BIOLOGICAL ASSESSMENT

Effects of the Central Valley Project and State Water Project on Delta Smelt and Sacramento Splittail

Prepared for:
U.S. FISH AND WILDLIFE SERVICE
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EXECUTIVE SUMMARY

This report discusses the effects of the Central Valley Project and State Water Project on two fish species, delta smelt and Sacramento splittail. Delta smelt are listed as a threatened species by the U.S. Fish and Wildlife Service and California Department of Fish and Game. Sacramento splittail are currently a candidate species for listing as threatened by the Fish and Wildlife Service and, hence, have been included as part of this biological assessment. Major conclusions are summarized here.

Delta Smelt

- The midwater trawl index, the best index of adult smelt abundance, declined in the mid-1980s, then generally increased through the late 1980s and early 1990s. In 1993, the midwater trawl index was the sixth highest in the 25 years of record. The rebound of the adult population occurred in spite of the relatively low juvenile tow-net indices in all but three (1986, 1993, 1994) of the last twelve years.
- Although there is a significant statistical relationship between the fall adult delta smelt abundance index and the February-June outflow (as represented by the number of days the 2 ppt salinity is in Suisun Bay), outflow alone accounts for less than 25% of the variation in the adult smelt abundance index. The highly variable response of delta smelt to outflow suggests outflow may be a necessary but not sufficient condition for a high abundance index. Other unknown environmental factors determine whether or not that opportunity is realized.
- The number of spawners may also have a small effect on the abundance of juvenile and subadult delta smelt later in the year (stock recruitment). The number of spawners can account for less than 25% of the variability in the summer juvenile abundance index and less than 18% of the variability in the fall adult abundance index, indicating that environmental factors are extremely important in determining year-class strength.
- Abundance trends may also be influenced by water transparency, toxins, contaminants, predation, competition, disease and food abundance, but the relative importance of these and other factors cannot be determined at this time.
- Smelt entrainment at the CVP and SWP Delta intakes appears to be relatively greater in dry years. Based on the number of smelt salvaged at the CVP and SWP pumping plants in the southern Delta, more juvenile smelt appear to be lost at the plants in drier years, when lower outflow contributes to a greater portion of the population near the pumps. However, no correlation could be found between the number of smelt salvaged at the two pumping plants and abundance indices of smelt in summer or fall. Similarly, no relationship could be established between exports or the proportion of inflow diverted and salvage or abundance levels.
- Operation of the CVP and SWP using criteria established by the National Marine Fisheries Service in the biological opinion for winter-run Chinook salmon has a number of benefits to delta smelt that substantially add to those contained in Decision 1485.

- There are serious limitations in all of the surveys that capture splittail, making it difficult to describe abundance trends. None of the surveys analyzed to date accurately describe adult abundance trends in potentially important upstream areas.
- Four abundance indices developed for diverse regions of the estuary provide no evidence that there has been a decline in the number of adult splittail. By contrast, the Suisun Marsh study showed a major decline after 1980 followed by little or no resurgence since then. This finding suggests that the Suisun Marsh population may be regulated by other factors (or to a greater degree) than those in other regions.
- There is some indication that production of young splittail in the estuary was reduced in the late 1980s, but recent data suggest that recruitment improved substantially in recent years. The Fish and Wildlife Service beach seine survey, which provides the broadest coverage of the splittail range, shows 1993 abundance was the highest in the history of the survey. Juvenile abundance has not rebounded in Suisun Marsh.
- There is no evidence that entrainment loss at pumping plants has a significant negative effect on splittail abundance. Analysis of salvage data demonstrates that entrainment increases primarily when large numbers of splittail are present in the system.
- The recent drought appears to be the primary cause of recent lower abundance of splittail based on a strong correlation with delta outflow. Abundance is also well-correlated with the duration of floodplain inundation, which may provide a large amount of additional spawning, rearing, and foraging habitat in wet years. Except for 1993, little flooding has occurred in the range of splittail since 1986, perhaps contributing to a series of weaker year-classes in the estuary.
- Spawning is often successful in many areas in the Sacramento and San Joaquin rivers and the northern and central Delta in both wet and dry years. However, juvenile abundance trends in the lower part of the system appear to be strongly correlated with Delta outflow and with the duration of floodplain inundation. A possible mechanism for the response to very wet years is that floodplain inundation greatly expands spawning, rearing, and foraging habitat and high outflow transports young splittail into the lower portions of the system, where they are vulnerable to trawls.
- Despite a correlation between the position of 2 ppt salinity and splittail abundance, the species does not appear to be an entrapment zone specialist. It appears that region between Suisun Bay and the western Delta, the historical location of the entrapment zone, may provide only marginal habitat for young splittail except in above normal and wet years.
- If duration of floodplain inundation is responsible for most of the variation in juvenile splittail abundance, project-related changes to the hydraulics of the estuary are unlikely to have a major effect because splittail recruitment would depend primarily on uncontrolled flows. Alternatively, if outflow or salinity position are more important, the impacts of incremental changes in these variables from project operations should be reduced under National Marine Fisheries Service winter-run criteria as compared to Decision 1485.
- A number of other factors may influence splittail abundance including urban and agricultural pollution, exotic species, diking and draining of floodplain areas for agriculture, food abundance and recreational fishing.

