in the system. He did consider introductions to be a "major" and/or "secondary contributing" cause of declines of certain invertebrate species including *Eurytemora sp., Neomysis sp., and Crangon f.* presumably associating such declines with the introduction of two exotic zooplankton species (*Sinocalanus doerii* and *Psuedodiaptomous forbesi*) and the Asian clam. Interestingly, the three species are known to be important food items for larval fish using the delta, so as noted above, there would appear to be the potential for effects on these invertebrates to be imparted to higher trophic levels, e.g., fish. Moyle (1992) noted, however, that increases in the three introduced invertebrate species occurred subsequent to the initial declines in fish abundance, although *Sinocalanus d.* was reportedly introduced in 1976, well before such declines. Even under relatively stable environmental conditions a high degree of uncertainty exists regarding the response of native fish and invertebrate populations on non-native introductions. In the Bay and Delta, which is being subjected to new and changing conditions on almost a daily basis, we believe it is premature to rule out such introductions as contributors to the declines in abundance of certain fish species.

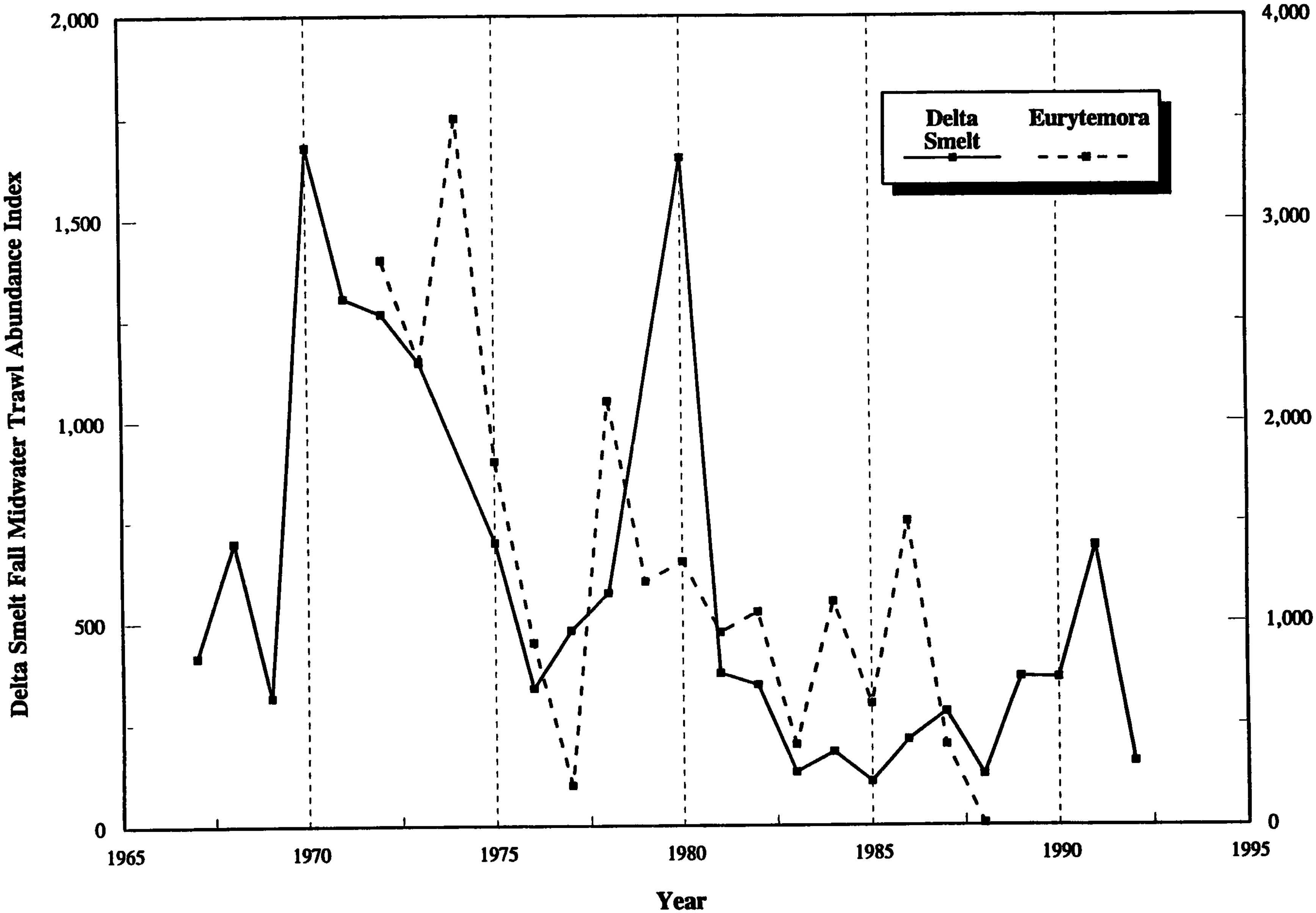


Figure 7. Delta smelt abundance and Eurytemora sp. densities in Suisun Bay for the period 1966 to 1992. Data from Herbold et al. (1992).

How these introduced species may impact or control fish abundance in the future has been largely overlooked, and yet factors directly into the success of the proposed EPA salinity standard for achieving stated goals. It may be possible to dismiss introduced species as being a major cause of the declines of fish abundance in the Bay and Delta, as has been done by Herbold et al. (1992) and Moyle (1992) (although we would disagree with this), but they cannot be ignored when considering the future recovery of the species. Moyle (1992) noted that the typical pattern for an invasive species is to become extremely abundant for a few years after the initial introduction and then to gradually decline as it becomes integrated into the ecosystem and regulated by environmental factors, competitors and predators. When describing the future of Potamocorbula sp., Moyle (1992) states, "if its populations follow the trajectories of other introduced species in the estuary, it will naturally become less abundant and more integrated into the ecosystem as the estuary recovers from its present stressed situation (assuming it is allowed to recover)." This is an oversimplification of the dynamics of introduced populations and one that cannot be assumed for the Asian clam or for that matter, other species that have been introduced into the Bay-Delta. Furthermore, the context in which it is stated presupposes that the introduced species will have no adverse impact on existing fish and invertebrate populations, either directly via predation, or indirectly through interspecific competition (for food and space), the latter effect resulting in shifts in species dominance and abundance and/or alterations in forage base and food web relationships. The changes in species composition and abundance that have already occurred in the Bay from the introductions of Potamocorbula sp, Sinocalanus sp, and Pseudodiaptomus sp., suggest their introductions have and will have more than just a casual influence on the overall ecosystem. Herbold et al. (1992) stated in regard to the Asian clam,

> "the short time which has elapsed since the almost complete conversion of the former diverse, fluctuating benthic community into the present, spreading monoculture of the Asian clam precludes any confident guesses on the long-term effects of the clam on other aquatic resources of the Bay."

A re-examination of the potential linkages between the most recent introductions and trends in fish abundance is warranted and absolutely essential for attaining long term restoration goals for the Bay and Delta. This should be done in the context of: 1) defining the extent to which "introduced species" may have contributed to existing declines in abundance; 2) evaluating projected ecological effects of the continued growth and propagation of the introduced species on existing populations *in the absence of any EPA standard*; and 3) conducting an ecological risk assessment of *effects of implementation of the X2 standard on propagation and potential expansion of introduced species, and resulting impacts on existing* *fish populations.* The EPA should fully evaluate both ecological benefits and risks associated with the implementation of the salinity standard.

7.0 EXPLOITATION - FISHING REGULATIONS

Although beyond the scope of this review, the effects of fishing pressure and exploitation of the fishery resource also warrant consideration. These include both commercial and sport fisheries, as well as the illegal take (poaching) of fish. Species potentially affected by overexploitation include salmon and steelhead, striped bass, and others which support a commercial fishery (e.g., shad). However, even species which are of neither sport nor commercial importance can be directly affected if the harvest techniques applied to the target species prove harmful to others (e.g., seining, gill netting, etc.).

An analysis of fishing regulations and catch statistics should be completed over time to determine the potential for overharvest and angling mortality to be one of the factors influencing species abundance.

8.0 POLLUTION

The San Francisco Bay region is one of the most densely populated areas in the country and a region which is widely recognized for its industrial and agricultural developments. As population densities have increased, so to has the production of agricultural, industrial, and municipal wastes and the need for treatment/disposal of such wastes. The significance of the pollution problem relative to the Bay-Delta system was underscored in the recent "Status and Trends Report on Pollutants in the San Francisco Estuary," prepared by Davis et al. (1991), and summarily presented in Monroe and Kelly (1992).

Davis et al. (1991) provided a brief chronology of the development of the system and the increase in pollution that accompanied such. The timeline for pollution we have constructed (Figure 1) begins in the early 1950s when the first primary water treatment facilities were employed. This predates any regulatory mandates controlling pollution and therefore signals the general recognition that impacts were occurring to the Bay-Delta system. In addition to municipal waste loads, Davis et al. (1991) considered the construction and operation of several refineries, the application of synthetic organic pesticides, and water development projects as major contributors to the abundance and fate of pollutants in the Estuary. The latter component relates to hydrodynamics and how pollutants are moved throughout the system.

As suggested above, the first evidence of biological degradation to the Estuary via pollutant discharge was provided in the early 1950s. This was noted by Filce (1954) who evaluated the benthic community composition in portions of San Pablo Bay. Primary treatment by several publicly owned treatment works (POTWs) subsequently occurred, with secondary treatment initiated in the 1960s. With the passage of the Federal Clean Water Act of 1972, both municipal and industrial dischargers were required to meet certain water quality standards. Because of improvements in waste water treatment technologies, the number of treatment plants has actually decreased from 82 to 58 (Davis et al., 1991). Of these, 37% receive tertiary treatment and the remaining 63% secondary treatment. The result of these improvements has been a steady decline in the quantity of biological oxygen demand (BOD) loadings and suspended solids released into the Bay (Figure 8). Consequently, it is generally agreed that most of the "conventional" pollutants have been controlled and that concerns over nutrient enrichment and eutrophication have been reduced.