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Chapter 1

INTRODUCTION

As part of the formal consultation process between the U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation in regard to delta smelt and Sacramento splittail, this biological assessment enumerates potential effects on these two species of existing water transport and diversion facilities, specifically the Central Valley Project of the Bureau of Reclamation and the State Water Project of the California Department of Water Resources. Other facilities and factors impacting delta smelt and splittail are also described in this assessment.

Delta smelt is listed as a threatened species under the Endangered Species Act of 1973. In 1994, similar status was proposed for Sacramento splittail. Section 7 of the Endangered Species Act requires federal agencies to consult on any actions they take that may affect species listed as threatened or endangered. Operations of the Central Valley Project and State Water Project clearly have the potential to affect delta smelt; therefore, the Bureau of Reclamation and the Fish and Wildlife Service will initiate a Section 7 consultation. The consultation will be based on the present CVP/SWP operations as modified by requirements of the Section 7 consultation on winter-run Chinook salmon. This assessment includes as the project baseline operations from 1993 and 1994 that have been changed due to implementation of the Central Valley Project Improvement Act. Additionally, proposed operational changes are included as part of the project description.

Although the primary purpose of this biological assessment is to fulfill requirements of the federal Endangered Species Act, it is also intended for use in any consultation relative to delta smelt and splittail that may be undertaken pursuant to the California Endangered Species Act.

The delta smelt occurs primarily in the lower Sacramento and San Joaquin rivers, in the delta above their confluence, and in Suisun Bay. The range of splittail is more extensive, with recent observations as far north as the upper Sacramento River and to the Tuolumne River, a tributary of the San Joaquin River. During wet years, both are also found in San Pablo Bay. The Bay/Delta estuary extends from the Golden Gate, at the entrance to San Francisco Bay, upstream in the Sacramento and San Joaquin rivers to the uppermost influence of the tides (Figure 1). The Sacramento and San Joaquin rivers are the major streams in California's Central Valley, and this vast estuary is one of the most highly modified estuaries in the world (Conomos 1979).

This assessment describes the CVP/SWP facilities and how they are operated, the biology of delta smelt and splittail, potential factors affecting their abundance and distribution, and the overall effect of coordinated CVP/SWP operations on these species. Since knowledge of factors affecting the two species is limited, data and current hypotheses examined for this report are expected to undergo further assessment and revision during the consultation process. Further analyses are underway, and results will be documented for use in the Section 7 consultation.

Appendix A is a list of some factors that could be investigated in the future.

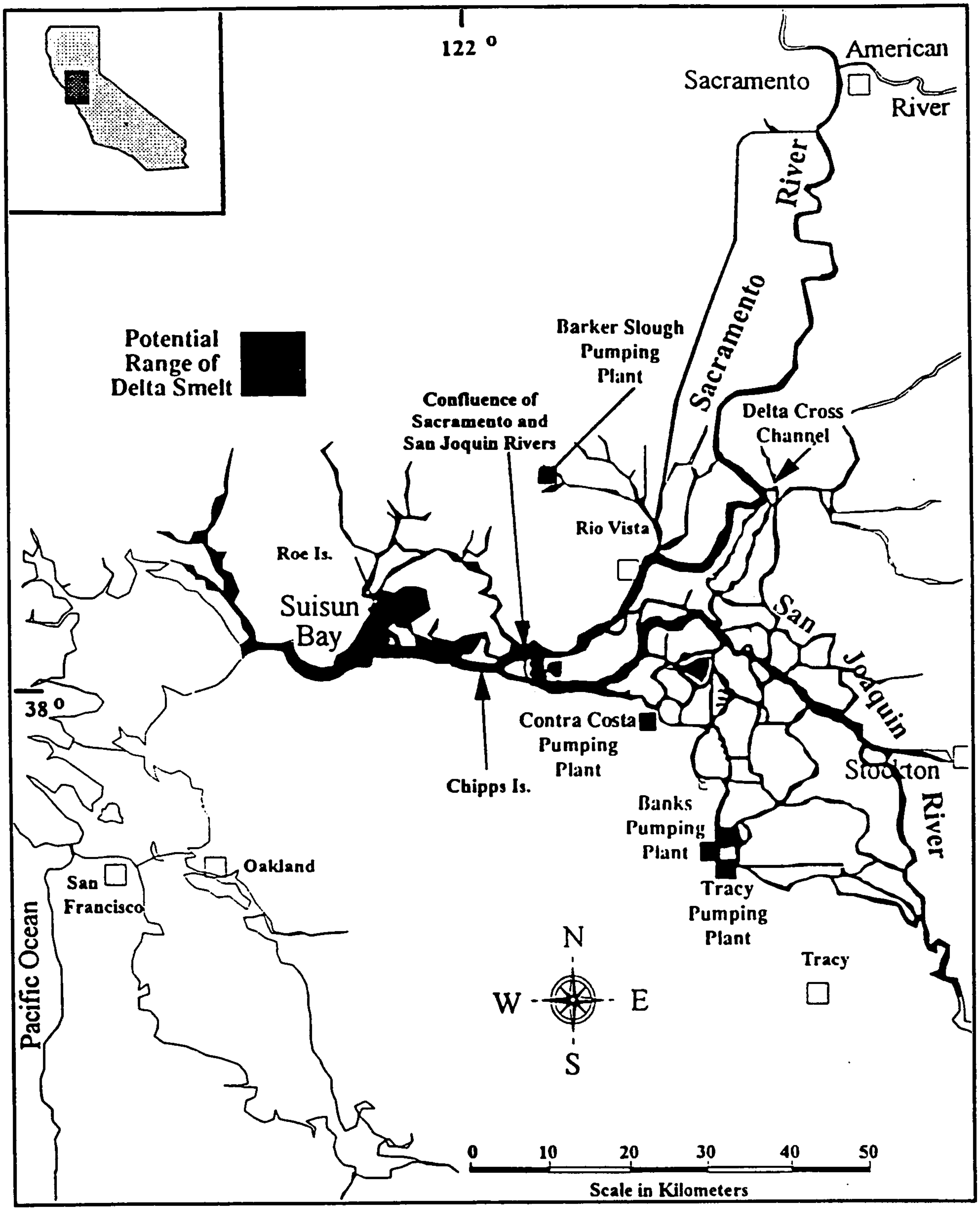

Figure 1
SACRAMENTO-SAN JOAQUIN ESTUARY

Chapter 2

CENTRAL VALLEY PROJECT AND STATE WATER PROJECT DELTA FACILITIES AND OPERATIONS

Two major interbasin water delivery systems — the State Water Project and the federal Central Valley Project — divert water from the southern Delta. Both projects include major reservoirs north of the Delta, and both transport water released from storage to areas south and west of the Delta (Figure 2).

The main purpose of the State Water Project is to store water and distribute it to urban and agricultural areas of need in Northern California, the San Francisco Bay Area, the San Joaquin Valley, and Southern California. Other project functions include flood control, water quality maintenance, power generation, recreation, and fish and wildlife enhancement. The SWP includes 14 reservoirs; the North Bay and South Bay aqueducts; the California Aqueduct including the East, West, and Coastal branches; and power and pumping plants. The California Aqueduct extends more than 600 miles — two-thirds the length of California. It is the largest state-built, multi-purpose water project in the country.

The primary purpose of the federal Central Valley Project, as expanded by the Central Valley Project Improvement Act, is to provide water for irrigation throughout the Central Valley. Other purposes include urban water supply, water quality, flood control, power generation, recreation, and fish and wildlife habitat enhancement. The CVP includes 20 reservoirs; 500 miles of canals, including the Delta-Mendota Canal; and other facilities.

Some facilities have been developed for joint use by the CVP and SWP. These include San Luis Reservoir, O'Neill Forebay, more than 100 miles of the California Aqueduct, and related pumping facilities.

Use of Delta channels for conveying water supply began in 1940, with completion of Contra Costa Canal — the first unit of the CVP. Since initial operation of Shasta Dam in 1944 and the Delta-Mendota Canal and Delta Cross Channel in 1951 (all CVP) and Oroville Reservoir and the California Aqueduct in 1968 (both SWP), water project diversions from the Delta increased steadily through 1989, when they reached about 6 million acre-feet. Since 1990, diversions have been reduced by drought or by conditions and restrictions intended to avoid jeopardizing protected species.

In this chapter describing SWP and CVP operations, we have included discussions of actions undertaken to protect fish and wildlife resources in general and delta smelt and Sacramento splittail in particular. Each section in this chapter ends with a brief discussion of how operations of the projects are adjusted to avoid and minimize impacts on fish and wildlife.

State Water Project Facilities, Capacity, and Demand

Banks Pumping Plant, about 12 miles northwest of Tracy, provides the initial lift of water from sea level to elevation 244 feet at the beginning of the California Aqueduct. Water entering the aqueduct flows to Bethany Reservoir, from which South Bay Aqueduct diverts water. Most of the water continues south by gravity to O'Neill Forebay, where it is pumped into San Luis Reservoir or conveyed to the San Joaquin Valley and Southern California.