At the same time questions have developed regarding the role the organically enriched untreated effluents had to primary production and its relationship to invertebrate and fish production. Indeed, Tsai et al. (1991) suggested that improvements in sewage treatment

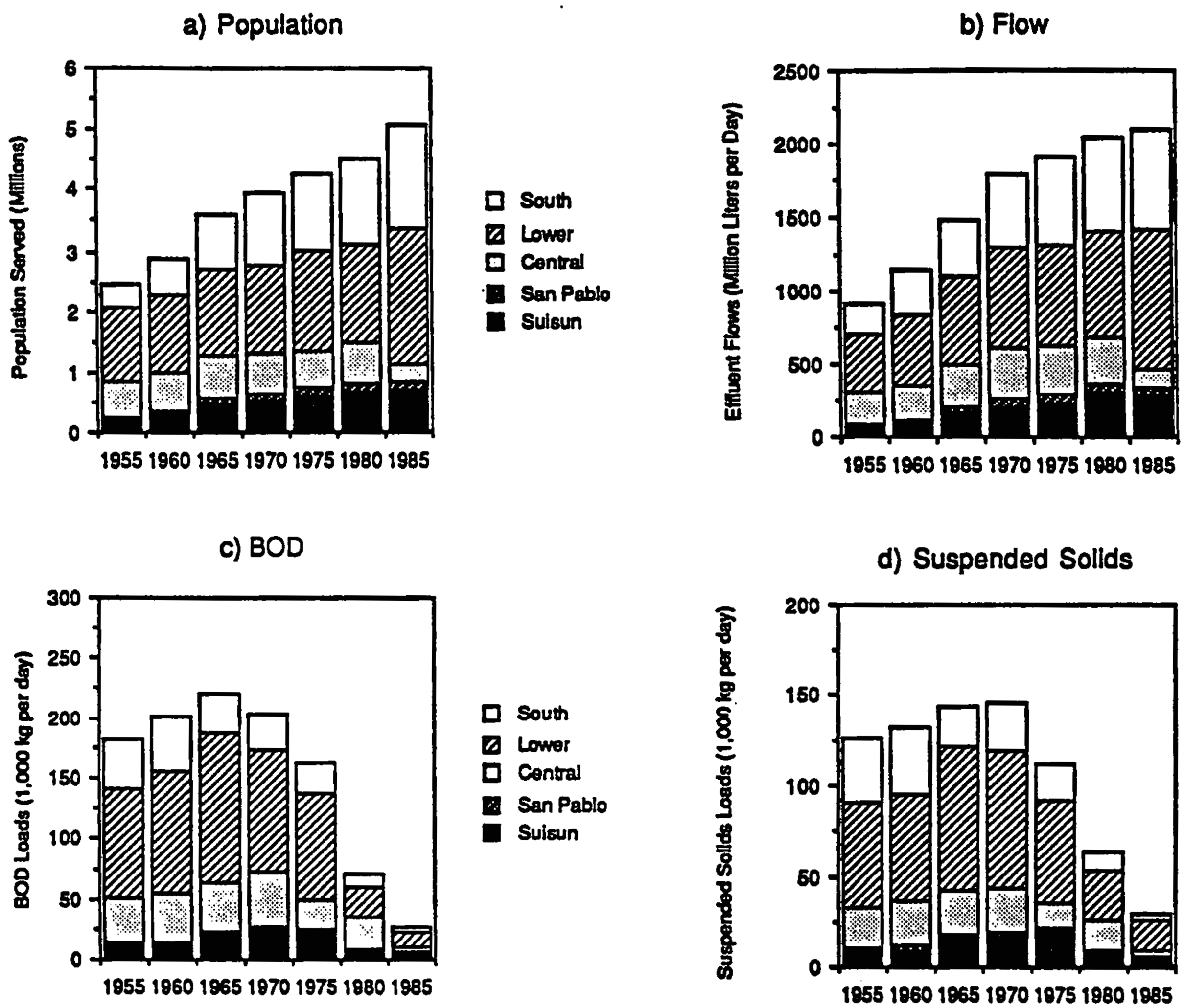


Figure 8. Trends in biological oxygen demand (BOD) and suspended solids loadings to the San Francisco/Sacramento-San Joaquin Estuary. Data from Davis et al. (1991).

processes were in part, responsible for declines in striped bass populations in the Potomac River estuary. Based on an analysis of biological oxygen demand loadings from sewage treatment plants and total commercial harvest of striped bass from 1938 to 1983, they suggested a relationship existed between sewage nutrients and the status of the fishery. They hypothesized that the nutrient loadings to the system during the 1940s through 1960s (pre-secondary treatment) increased the fertility of the estuary and resulted in increased abundance. The development and implementation of secondary treatment in the early 1970s subsequently reduced the nutrient loading and the fertility of the waters in important spawning and nursery habitats, and thus contributed to the declines in abundance. The Bay-Delta system differs from that in the Potomac system in that the majority of sewage loadings occurred in the south, lower and central regions of the Bay. Moyle (1992) raised this point in discounting this type of causal relationship as operating in the Bay-Delta system. Stevens et al. (1985) briefly discussed this potential in their review of factors related to striped bass declines. They noted that the hypothesis had been raised by C. Hanson, and that a relationship existed between zooplankton concentrations at the place of initial feeding by striped bass and an index of organic loading. Stevens et al. (1985) suggested that these changes may have resulted from improvements in waste treatment and that a linkage to striped bass decline may exist. A review of the trends in abundance of the major zooplankton species (rotifers, cladocerans, and copepods) as presented in Herbold et al. (1992) does suggest a decreasing trend during the same time when BOD loadings were being reduced in the Bay. The Food Chain Group of the Interagency Ecological Studies Program (IESP) has been evaluating various hypothesis regarding potential food limitations as controlling fish abundance in the Sacramento-San Joaquin Estuary, but so far, no overall conclusions have been reached. Miller (1991) completed a brief comparison of relative densities of food organisms between the Sacramento-San Joaquin system and several in the eastern U.S. (Chesapeake Bay, Potomac River, Sassafras River, Pamunkey River, Roanoke River) and suggested that food limitations could be a problem. The degree to which nutrient loadings may be affecting this condition should be evaluated further.

According to Munro and Kelly (1992), chemicals now pose the greatest threat to the estuary. Davis et al. (1991) prepared a listing of pollutants of greatest concern, which were grouped into three major categories: trace elements, ogranochlorines and other pesticides, and petroleum hydrocarbons. Munro and Kelly (1992) identified eleven different sources of these pollutants to the estuary including the following:

- *Municipal wastewater treatment plants*: process human waste, trace elements, synthetic organic chemicals (some pesticides), and solid materials.

- *Industrial facilities:* petroleum refineries, pulp and paper mills, chemical manufacturers; metal processing plants.

- *Urban runoff:* rainwater runoff from streets, storm sewers, excess irrigation flows (source of a variety of pollutant types).

- *Nonurban runoff:* runoff from agricultural land, forests and pasture lands (pesticide and herbicide contamination).

- *Riverine inputs:* sources of pollutants which originate upstream and are transported to estuary (include municipal, agricultural, manufacturing etc.).

- *Dredging and Dredge Material Disposal:* resuspension of pollutants during dredging operations (sediment and pollution interactions).

- *Atmospheric deposition:* aerosols and vapor (small contribution to Bay).

- *Marine Vessel discharge:* sewage and "gray"water disposal into the Bay and Delta (source of nutrient loadings, also introduction of exotics).

- *Accidental Spills*: primarily petroleum products.

- *Leakage from Waste Disposal Sites*: hazardous waste sites and municipal land fills.

The degree to which these sources of contaminants are individually and collectively impacting the aquatic biota of the Bay-Delta has only recently come under investigation. Phillips (1987) provided a review of the major findings relative to pollutant effects and fish population abundance. He noted possible linkages for at least two species, striped bass, and starry flounder. Cashman et al. (1992) evaluated moribund striped bass for contaminant uptake and found residues in livers of materials that could have originated from industrial, agricultural and urban sources. Cashman et al.(1992) suggested that pollutant uptake could be responsible, in part to the seasonal "die off" of striped bass which has occurred in the Delta. This "die off" apparently corresponds to the discharge of several herbicides (molinate and thiobencarb) used in the cultivation of rice. The use of these herbicides has raised widespread concerns over possible toxicological effects to aquatic biota in the Delta, and in particular striped bass. As a result, water quality criteria were developed for both molinate and thiobencarb by the CDFG (Harrington, 1990). The recommended water quality criteria for molinate was 13 μg/l, and 3.1. μg/l for thiobencarb. According to Harrington (1990), these concentrations should pose no hazard for mysids (shrimp) in the Sacramento River, although some risks occur in the agricultural drains. Because young striped bass may use backwater and slough habitats, it seems logical they may likewise be at risk. The levels developed by Harrington were much lower than those recommended by Finlayson (1983)(as reported in Cornacchia et al. (1984)) who suggested a criterion of 90 $\mu g/l$. However, Finlayson's criteria were presented as interim guidelines until more detailed studies could be completed; they were based on literature values and were designed to protect the most sensitive species of fish occurring in the agricultural drains.

Davis et al. (1992) also presented evidence suggesting that starry flounder may be impacted by pollutants. Studies have shown that fish from the Central Bay have higher concentrations of Polyclorinated biphenyls (PCB's) and other organic pollutants than fish from northern San Pablo Bay. This has been linked to poor reproductive success. However, Davis et al. (1992) noted that the degree to which these effects may be influencing the populations and fishery in the Estuary remains unknown.

Because of the wide diversity in the types of chemicals being discharged (and the point source location) to the Bay-Delta system, it is not surprising that relatively little can be said of their potential effects on fin and shell fish abundance, certainly not in a quantitative sense. The fate and transport of these chemicals is poorly understood, and their ultimate effects on aquatic biota are difficult to evaluate. Davis et al. (1992) reported the following observations as suggestive that pollutants are having a significant effect on the estuary:

- Certain creeks and rivers in the Bay-Delta catchment and some sediments are toxic in bioassays.
- Numbers of species and abundance of benthic invertebrates has decreased in certain highly polluted areas.
- There is statistical evidence that reproduction of starry flounder may be negatively affected by PCB's.
- High concentrations of silver and copper are found in shell fish in the South Bay.
- Evidence exists that genotoxic chemicals may be impacting starry flounder.

This has resulted in many researchers concluding that pollutants are having a deleterious effect on the biota of the Estuary. Unfortunately, as noted by Davis et al. (1992), the actual cause:effect relationships will likely only be established from laboratory studies, and the degree to which the results can be transferred to field conditions is uncertain.

What is certain is that the Bay-Delta system has and continues to receive the discharge from thousands of point and non-point sources of pollution. The fate of these chemicals and their potential effect on the aquatic ecosystem of the estuary can only be determined through a long term commitment of all responsible and potentially responsible parties (agricultural, industrial, municipal) and regulatory agencies. This commitment should be in the form of applied research focused on: 1) identifying sources and fate/transport mechanisms of all major contaminants; and 2) eliminating/controlling to acceptable levels the release of such sources to the Bay-Delta. The quality of water needed to support populations of estuarine, freshwater and marine species in the Bay-Delta is dependent on more than just a certain concentration of salinity. It appears as though the EPA has not adequately addressed the effects of other existing water quality related factors that are influencing the ecosystem, or attempted to apportion-out their relative contribution to the perceived declines in abundance. This seems inconsistent with the stated objectives of the Clean Water Act (CWA) which, as noted in section B (Statutory Basis and Purpose) on page 15 of the Proposed Standards, are to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. As noted earlier, this places the burden of restoring species abundance solely on the water users and exporters *(entities which can influence salinity)*, without addressing the sources and effects of other contributing factors such as pollutants *(entities which can influence other water quality parameters)*.

9.0 UPSTREAM IMPACTS - DAMS, RESERVOIRS, HATCHERY CONSTRUCTION

Upstream or offsite impacts to fish are those associated with dams, reservoirs, and hatchery construction. In general, these types of impacts will not be reduced by the X2 salinity standard, and other measures (e.g., screening of diversions, flow regulation) must be implemented to protect species which utilize upstream habitats. However, the proposed salmon smolt survival indices are based on several flow related variables (e.g., temperature, out of stream diversions, export rates) and are being promoted as a means to restore conditions to 1960-1970s levels. Such indices are only focused on the downstream migration of smolts, and do not consider the broader problem of habitat loss, or problems associated with adult upstream migrations.

9.1 DAMS AND RESERVOIRS

The declines in chinook salmon and other anadromous species have largely resulted from dams and diversions upstream of the Delta and Estuary. The majority of these were constructed between 1950 to 1970 (Figure 2; Table 2) during which the upstream cumulative storage capacity more than tripled (Figure 9). Smith and Kato (1979) provided an excellent summary of the declines in salmon stocks in the Sacramento and San Joaquin systems. They noted that even before many of the major dams were constructed, upstream diversions and storage projects had "cut-off" or removed about 80% of the original Sacramento-San Joaquin spawning grounds. Construction of Shasta Dam in 1944 removed approximately 50% of the spawning habitats of the river (Skinner, 1962), while construction of Friant Dam essentially eliminated salmon runs from the mainstem of the San Joaquin River (Menchen, 1977). Although several mitigation hatcheries were constructed to attempt to offset these losses (see below), these have had mixed success, and there is continuing controversy regarding how to manage a mixed stock fishery. Even so, it is obvious that the habitat conditions which historically existed and which shaped the upper limits of the carrying capacity of the system have been dramatically reduced.

In addition to the direct impacts associated with loss of habitat, the operations of these facilities have altered the natural flow and water quality regimes in the lower rivers. In general, the operation of the dams has served to reduce the magnitude of the spring flows (water is stored during this period) and increase flows during the summer and early fall, periods of normally low flow. This has occurred to match hydropower demands, flood control and water diversion needs. Notwithstanding the loss of habitat, this alteration in regime has created both positive and negative conditions on the fishery resource. Within the

Table 2. Capacities and year completed of the major storage and multipurpose reservoirs in the Sacramento-San Joaquin Draniages.(Kahrl, W. et al.)

Dam	Reservoir	Stream	Capacity (million acre-ft)	Owner	Year Completed	Cumulative Capacity (million acre-ft)
Buena Vista	Buena Vista	Kern River	0.21	Boswell County & Tenneco W.	1890	0
O'Shaughnessy	Hetch Hetchy	Tuolumne River	0.36	City & County of San Francisco	1923	1
Almanor	Almanor	North Fork Feather River	1.31	Pacific Gas & Electric	1927	2
Shaver	Shaver	Stevenson Creek	0.14	Southern California Edison	1927	2
Bucks	Bucks	Bucks Creek	0.10	Pacific Gas & Electric	1928	2
Pardee	Pardee	Mokelumne River	0.21	East Bay Municipal Utilities District	1929	2
Salt Springs	Salt Springs	North Fork Mokelumne River	0.14	Pacific Gas & Electric	1931	2
Friant	Millerton	San Joaquin River	0.52	U.S. Bureau of Reclamation	1947	3
Shasta	Shasta	Sacramento River	4.50	U.S. Bureau of Reclamation	1949	7
Isabella	Isabella	Kern River	0.57	Army Corps of Engineers	1953	8
Pine Flat	Pine Flat	Kings River	1.00	Army Corps of Engineers	1954	9
Cherry Valley	Lloyd	Cherry Creek	0.27	City & County of San Francisco	1956	9
Folsom	Folsom	American River	1.01	U.S. Bureau of Reclamation	1956	10
Monticello	Berryessa	Putah Creek	1.60	U.S. Bureau of Reclamation	1957	12
Courtright	Courtright	Helms Creek	0.12	Pacific Gas & Electric	1958	12
Wishon	Wishon	North Fork Kings River	0.13	Pacific Gas & Electric	1958	12
Trinity	Clair Engle	Trinity River	2.45	U.S. Bureau of Reclamation	1960	15
Mammoth Pool	Mammoth Pool	San Joaquin River	0.12	Southern California Edison	1960	15
Terminus	Kaweah	Kaweah River	0.15	Army Corps of Engineers	1962	15
Whiskeytown	Whiskeytown	Clear Creek	0.24	U.S. Bureau of Reclamation	1963	15
Union Valley	Union Valley	Silver Creek	0.27	Sacramento MUD	1963	15
Camp Far West	Camp Far West	Bear River	0.10	South Sutter Water District	1963	16
Camanche	Camanche	Mokelumne River	0.43	East Bay Municipal Utilities District	1963	16
Black Butte	Black Butte	Stony Creek	0.16	Army Corps of Engineers	1963	16
New Hogan	New Hogan	Calaveras River	0.33	Army Corps of Engineers	1964	16
L.L. Anderson	French Meadows	Middle Fork American River	0.13	Placer County Water Agency	1965	17
New Exchequer	McLure	Merced River	1.03	Merced Irrigation District	1966	18
Hell Hole	Hell Hole	Rubicon River	0.21	Placer County Water Agency	1966	18
San Luis	San Luis	San Luis Creek	2.04	U.S. Bureau of Reclamation	1967	20
Oroville	Oroville	Feather River	3.48	Department of Water Resources	1968	23
Don Pedro	Don Pedro	Tuolumne River	2.03	Turlock & Modesto Irrigation Districts	1970	25
New Bullards Bar	Bullards Bar	North Yuba River	0.97	Yuba County Water Agency	1970	26
Buchanan	Buchanan	Chowchilla River	0.15	Army Corps of Engineers	1975	26
Indian Valley	Indian Valley	North Fork Cache Creek	0.30	Yolo County FCWCD	1975	27
New Melones	New Melones	Stanislaus River	2.40	Army Corps of Engineers	1978	29