An open intake channel conveys water to Harvey O. Banks Delta Pumping Plant from Clifton Court Forebay. The forebay provides storage for off-peak pumping and permits regulation of flows into the pumping plant.

All water arriving at Banks Pumping Plant first flows through the primary intake channel of the John E. Skinner Delta Fish Protective Facility. Fish screens across the intake channel direct fish into bypass openings leading into the salvage facilities. The main purpose of the fish facility is to reduce the number of fish and the amount of floating debris conveyed to the pumps.

Banks Pumping Plant initial facilities (seven pumps) were constructed in 1962. The plant was completed in 1992 with the addition of four pumps. Of the eleven pumps, two are rated at 375 cfs capacity, five at 1,130 cfs, and four at 1,067 cfs. Water is pumped into the California Aqueduct through five discharge lines ranging from 13.5 to 15 feet in diameter.

Most of the year, average daily diversions are limited to 6,680 cfs, as set forth by U.S. Army Corps of Engineers criteria dated October 13, 1981. Diversions may be increased by one-third of San Joaquin River flow at Vernalis during mid-December to mid-March if that flow exceeds 1,000 cfs. The maximum diversion rate during this period would be 10,300 cfs, the nominal capacity of the California Aqueduct. Average monthly pumping rates are summarized in Figure 3.