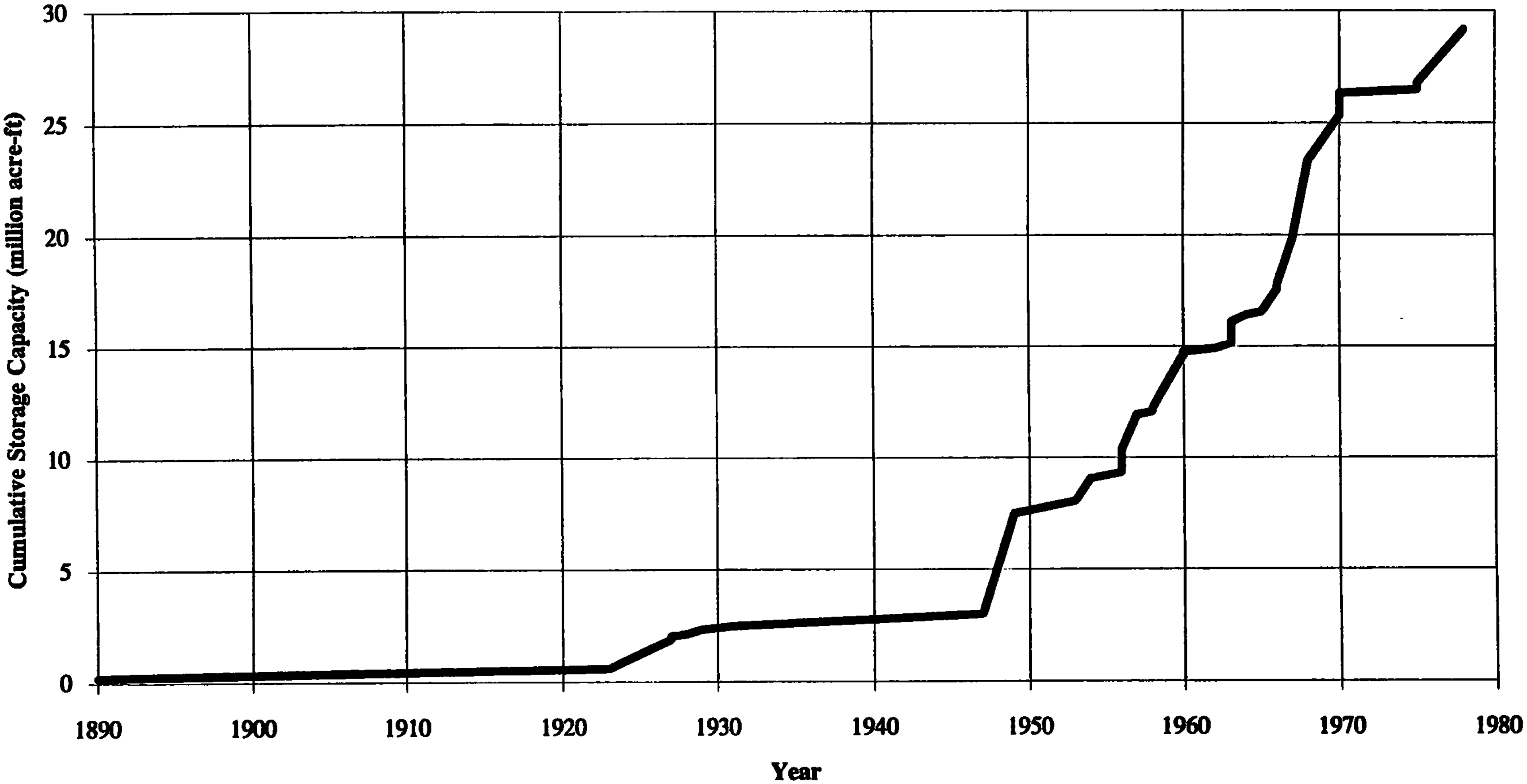


Figure 9. Cumulative storage capacity within the Sacramento-San Joaquine River Basin, 1890-1980. (Kahrl, W. et al.)

river, the regulation of flows in the Sacramento has provided more physical habitat in the system during the summer months through increased flow releases. In addition, the selective withdrawal of water at depth from Shasta Reservoir provides the ability to regulate the thermal regime in the river; i.e., provide important coldwater releases during periods when salmon are holding in the river. This reportedly had a major benefit to the winter run stocks of chinook salmon which showed a steady increase in population size after construction of Shasta Dam (Slater, 1963). On the impact side, the altered flow regime has reduced the magnitude of the spring runoff, which has biological importance in transporting juvenile fish and smolts downstream to the estuary. Delays in this transport process can increase mortality rates through increased predation and losses in diversion canals. The effects of the altered flow regime on the estuarine species are less understood, but are directly related to the proposed EPA salinity standard; i.e., greater outflows are needed to maintain the 2 ppt isohaline in selected habitats. The concern also relates to losses to the CVP and SWP projects via flow reversals.

9.2 HATCHERIES

In conjunction with the construction of major dams, numerous hatcheries have been developed as mitigation for lost habitat and to supplement existing runs of salmon and steelhead. These have included:

- Nimbus Hatchery - 1955
- Mokelumne River Hatchery - 1964
- Coleman National Fish Hatchery - 1967
- Feather River Hatchery - 1967
- Merced River Fish Facility - 1970
- Tehama Colusa Fish Facility - 1974

As noted, the majority of these were constructed to compensate for lost habitat or loss of specific fish runs resulting from water developments. For example, the Mokelumne hatchery was constructed to mitigate for the loss of fall-run king salmon and steelhead trout spawning was lost due to the construction of the Comanche Dam. The Merced River facility was constructed to compensate for fish losses due to the construction of the Crocker-Huffman Dam, a tributary to the San Joaquin River. The Tehama-Colusa facility was constructed on the Sacramento River to mitigate for losses associated with Shasta Dam and Red Bluff dam. Several of these facilities (Tehama Colusa, Mokelumne) include spawning channels which allow for the natural spawning of adult fish.

Collectively, these facilities have produced hundreds of millions of fish (salmon and steelhead) which have been released into the Sacramento and San Joaquin systems (Figure 10); a summarization of the overall contributions was provided by Cramer (1990).

In general, the use of hatchery reared salmon and steelhead to supplement wild stocks of fish has been an accepted practice since the late 19th century. Aside from the originally perceived benefits of these facilities, i.e., the ability to maintain and/or augment fish runs in selected systems, and to provide for recreational harvest, the operation of hatcheries does have certain negative impacts relative to the Bay-Delta ecosystem. These can be categorized into operational and biological effects.

From an operational perspective, the above hatcheries are point-source contributors of organic and biological oxygen demand (BOD) loadings to receiving waters, and their discharge has been related to shifts in benthic community structure (Kendra, 1991; Munro et al., 1985). Although hatcheries must comply with the Clean Water Act and must have a National Pollution Discharge Elimination System (NPDES) permits, organic loading still occurs, and may, in the case of the Sacramento-San Joaquin systems contribute to particulate organic carbon (POC) levels in the Bay-Delta.

The biological impacts of hatchery outplants have only recently begun to be evaluated. In part, this is because it has taken time for the biological systems to respond to this type of "artificial" control placed on existing natural components. Recent studies in the Columbia River system have suggested that the hatchery programs are being less than successful relative to the number of returning adult fish. McIntyre (1985) noted that a conundrum exists in the system in that as many or more smolts are entering the ocean as in the past, and yet the returns of hatchery fish show a declining trend. It is likely that a similar trend has or may potentially occur in the Sacramento-San Joaquin systems. Chapman et al. (1991), as part of an overall review of the status of Snake River chinook salmon completed a comprehensive evaluation of hatchery operations in Snake and Columbia systems. Their analysis suggested that overall, fish produced in natural environments survive better than hatchery produced fish. As evidence, they cited the higher percentage of returns of adult wild fish, compared to their contribution as smolts, which was much lower than the proportion of hatchery fish. That is, even though the percentage of wild stock smolts was smaller than that provided by hatchery stocks, they resulted in a much greater percentage of the numbers of returning adults. Chapman et al. (1991) noted that although current hatchery practices remain focused on total production, there is an increasing awareness that smolt quality and genetic conservation are the real key factors governing the success of

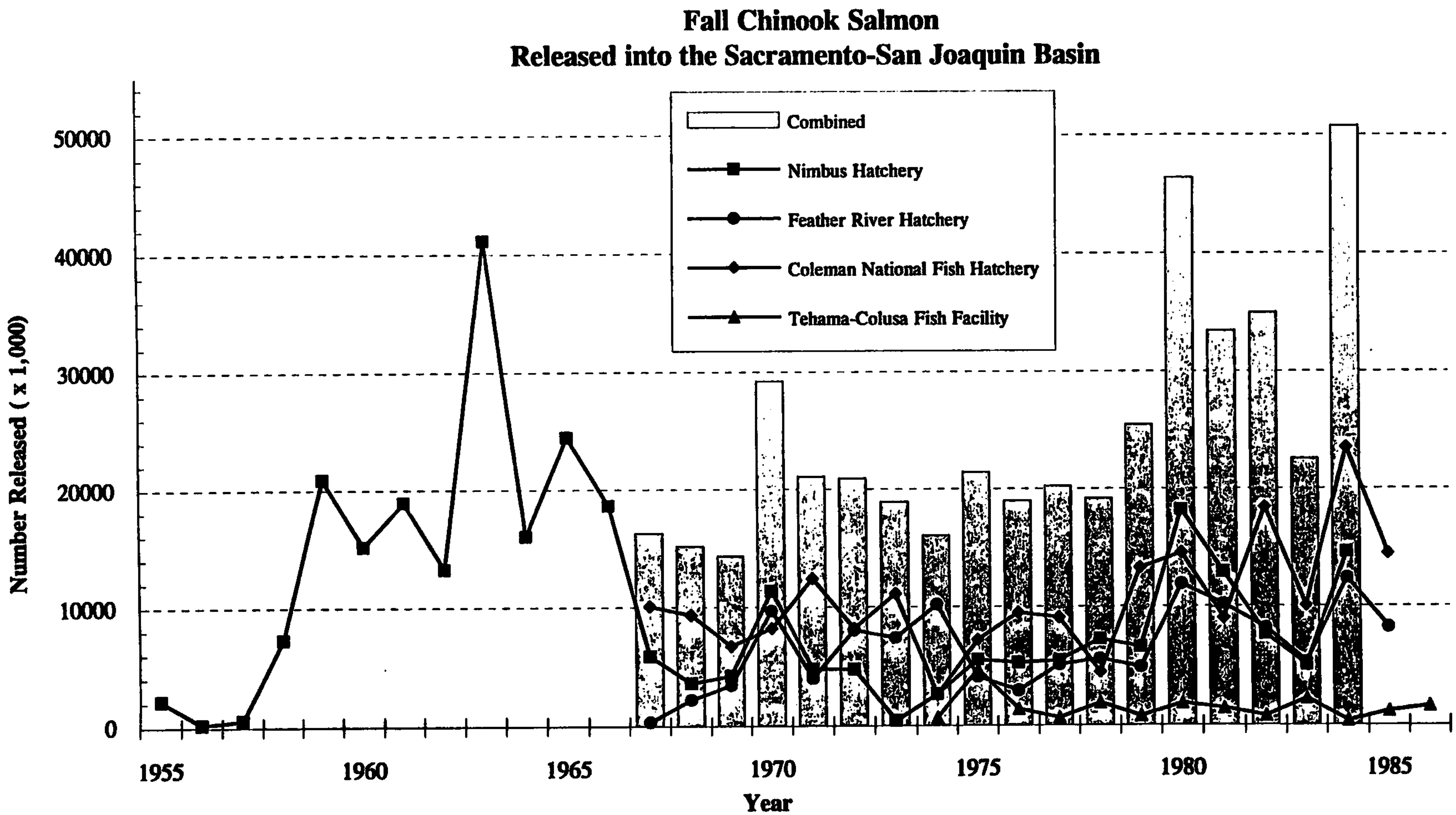


Figure 10. Annual production of fall chinook salmon released into the Sacramento-San Joaquin Basin from hatcheries, and combined annual production. (Data from Cramer 1990).