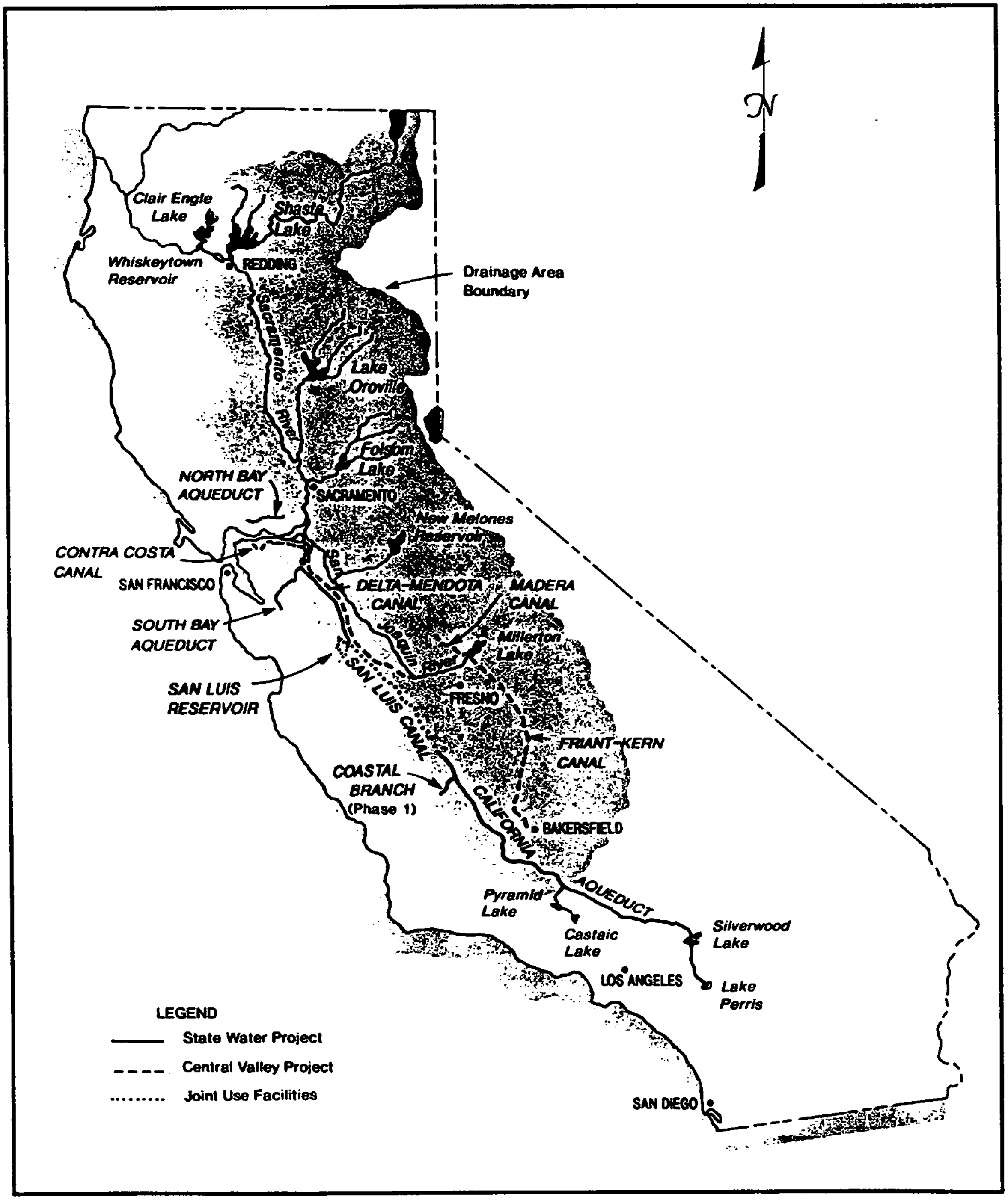

Figure 2
MAJOR FEATURES OF THE CENTRAL VALLEY PROJECT AND STATE WATER PROJECT

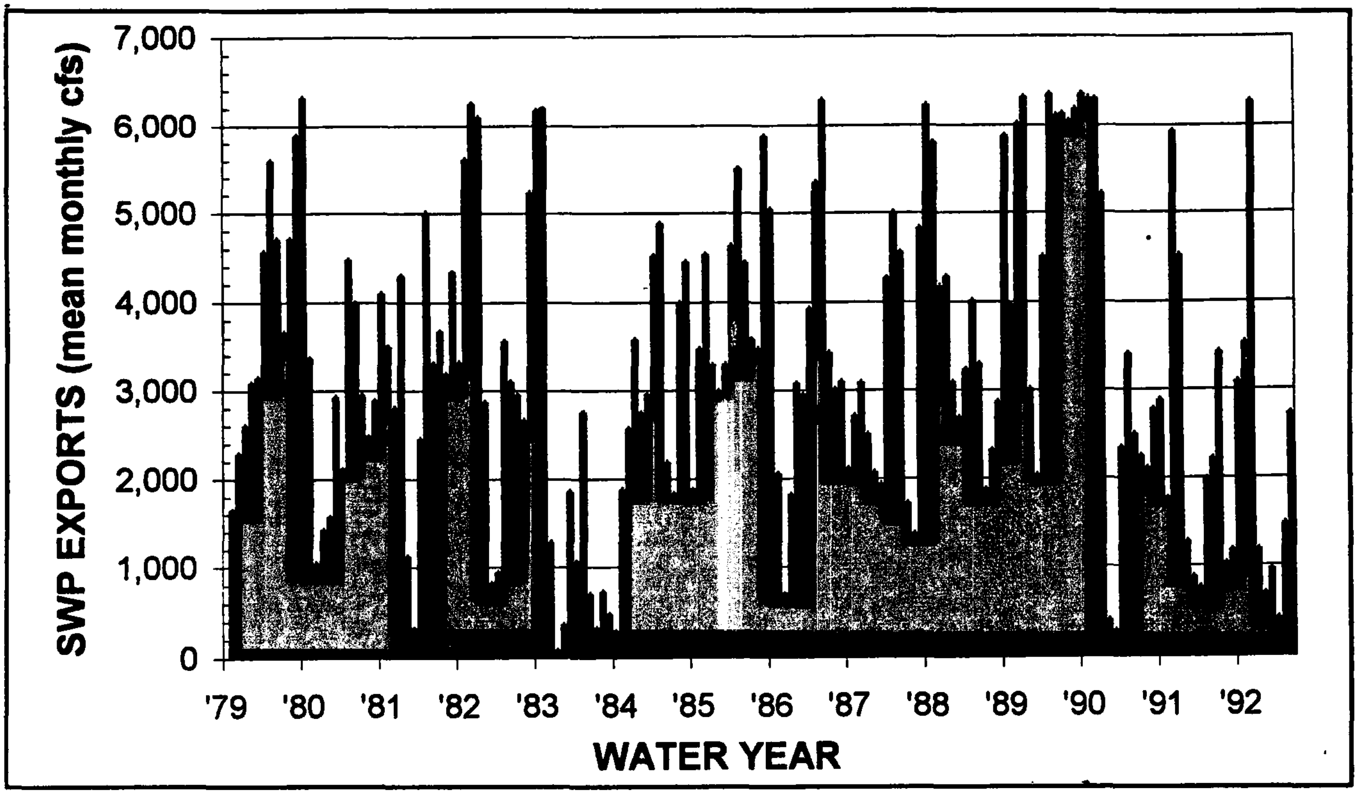

Figure 3
AVERAGE MONTHLY STATE WATER PROJECT PUMPING, WATER YEARS 1978 TO 1992
From the DAYFLOW Database

Additional limitations on export pumping are imposed by Water Right Decision 1485.[1] The maximum average monthly diversion rate is limited to 3,000 cfs in May and June and 4,600 cfs in July. Exports can be further reduced to a mean rate of 2,000 cfs during May and June if releases for export are exceeding natural inflow at Lake Oroville.[2]

Exports are also restricted under the long-term biological opinion for winter-run Chinook salmon and the 1994 opinion for delta smelt. These restrictions and other requirements of the biological opinions are discussed later in this chapter.

In average or above-average runoff years, Banks Pumping Plant would typically divert near allowable export rates during September and the first half of October to move water from Lake Oroville to San Luis Reservoir. A portion of late summer and fall capacity is used to wheel 195,000 acre-feet of water for the CVP to replace water not pumped during May and June in compliance with Decision 1485 criteria. In December through March, maximum export rates are generally required to capture uncontrolled runoff in the Delta to fill the SWP share (1,062 TAF) of San Luis Reservoir.

Entitlement water deliveries to SWP contractors are also maintained during these periods. Peak contractor delivery patterns during spring and summer are satisfied by direct diversions from the Delta in conjunction with releases from San Luis Reservoir and SWP reservoirs in Southern California. At times, unused Delta pumping capacity would be available to move additional water for direct delivery or into storage south of the Delta for future use.

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[1] State Water Resources Control Board. Water Right Decision 1485: Sacramento-San Joaquin Delta and Suisun Marsh. August 1978.

[2] This criterion is set forth in a letter dated January 5, 1987, from the California Department of Water Resources to the California Department of Fish and Game.

Optimum operation of the two projects to ensure reliable water supply to south-of-Delta users would frequently involve pumping at capacity whenever water and south-of-Delta storage space were available and it was economically feasible to pump (minimum energy costs). Under this scenario, however, there would be significant impacts to fisheries during sensitive periods. Operating procedures have, therefore, been modified by California water rights decisions (for example, Decision 1485) and other export and operations restrictions. These restrictions contribute to avoidance and minimization of impacts to threatened and endangered species.

Water Demands

Contracts executed in the early 1960s established maximum annual entitlement water amounts each long-term contractor may request from the State Water Project. These annual quantities, known as "Table A", reflect each contractor's projected water needs at the time the contracts were signed. Every September, each contractor must submit a request[1] to the Department of Water Resources for water delivery for the next 5 years. These projections form the basis for SWP planning and operation studies in the upcoming year. In 1993, contractor entitlement requests were about 3.8 million acre-feet. Maximum entitlement deliveries for long-term water contractors are 4.218 MAF annually.

Basically, SWP water deliveries consist of two categories: agricultural and municipal/industrial. Water supply contracts provide for a maximum reduction in agricultural water deliveries of up to 50% in any one year without reductions in M&I deliveries. If cutbacks dictate agricultural shortages of more than 50% in one year, M&I users must share the amount above 50%. In addition, agricultural water deliveries may not be reduced by more than 100% in any seven consecutive years. Shortages above this amount must be shared equally between agricultural and M&I contractors.

Following are descriptions of other categories of water that could be pumped at Banks Pumping Plant in addition to Table A entitlement water.

- ***Make-up water*** is a requested amount of entitlement water the State Water Project is unable to deliver at a given time. Contractors may elect to receive the undelivered water at other times during the year or in succeeding years, providing water and delivery capability are available.
- ***Unscheduled water*** is also water in excess of entitlement demands but is not scheduled in advance for contractor delivery. It is unstored water available in the Delta for export, as opposed to being released from project storage.
- ***Surplus water*** is water beyond that required to meet all entitlement demands and other commitments. Surplus water can be delivered to contractors when capacity is available. Surplus water may be released from storage and is scheduled in advance by contractors. Priority is given to agricultural use or ground water replenishment.
- ***Wet-weather water*** can be credited to South Bay or San Joaquin Valley contractors for use in the future in years when above-normal water supplies locally reduce the need for SWP water.
- ***Regulated delivery of local supply*** is a term used when SWP facilities are used to transport non-SWP water for long-term contractors under various agreements for local water rights.
- ***Carryover water*** is a portion of a contractor's current year entitlement that may be deferred until the following year. Under DWR policy, carryover water cannot affect the next year's water delivery approvals.
- ***Wheeling*** of non-SWP water through SWP facilities is done under a variety of arrangements for long-term contractors and for the CVP.

Recently, urban water users have taken action to reduce water demand and, therefore, impacts of the SWP on environmental resources by instituting conservation programs of "best management practices". These programs are intended to reduce per-capita water use in urban areas by more than 10% on a permanent basis and without rationing.

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[1] The requests cannot exceed a contractor's Table A allocations.

Water Allocation

Allocation of water supplies for a given year is based on four variables:

- Forecast water supplies based on the Sacramento River Index[1].
- Amount of carry-over storage in Oroville and San Luis reservoirs.
- Projected requirement for end-of-year carry-over storage.
- SWP system delivery capability.

These criteria ensure that sufficient water is carried over in storage to protect Delta water quality the next year, to meet fishery requirements, and to provide an emergency reserve. Beginning each year in December, initial allocations of entitlement deliveries are determined based on the four criteria. Allocations are updated monthly until May, and more often if storms result in a significant increase in the Sacramento River Index.

Following is a chronology of the SWP water delivery allocation process.