supplementation programs. Factors that must be considered include; disease transfer, interactions with wild stocks, timing of release of outplants, and the age and size at release. Such factors are especially important when considering potential effects on endangered species. In fact, Meffe (1986) proposed a set of guidelines (presented in Chapman et al., 1991) for managing long-term genetic resources of endangered species. These include:

- Genetic monitoring of wild and hatchery stocks
- Maintaining largest feasible effective population size in wild and hatchery stocks
- Integrating wild spawners from supplemented stock to hatchery broodstock
- Avoid inbreeding that can occur from selective mating
- Supplementing with non-smolt life history stages
- Don't use hatchery stocks to supplement genetically dissimilar wild stocks

It light of the recent listings of the winter-run chinook and the consideration of listing of other stocks, it is imperative that these guidelines at least be reviewed and to the extent practical, applied in the management of hatchery stocks in the Sacramento and San Joaquin systems. The CDF&G has apparently recently completed a Biological Assessment for the Coleman Fish hatchery to evaluate the potential effects of its operation (fall and late-fall run chinook production) on winter-run chinook. The National Marine Fisheries Service (NMFS) is scheduled to issue its Biological Opinion regarding a jeopardy/non-jeopardy decision in the near future.

Chapman et al. (1991) also suggested that in some cases, hatchery augmentation and/or interference with natural populations may reduce indigenous populations. They cited examples where wild stocks of chinook salmon increased, where no hatchery supplementation occurred, while populations with hatchery supplementation did not. In another drainage, hatchery stocking proved to be quite effective in restoring fish populations, presumably because the indigenous stocks were essentially gone prior to any stocking. These same types of situations have likely occurred in the Sacramento-San Joaquin systems, and may in part explain some of the more recent declines in native stocks of fish. This warrants a detailed evaluation.

The intent of the proposed salmon smolt survival indices is to provide a set of conditions in the Sacramento and San Joaquin rivers conducive to the successful migration of smolts to the ocean. The indices were computed based on various flow releases and conditions existing in the river (e.g., open/closure of Georgiana Slough). Via a backcalculation of hydrologic data, the EPA computed what the index values would be circa 1956-1970, and adopted these values (with some additional adjustment for the San Joaquin system) as the proposed salmon smolt criteria.

In light of the situation that has developed in the Columbia River, we believe it should be noted that providing smolt passage to the ocean does not guarantee a high adult return rate to the respective systems. Many other factors, including the influences of hatchery outplants and, in the case of salmon and steelhead, ocean harvest, serve to control the numbers of returning adults. The EPA standard based on a smolt survival index alone is too narrowly focused and assumes a "fix" to the problem can occur through adjustments in certain flow characteristics and reductions in diversion impacts. While acknowledging that impacts do indeed occur to smolts from flow regulation and that measures to reduce or eliminate such impacts are warranted, it is unclear how and to what degree the setting of the smolt survival index will accomplish this. Furthermore, we believe that of equal importance to increasing downstream smolt survival through adjustments in flow, are efforts to reduce losses into the myriad of unscreened diversions within the Bay-Delta system. In addition, more emphasis should be placed on improving adult returns, including an evaluation of the effectiveness of the hatchery programs and a critical review of ocean harvest and exploitation impacts.

10.0 RANKING OF IMPACTS - APPORTIONMENT OF INJURY

As part of Moyle's (1992) testimony, he presented a ranking of the 12 categories of factors identified as causing potential declines in aquatic species in the Bay and Delta. Although no details were provided, it was assumed the rankings were subjective and based on the authors' (P. Moyle) experience and understanding of the system. Excluding "out of delta factors" (those factors which operate outside of the Delta), the highest and most frequently cited of the causes was the SWP/CVP pumping operations. This was cited as being the number one factor influencing abundance for 73% of the fish species considered. Natural factors including extended periods of drought, floods, and climatic change were considered as secondary contributors to changes in population abundance for 82% of the fish species. The majority of the remaining factors were considered as having only a minor, unlikely, or no causal effect on changes in fish abundance.

As noted by Jassby (1992) in his discussion of the biological relationship between X2 and abundance, "statistical relationships are not proof of causal connections." Thus, it was not the intent of his analysis to suggest that X2 alone, or salinity in general, controlled the biological resources of the estuary. Similarly, we are not suggesting that any single "other factor" is controlling the resource; it is the combination of factors that have shaped the existing conditions of the system. Nevertheless, the EPA standard does suggest that the provision of the 2 ppt isohaline at specific locations in the Delta and at certain times will alone, substantially benefit the aquatic ecosystem.

As described earlier (See Section 1), the X2 standard only applies to salinity and the outflows needed to influence its location. The biological premise of EPA's proposed X2 standard is that a variety of aquatic organisms have an affinity to the 2 ppt isohaline and the closely associated "entrapment zone" (primarily for its presumed increased productivity), and that the entire ecosystem would benefit from its location at or below certain locations at certain times of the year. Jassby (1992) and Herbold et al. (1992) presented information which purportedly was the foundational material for the standard. However, a review of their materials indicated that the position of the low salinity isohaline would, based on the information they presented, have its greatest influence on only 1-2 fish species (e.g., Delta smelt, splittail). This is because of studies which have reported close associations of Delta smelt and the location of the entrapment zone (Moyle et al., 1992). For the other species discussed by Herbold et al. (1992), there is no evidence of a direct dependency or benefit from the position of the 2 ppt isohaline, although for most, there are no negative effects either (See R2, 1994). Even for Delta smelt, the species most often cited as benefitting from the X2 location, data from the mid-water trawl studies exhibit high catch rates over a wide range of habitat conditions, both below and above Chipps Island, independent of X2 location. A more detailed assessment of MWT catch data and an evaluation of the biological basis for the standard are presented in R2 (1994b).

Potential benefits of the X2 standard will only be realized for those species which directly depend upon the location and area provided by the entrapment zone, or those positively affected by the increased inflows of water and decreased exports of water required to maintain this standard. Thus, for most species, even for Delta smelt, the data suggest that factors other than the duration at which X2 is at a particular location are operating to affect existing population dynamics. Some of these are related to direct and indirect effects of the quantity of inflows, magnitude of exports, and outflow conditions to the Bay and Delta. Others are related to both natural and anthropogenic impacts that have occurred in concert with the industrial, agricultural, and urban development of the Bay and Delta. These factors should be considered by the EPA when setting water quality standards. Failure to do so may result in the setting of standards which are unnecessarily restrictive on certain user groups, even though data are lacking which provide demonstrable evidence of the biological benefits of the imposed constraints.

The "fixing" of the Bay-Delta ecosystem will require more than just modifications in outflow patterns, exports, and reductions in losses of fish into SWP and CVP systems. The factors associated with introduced species, impoundments, land developments, pollution, infrastructure, fishing mortality, and others must also be addressed. This could be completed through a process whereby the total injury to the resource (measured as a function of fish losses below an established baseline) is apportioned to various factors. The responsibilities for restoration could then be equitably assigned between all user groups, resulting in the development and implementation of measures which are truly focused on remedying all of the major problems impacting the Bay-Delta ecosystem.

11.0 ON THE SELECTION OF AN APPROPRIATE BASELINE CONDITION

The Bay-Delta ecosystem is not a static system and has been changing and adjusting its character, morphology, species composition, etc. for literally thousands of years, with most man-induced changes occurring within the last century (Figure 2). The changes that are man-induced over the relatively recent time span have created an ever changing set of conditions that alternately (depending on complex interactions of physical, chemical and hydrologic parameters) favor or dis-favor certain assemblages of fish. To re-establish the same relative abundances of certain "target" fish species as existed in 1965-1976 would require a "reset" of the major factors that shaped the populations to levels at that time, and the elimination or control of factors responsible for reducing the populations to present day levels. Although an admirable and biologically and politically correct objective, such goals can only be achieved through direct action in the Bay-Delta focused not only on the control of water quality and quantity issues, but also on the creation/restoration of lost physical habitats, elimination of known and controllable sources of mortality such as: intake and diversion screening, powerplant entrainment, thermal pollution, contaminant toxicity, excessive predation, overexploitation, and the control/management of introduced species which may be altering delicate species:food chain relationships. Given the myriad of other factors that are influencing the system, it is unclear and uncertain as to how these species will respond in the long term. We would suspect that attainment of abundance levels to those that occurred in the late 1960s-early 1970s may be possible for some species, while for others, there may be no change or a continuing decline. The setting of a reference time frame ("baseline") to target recovery goals is complicated and should take into consideration other factors/conditions that have subsequently developed and which would interfere with the restoration of a given species. The proposed EPA standard suggests that... "Land use patterns and upstream water developments had largely stabilized by the end of this period (1960s-1970s) so that increases in project impacts are the dominant change associated with the subsequent decline in fishery resources." We suggest that the Bay-Delta ecosystem has been subjected almost continuously to new and changing factors (both flow and non-flow related) that can influence species abundance. Indeed, a strong argument can be made that the species assemblages present in the 1960-1970s were but a transitory stop in the continuing process of populations responding to previous impacts. It should be noted that the response of populations to environmental perturbations can take many years to manifest a change and reveal overall effects, especially when species interactions are complex. Consequently, EPA should consider establishing goals based on a "use attainability" concept, which would factor in other effects that may ultimately limit population response. This would provide a more realistic and technically supportable restoration goal and one that is achievable than the establishment of goals based on some arbitrary time period.

12.0 SUMMARY AND CONCLUSIONS

This document has served to review and discuss a variety of "other factors" which may be influencing or in some way impacting the aquatic resources in the Bay-Delta. The review was completed to address the underlying question of the likelihood to which the proposed EPA standard would or would not achieve the stated objective of restoring habitat conditions and species abundances to late 1960s-early 1970s levels; i.e., what is the effectiveness of the standard? This was deemed important, in as much as the entire basis and technical justification for the standard presupposes that all (at least the majority) of the problems in the estuary are the result of the water project operations. EPA provides justification for the standard by pointing to those operations and how they have negatively influenced the location of the 2 ppt salinity isohaline. The intent of the standard then is to ensure that the 2 ppt would be at specified, biologically important locations at certain times and for specified durations deemed necessary to promote fish production.

Based on our evaluation, we have concluded that there are a number of other factors (e.g., introduced species, upstream effects) which will continue to operate even with the X2 standard imposed. These, either singly or in combination may prevent or limit the biological responses achievable through the manipulation of salinity. Because of the high water costs associated with meeting the standard, a more detailed analysis is recommended to evaluate the overall benefits to the resource attainable through its promulgation.

13.0 STATISTICAL COMPARISONS - OTHER FACTORS

As described throughout this report, many environmental factors in addition to salinity are likely to be important in determining the abundance and distribution of aquatic life in the Bay-Delta ecosystem. Proponents of the X2 standard have argued that salinity in the Bay-Delta is correlated with a number of other factors, including outflow, particulate organic carbon concentrations, primary production, and the abundance of invertebrate food items (e.g., zooplankton) important to fish. The EPA is presently considering the implementation of a salinity standard largely because of the association of salinity with important and integral components of the Bay-Delta ecosystem. A major criticism towards the EPA's support of a salinity standard is the lack of evidence for cause-and-effect relationships between salinity and the ecosystem components and processes which the standard is intended to protect. It is possible that many factors may "explain" the variation in these ecosystem components just as well or better then salinity. However, potential relationships between factors other than salinity and the annual abundance indices used by Jassby (1993) to support the X2 salinity standard have not been explored in detail. Hence, only one of many possible hypothesis has been tested so far: i.e., the position of the 2 ppt isohaline is important to the annual abundance of "key" species of the Bay-Delta ecosystem.

In order to evaluate the strength of the EPA's argument that salinity is the "best" criteria for protecting aquatic resources in the San Francisco Bay Estuary and the Sacramento-San Joaquin Delta, we analyzed correlations between "key" estuarine species and a number of environmental factors. The fish species we considered in our analysis included Delta smelt, longfin smelt, Sacramento splittail, starry flounder, striped bass, and threadfin shad. Those environmental factors we considered included:

- *Time.* Relationships between time (i.e. year) and abundance values were evaluated.

- *Flow.* Flow related variables included in our analysis include annual mean inflow and outflow to the Delta, mean annual flows diverted to the SWP and CVP, and days of reverse flows per year.

- *Salinity.* The mean position of X2 (2 ppt isohaline) was included to test the relative "predictive" strength of this proposed water quality criteria against other environmental factors.

- *Food Abundance.* The annual concentrations of *Neomysis mercedis* (entire Delta, Suisun Bay, and west Delta), *Eurytomora affinis*, other Cyclopoids, total zooplankton concentrations (west Delta and Suisun Bay), and *Crangon franciscorum* abundance were included in this analysis to identify potential relationships between invertebrate food abundance and fish abundance.

- *Organic Matter Inputs and Primary Productivity.* Particulate organic matter concentrations (Suisun Bay) and yearly peak Chlorophyll-*a* concentrations (Suisun Bay) were included in this analysis.

- *Water Quality.* Water quality parameters tested for "predictive" capabilities included biological oxygen demand (average annual loading to Suisun Bay and western Sacramento-San Joaquin Delta), turbidity (secchi depth for entire Delta, as well as for Sacramento and San-Joaquin rivers), water temperature (average for all Bay-Delta midwater trawl sampling stations), and electroconductivity (also average for all Bay-Delta midwater trawl sampling stations).

Pearson correlation coefficients were calculated to test the capabilities of these environmental factors in "predicting" the annual abundance values of selected fish and invertebrates of the Bay-Delta system. Species tested included longfin smelt, Delta smelt, striped bass (young-of-year), starry flounder, Sacramento splittail, threadfin shad, and the Bay shrimp *Crangon franciscorum*. In addition, the abundance of adult steelhead captured at Red Bluff, California were used to identify spurious correlations which might occur between environmental variables in the Bay-Delta and the abundance of a fish species which is dependent upon factors occurring outside of this region.

The position of X2 was not among the environmental factors which showed the highest correlation with abundance for each of the species analyzed (Table 3). Particulate organic carbon concentrations (POC) in Suisun Bay were found to have the highest correlation with longfin smelt abundance ($r = 0.71$). The abundance of Delta Smelt and striped bass was most highly correlated with the density of zooplankton in Suisun bay ($r = 0.93$ and 0.69, respectively). Alternatively, the abundance of threadfin shad was most highly correlated with the density of zooplankton in the west Delta ($r = 0.92$). Sacramento splittail were also highly correlated to a food item: *Crangon franciscorum*. The correlation coefficient between the annual abundance of the starry flounder and the abundance of this Bay shrimp species was 0.82. The use of *Crangon* as a food item for Sacramento splittail is uncertain, since these fish probably feed on smaller food items such as opossum shrimp. However, splittail may be correlated with *Crangon* abundance due to similar habitat or salinity preferences, or alternatively due to a dependence upon similar invertebrate food types. Both starry flounder and *Crangon fraciscorum* abundance indices were most highly correlated to average annual flows in the Delta. The abundance of starry flounder was most highly correlated to average outflow values ($r = 0.75$), while the abundance of *Crangon franciscorum* was most highly

Table 3. Pearson correlation coefficients for relationships between annual fish abundance indices and selected environmental variables (highest value for each is highlighted).

Variable	Longfin Smelt	Delta Smelt	Striped Bass	Starry Flounder	Splittail	Threadfin Shad	*Crangon f.*	Steelhead (Red Bluff)
Year Sampled	-0.43	-0.36	-0.57	-0.49	0.00	-0.53	-0.59	-0.86
Diversions (average annual flow)	-0.42	-0.38	-0.62	-0.50	-0.06	-0.67	-0.19	-0.76
Average Annual Delta Outflow (cfs)	0.58	0.03	0.65	0.75	0.80	-0.12	0.95	0.16
Average Annual Delta Inflow (cfs)	0.55	-0.01	0.61	0.74	0.81	-0.18	0.96	0.10
Reverse Flows, Days per Year	-0.22	-0.17	-0.21	-0.35	-0.22	-0.14	-0.43	-0.37
X2 Position (km); (February-June)	-0.63	-0.12	-0.67	-0.66	-0.65	0.10	-0.93	-0.26
Crangon franciscorum abundance	0.65	-0.01	0.78	0.62	0.82	-0.18	-	0.10
Neomysis Abundance (entire Delta)	0.45	0.35	0.15	-0.10	0.12	-0.27	0.44	0.44
Neomysis Abundance (Suisun Bay)	-0.03	0.36	-0.06	-0.75	-0.24	-0.43	-0.04	0.81
Neomysis Abundance (west Delta)	-0.32	0.09	-0.07	-0.61	-0.36	0.18	-0.85	0.36
Eurytomora Abundance	0.01	0.59	0.19	-0.08	-0.18	-0.14	0.34	0.36
Other Cyclopoids	0.49	0.64	-0.15	-0.09	0.08	0.34	0.20	0.20
Zooplankton Abundance (west Delta)	-0.60	0.26	-0.04	-	-0.39	0.92	-	0.33
Zooplankton Abundance (Suisun Bay)	0.07	0.93	0.69	-	0.07	0.19	-	0.38
Particulate Organic Carbon (Suisun Bay)	0.71	0.19	0.63	0.46	0.70	-0.22	0.82	0.19
Chlorophyll-A Annual Peak (Suisun Bay)	0.23	0.48	0.21	0.02	-0.04	-0.14	0.46	0.53
Biological Oxygen Demand	-0.32	0.50	0.45	-	-0.76	-0.18	-	0.82
Water Temperature (mean midwater trawl)	-0.40	-0.15	-0.34	0.30	-0.10	-0.12	-0.29	-0.26
Secchi Depth (midwater trawl)	-0.52	0.14	-0.41	-0.28	-0.49	0.03	-0.70	-0.06
Secchi Depth (Sacramento and S.J. Rivers.)	-0.27	-0.38	-0.41	-0.37	-0.12	-0.36	-0.56	-0.62
Electroconductivity (average midwater trawl)	-0.47	0.20	-0.53	-0.68	-0.54	0.21	-0.88	0.08

correlated to inflow (r = 0.96). The abundance of steelhead trout captured at Red Bluff was most highly correlated with time (i.e., year sampled).