- December.
  Initial allocations are made, based on operation studies using the four criteria and an assumed historical 90% exceedence[2] water supply.
- January and February.
  Allocations will not be reduced, even if water supply forecasts and operation studies indicate the initial allocation may be too high. Allocations may be increased if the water supply forecast (99% exceedence) and operation studies show delivery capability to be greater than forecast the month before.
- March.
  Allocations will be reduced if the supply is less than forecast in December. Allocations can be increased based on forecasted 99% exceedence water supplies.
- April and May.
  Allocations will not be reduced further unless operational storage and forecast runoff (99% exceedence) indicate carry-over conservation storage will fall below targeted minimums. Increases in water delivery allocations can be made based on improved 99% exceedence forecasts and supportive operational studies. Final allocations are based on the May water supply forecast.

Central Valley Project Facilities, Capacity, and Demand

At Tracy Pumping Plant, about 5 miles north of Tracy, CVP water is lifted 197 feet into the Delta-Mendota Canal. The intake canal at this CVP facility includes Tracy Fish Screen, which intercepts debris and salvages fish entrained into the pumping plant. The earth-lined intake channel to Tracy Pumping Plant is 2.5 miles long.

Tracy Pumping Plant consists of six pumps, one rated at 800 cfs, two rated at 850 cfs, and three at 950 cfs. Water is pumped through three 15-foot-diameter discharge pipes and carried about 1 mile to Delta-Mendota Canal. Average monthly pumping rates are shown in Figure 4.

Tracy Pumping Plant flows can range from less than 1,000 cfs to almost 5,000 cfs. Maximum sustained rate is about 4,600 cfs, the nominal capacity of the first 13.7 miles of Delta-Mendota Canal. Typical pumping rates are between 4,000 and 4,600 cfs except when restrictions are imposed by water right or endangered species requirements. Regulatory requirements limit pumping rates to avoid entrainment of juvenile fish or species and life stages of special concern. For example, Decision 1485 restricts pumping rates to 3,000 cfs during critical striped bass spawning periods in May and June. Pumping is also restricted when threatened winter-run salmon and delta smelt are exposed to facility diversions.

To meet water contractor demands, Tracy Pumping Plant is usually operated at or near maximum capacity. Except during the peak irrigation season,

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[1] The Sacramento River Index is the sum of measured runoff at four locations: Sacramento River near Red Bluff, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake.

[2] Exceedence refers to the probability that a particular value will exceed a specified magnitude; for example, 90% exceedence means the water supply will be exceeded 90% of the time.