It should be noted that average annual outflows and inflows in the Delta are very highly correlated, having an r-value of 0.99. Consequently, it is extremely difficult to discern different effects of Delta outflows and inflows on those species reviewed. The position of X2 is also highly correlated to average annual inflows and outflows, having an r-value of −0.89 for each. The influence of inflows on biological processes in the Delta is an extremely important one, and one that is often difficult to disassociate from other environmental factors.

The large number of correlations among environmental factors and fish abundance can be analyzed in a cluster analysis to determine whether patterns among these correlations is evident. A cluster analysis was completed for all environmental factors and fish species considered earlier (Figure 11). The grouping of variables in the cluster "tree diagram" indicate hierarchical patterns of correlation among these variables. Inflows and outflows had the highest correlation of all variables, and these in turn were grouped with the abundance of *Crangon franciscorum*. Sacramento splittail, starry flounder, and striped bass were also grouped with these "flow associated" variables. Longfin smelt were also grouped with these flow-related variables, but to a lesser extent than the previous species. Alternatively, Delta smelt and threadfin shad were grouped with food items (cyclopoids and other zooplankton). The abundance of *Neomysis*, *Eurytomora*, and peak chlorophyll-*a* values were included in grouping of "food" or "production" variables which were secondary to that in which Delta smelt and threadfin shad were included. Finally, a grouping of "time" related variables included annual diversions, secchi (turbidity) values, and the position of X2. This group were moderately associated with the flow and food variables, as indicated by the branching hierarchy in the cluster tree diagram.

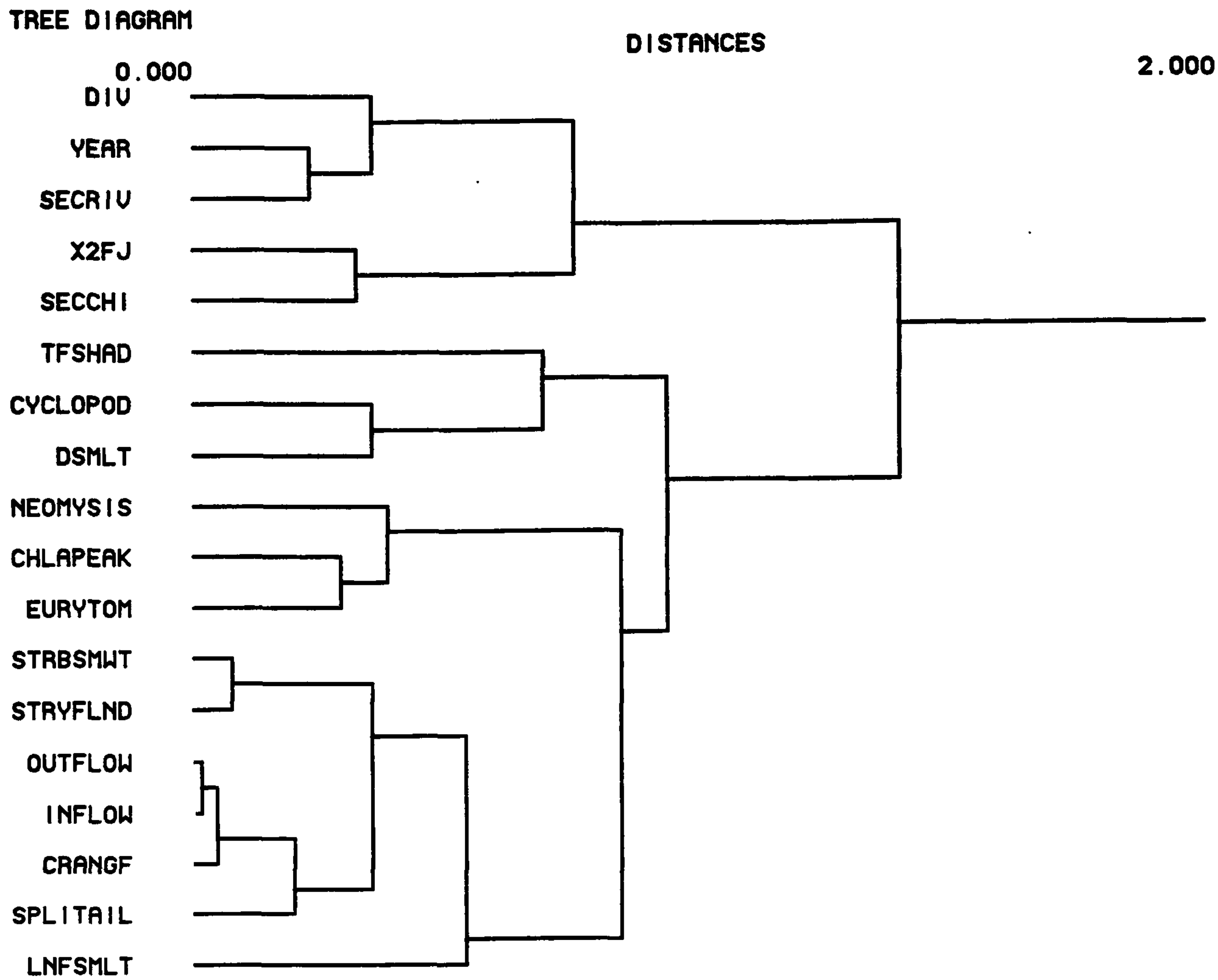


Figure 11. Cluster analysis showing associations among environmental variables and fish abundance in the Sacramento-San Joaquin Delta. Clustering of variables is based upon a Pearson distance metric employing the average linkage method.

Key to variables used:
INFLOW = average annual inflow (cfs)
OUTFLOW = average annual outflow (cfs)
DIV = average annual diversions (cfs)
YEAR = year sampled
X2FJ = mean position of X2 from February to June
CHLAPEAK = peak yearly chlorophyll-A value in Suisun Bay
SECCHI = mean annual secchi depth (m) for all midwater trawl sampling stations
SECRIV = mean annual secchi depth (m) for midwater trawl stations in Sacramento and San Joaquin Rivers
CRANGF = annual mean abundance index for *Crangon francisorum*
NEOMYSIS = annual mean abundance of *Neomysis mercedis* in Delta and Bay
EURYTOM = annual mean abundance of *Eurytomora*
CYCLOPOD = annual mean abundance of other cyclopoids
LNFSMLT = annual abundance index for longfin smelt (midwater trawl)
TFSHAD = annual abundance index for threadfin shad (midwater trawl)
STRBSMWT = annual abundance index for striped bass (midwater trawl)
STRFLND = annual abundance index for starry flounder (bay study)
SPLITAIL = annual abundance index for Sacramento splittail (midwater trawl)

14.0 REFERENCES

Brown, R. 1992. Bay/Delta Fish Resources. Department of Water Resources. July 1992. WRINT DWR-30.

California Department of Fish and Game. 1987b. Delta Outflow Effects on the Abundance and Distribution of San Francisco Bay Fish and Invertebrates. Exhibit No. 60, California Water Resources Control Board, 1987 Water Quality/Water Rights Proceeding of the San Francisco Bay/Sacramento-San Joaquin Delta, Sacramento. 345 pp.

California Department of Fish and Game. 1989. Striped Bass Restoration and Management Plan for the Sacramento-San Joaquin Estuary Phase I. California Dept. Fish Game, Sacramento.

California Department of Water Resources. 1993. Sacramento San Joaquin Delta atlas.

Carlton, J.T., J.K. Thompson, L.E. Schemel, and F.H. Nichols. 1990. Remarkable invasion of San Francisco Bay: (California USA) by the Asian clam Potamocorbula amurensis. I. Introduction and dispersal. Mar. Ecol. Proj. Ser. 66: 81-94.

Cashman, J.R., D.A. Maltby, R.S. Nishioka, H.A. Bern, S.J. Gee, and B.D. Hammock. 1992. Chemcial contamination and the annual summer die-off of striped bass (Morone saxatilis) in the Sacramento-San Joaquin Delta. Reprinted from Chemical Research in Toxicology, 1992, 5.

Chapman, D.W., A. Giorgi, M. Hill, A. Maule, S. McCutcheon, D. Park, W. Platts, K. Pratt, J. Seeb, L. Seeb, and F. Utter. 1991. Status of Snake River chinook salmon. Report prepared by Don Chapman Consultants, for Pacific Northwest Utilities Conference Committee.

Cornacchia, J.W., D.B. Cohen, G.W. Bowes, R.J. Schnagl, and B.L. Montoya. 1984. Rice herbicides: molinate and thiobencarb. Special projects report No. 84-4sp. California State Water Resources Control Board. Toxic Substances Control Program.

Cramer, S.P. 1990. Contribution of Sacramento Basin hatcheries to ocean catch and river escapement of fall chinook salmon. Report prepared for California Department of Water Resources.

Davis, J.A., A.J. Gunther, B.J. Richardson, J.M. O'Connor, R.B. Spies, E. Wyatt, E. Larson and E.C. Meiorin. 1991. Status and trends report on pollutants in the San Francisco Estuary. March. Prepared by the Aquatic Habitat Institute for the San Francisco Estuary Project, U. S. Environmental Protection Agency. San Francisco, California. 241 pp.

Filce F.P. 1954. An ecological study of the Castro Creek area of San Pablo Bay. Wasmann J. Biol, 12, 1-24.

Finlayson, B.J. 1983. Memorandum from B.J. Finlayson , Water Quality Biologist, Department of Fish and game, to Olaf Leifson, Chief, Environmental Monitoring and Pest Management, DFA, (Nov. 21).

Gunther, A.J., J.A. Davis, J.M. O'Connor, D.J.H. Phillips, K.S. Kramer, B.J. Richardson, and P. Williams. 1990. Status and trends report on dredging and waterway modification in the San Francisco Estuary. Prepared by the Aquatic Habitat Institute for the San Francisco Estuary Project, Oakland, California. 250 pp.

Harrington, J. 1990. Hazard assessment of the rice herbicides molinate and thiobencarb to aquatic organisms in the Sacramento River system. California Department of Fish and Game, Environmental Services Division Administrative Report 90-1.

Hassler, J.T. 1988. Species Profiles: Life Histories and Environmental Requirement of Coastal Fisheries and Invertebrates (Pacific Southwest) -- Striped Bass. U.S. Fish and Wildlife Service. Biol. Rep. No. 82(11-82) U.S. Army Corps of Engineers, TR EL-82-4, 29 pp.

Herbold, B., A. Jassby, and P.B. Moyle. 1992. Status and trends report on aquatic resources in the San Francisco Estuary. San Francisco Estuary Project, Oakland, California.

Herbold, B., and P. Moyle. 1989. The ecology of the Sacramento-San Joaquin Delta: a community profile. Biological Report 85(7.22), National Wetlands Research Center. 106 pp.

Herrgesell, P.L. (compiler). 1990. 1989 Annual Report Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. California Dept. Water Resources, Sacramento, 112 pp.

Herrgesell, P.L. 1993. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary; 1991 Annual Report. Calif. Dept. of Water Resources and Calif. Dept. of Fish and Game. 150pp.

Jassby, A.D. 1992. The 2 ppt bottom isohaline as an index of conditions for biological resources. University of California, Davis. June 17, 1992. WRINT-SFEP-8.

Kahrl, W., W. Brown, S. Brand, M. Shelton, D. Fuller, and D. Ryan. 1979. The California Water Atlas. California Department of Water Resources.

Kendra, W. 1991. Quality of salmonid hatchery effluents during a summer low-flow season. Transactions of the American Fisheries Society 120:43-51.

Kohler, C.C., and W.R. Courtenay, Jr. 1986. American Fisheries Society position on introductions of aquatic species. Vol. 11, No. 2, pp 39-42.

Madrone Assoc. 1980. Sacramento-San Joaquin Delta wildlife habitat protection and restoration plan. Prepared for the U.S. Fish and Wildl. Srv. and California Dept. of Fish and Game.

McGinnis, S.M. 1984. Freshwater fishes of California. University of California Press, California Natural History Guides: 49, Berkeley, California. 316 pp.

McIntyre, J.D. 1985. A model for estimating deficits in the size of spawning stocks of spring chinook salmon in tributaries of the upper Columbia River. U.S. Fish and Wildlife Service, unpublished MS, Seattle, Wa.

Meffe, G.K. 1986. Conservation genetics and the management of endangered fishes. Fisheries 11(1):14-23.

Meiorin, E.C., M.H. Josselyn, R. Crawford, J. Calloway, K. Miller, R. Pratt, T. Richardson, and R. Leidy. 1991. Status and trends report on wetlands and related habitats in the San Francisco Estuary. San Francisco Estuary Project, Oakland, California.

Miller, L. 1991. Concentration of food in the Sacramento-San Joaquin Estuary compared with other estuaries inhabited by striped bass. In IESP Working Papers 1-6 of the Food Chain Group; FCG-1990.

Monroe, M.W., and J. Kelly. 1992. State of the estuary, a report on conditions and problems in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. San Francisco Estuary Project, Oakland, California.

Moyle, P.B. 1976. Inland fishes of California. University of California Press. Berkeley, California.

Moyle, P.B. 1992. Causes of decline in estuarine fish species. Exhibit WRINT-NHI-9; testimony of Natural Heritage Institute.

Moyle, P.B., B. Herbold, D.E. Stevens, and L.W. Miller. 1992. Life history and status of Delta smelt in the Sacramento-San Joaquin estuary, California. Transactions of the American Fisheries Society. 121: 67-77.

Munro, K.A., S.C. Samis, and M.D. Nassichuk. 1985. The effect of hatchery effluents on water chemistry, periphyton and benthic invertebrates of selected British Columbia streams. Canadian Manuscript Report of Fisheries and Aquatic Sciences 1830.

Nichols, F.H., and M.M. Pamatmat. 1988. The Ecology of the Soft-Bottom Benthos of San Francisco Bay: A Community Profile. U.S. Fish and Wildlife Service, Biol. Rep. No. 85(7.19), Washington, D.C.

Nichols, F.H., J.K. Thompsón, and L.E. Schemel. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam Potamocorbula amurensis. II. Displacement of a former community. Mar. Eclo. Proj. Ser 66: 95-101.

Perkins, J.B., S. Potter, and L. Stone. 1991. Status and trends report on land use and population. Prepared by the Association of Bay Area Governments for the San Francisco Estuary Project, U.S. Environment Protection Agency. San Francisco, Calif. 186 pp.

Phillips, D.J.H. 1987. Toxic contaminants in the San Francisco Bay-Delta and their possible biological effects. 413pp. Aquatic Habitat Intitute. Richmond, California.

Shafland, P.L. 1986. A review of Florida's efforts to regulate, assess and manage exotic fishes. Vol. 11, NO. 2, pp 20-25.

Sigler, W.F., and J.W. Sigler. 1987. Fishes of the Great Basin, a natural history. University of Nevada Press, Reno, Nevada.

Skinner, J.E. (compiler). 1972. Ecological Studies of the Sacramento-San Joaquin Estuary. California Dept. Fish & Game, Delta Fish Wildl. Protect. Stud. Rep. No. 8, 94 pp.

Smith, S.E., and S. Kato. 1979. The fisheries of the San Francisco Bay: past, present and future. In T. J. Conomos (ed). San Francisco Bay: the urbanized estuary. Pages 445-468. Pacific Division, American Association for the Advancement of Science. San Francisco, California.

State Water Resources Control Board. 1993. Water Right Decision 1630. San Francisco Bay/Sacramento-San Joaquin Delta Estuary. Draft Document.

Stevens, D.E., D.W. Kohlhorst, L.W. Miller, and D.W. Kelley. 1985. The decline of striped bass in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society. 114:12-30.

SWRCB, 1991. Water quality control plan for salinity. San Francisco Bay/Sacramento-San Joaquin Delta Estuary. 91-15WR, May. State Water Resources Control Board, Sacramento, Calif.

Tsai, C., M. Wiley, and A. Chai. 1991. Rise and fall of the Potomac River striped bass stock: a hypothesis of the role of sewage. Transactions of the American Fisheries Society 120: 1-22.

U.S. Fish and Wildlife Service. 1992. Endangered Species Act of 1973. As amended through the 100th Congress. 1992.

Vincent, E.R. 1987. Effects of stocking catchable-size hatchery rainbow trout on two wild trout species in the Madison River and O'Dell Creek, Montana. North American Journal of Fisheries Management 7:91-105.

Wendt, P.G. 1987. Preliminary evaluation of factors controlling striped bass salvage loss at Skinner Fish Facility: quantity and direction of flow in the lower San Joaquin River, striped bass abundance and size, and total Delta exports. Department of Water Resources Technical Information Record.

Table A-1. Listing of major storage and multipurpose reservoirs, year completed and Figure 10 reference numbering.

Year	No.[1]	Dam	Reservoirs
1890	1	Buena Vista	Buena Vista
1910	2	Clear Lake (Modoc County)	Clear Lake
1913	3	Tahoe	Tahoe
1914	4	Clear Lake (Lake County)	Clear Lake
1917	5	Huntington Lake	Huntington Lake
1921	6	Big Sage	Big Sage
1921	7	Pillsbury	Pillsbury
1922	8	Copco Lake	Copco Lake
1923	9	O'Shaughnessy	Hetch Hetchy
1925	10	Calveras	Calveras
1927	11	Shaver	Shaver
1927	12	Almanor	Almanor
1928	13	Bukes	Bukes
1929	14	Pardee	Pardee
1931	15	Salt Spring	Salt Spring
1934	16	El Capitan	El Capitan
1938	17	Parker	Havasu
1938	18	Mathews	Mathews
1941	19	Crowley	Crowley
1943	20	San Vicente	San Vicente
1945	21	Shasta (CVP)	Shasta
1947	22	Friant	Millerton
1950	23	Anderson	Anderson
1953	24	Isabella	Isabella
1953	25	Cachuma	Cachuma
1954	26	Edison	Edison
1954	27	Pine Flat	Pine Flat
1955	28	Piru	Piru
1956	29	Folsom	Folsom
1956	30	CheryValley	Lloyd
1957	31	Beardsley	Beardsley
1957	32	Nacimiento	Nacimiento
1957	33	Monticello	Berryessa
1958	34	Twitchell	Twitchell
1958	35	Wishon	Wishon
1958	36	Courtright	Courtright

Table A-2. Listing of major aqueducts, year completed and Figure 10 reference numbering.

Year	No.[1]	Major Aqueducts
1913	1	Los Angeles
1929	2	Mokelumne River
1934	3	Hetch Hetchy
1938	4	All American
1940	5	Contra Costa
1941	6	Colorado River
1944	7	Friant-Kern
1947	8	Coachella
1947	9	San Diego No. 1
1951	10	Delta-Mendota Channel (CVP)
1951	11	Delta Cross Channel
1952	12	Madera
1957	13	Putah South
1959	14	Santa Rosa-Sonoma
1960	15	San Diego No. 2
1960	16	Corning
1961	17	Petaluma
1962	18	Tehama-Colusa
1965	19	South Bay
1968	20	North Bay
1972	21	California
1973	22	Folsom South
1975	23	Cross Valley