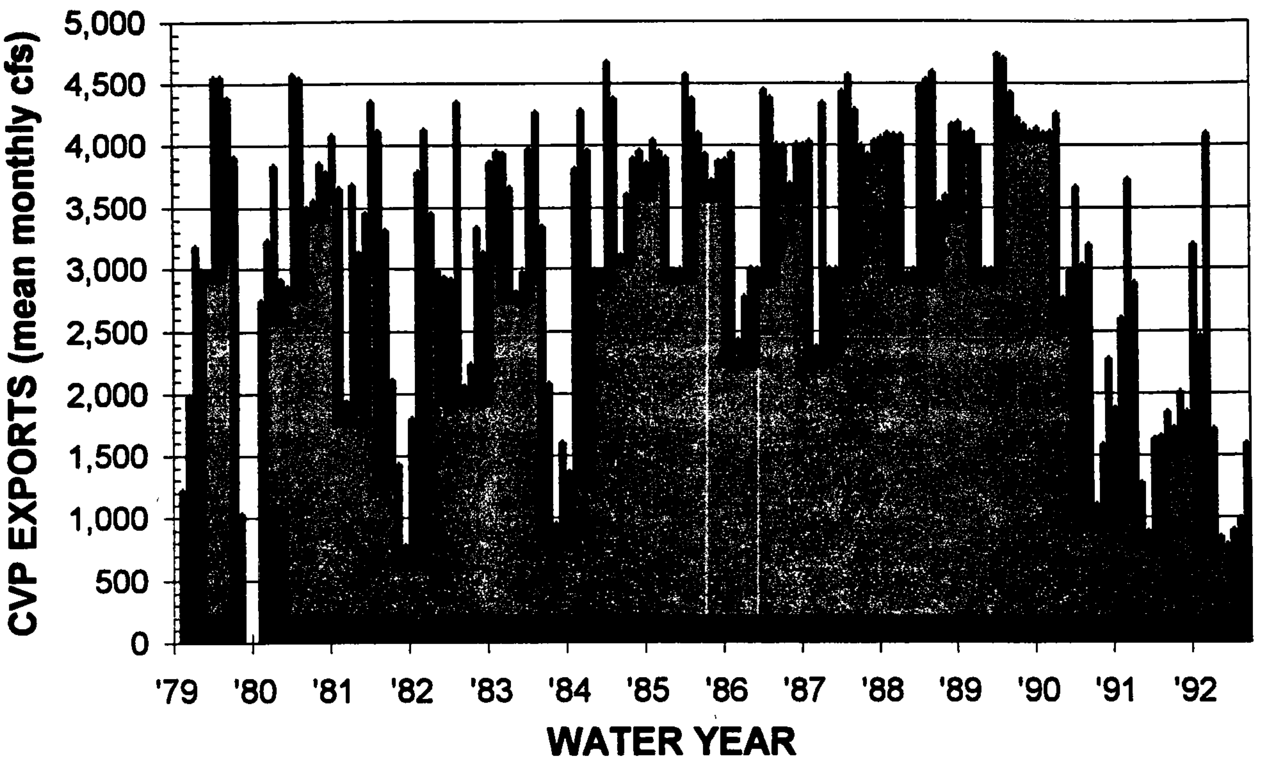


Figure 4
AVERAGE MONTHLY CENTRAL VALLEY PROJECT PUMPING, WATER YEARS 1978 TO 1992
From the DAYFLOW Database

pumping may be limited by conveyance capacity of Delta-Mendota Canal, or the re-lift capability (4,200 cfs) of O'Neill Pump/Generating Plant.

About half the CVP water supply is delivered to the San Joaquin Valley through the Delta-Mendota Canal and the San Luis Unit, but essentially all the water originates north of the Delta. To provide the water to contractors in the San Joaquin Valley, three things must be considered:

- Requirements of water service contractors and exchange contractors.
- Plans for filling and drawing down San Luis Reservoir.
- Plan for coordinating Delta pumping and San Luis Reservoir use.

Operators also incorporate Delta-Mendota and San Luis operations into plans for operating CVP facilities in and north of the Delta.

Water Demands

Estimated 1995-level demands for the CVP are about 3.5 MAF for the Delta export service areas and 3.1 MAF for the Sacramento Basin (including the American Basin). Table 1 gives a breakdown of these demands. The Bureau of Reclamation has water right settlement contracts totaling about 2.2 MAF on the Sacramento River. San Joaquin River Exchange contracts, plus water right settlement contracts on the San Joaquin River that total

Table 1
ANNUAL CVP 1995-LEVEL DEMANDS, BY USE
(In Million Acre-Feet; Totals Do Not Agree Due to Rounding)

	Water Rights	Project Agriculture	M&I	Refuge	Losses	Total
Delta	0.9	2.0	0.3	0.2	0.2	3.5
Sacramento Basin	2.2	0.5	0.3	0.1	—	3.1
Total	3.1	2.5	0.6	0.3	0.2	6.6

Water Rights, M&I, and Refuge are subject to maximum 25% reduction in CVP-OCAP.

about 0.88 MAF. These annual contract amounts must be supplied in full unless the forecasted Shasta inflow constitutes a critical water year as described in the terms of these contracts. When Shasta inflow is critical, San Joaquin Exchange contractors' supplies may be limited to 650,000 acre-feet. Sacramento River and other San Joaquin water right supplies may be reduced by 25%.

The other major components of CVP water demands are: refuge water supplies, municipal and industrial water supplies, and agricultural water service contracts. Also, the CVPIA requires the Bureau of Reclamation to annually manage 600-800 TAF of CVP yield for fish, wildlife, and habitat restoration in different water year types. Water allocation policy for M&I contracts and legislative requirements of CVPIA for refuge water deliveries provide a level of annual supply with no greater than 25% reductions. Agricultural water service contracts have no such limits on reductions. Because of the limitations on reductions in all other components of CVP water demands, agricultural water service contracts are vulnerable to any reductions in supply that cannot be apportioned to Refuge, M&I, or Water Right settlement contracts. Under existing CVP operations criteria, and given the estimated 1995 level of demands, agricultural water service contracts south of the Delta may seldom receive 100% of their contract supplies. In each of the last 5 years, CVP water deliveries have been limited because of insufficient supply, lack of conveyance capacity, or operational constraints on Delta pumping resulting from either endangered species protection (as in 1992, 1993, 1994) or implementation of CVPIA actions using a portion of the CVP yield (as in 1993).

To operate the CVP efficiently, entitlements of all types of water contractors must be combined with the pattern of requests for water. Schedules of water deliveries throughout the CVP must be coordinated with reservoir operations, release capability, and streamflow requirements from the northern CVP reservoirs and then with the capability to divert the water in the Delta and the pattern of fill and drawdown of San Luis reservoir.

Hardship Water

"Hardship" water supplies were delivered to some CVP contractors in 1990 and 1991. Hardship water has been allocated to agricultural water service contractors as an augmentation to their supply to minimally sustain permanent crops (trees and vines). For M&I contractors, hardship water has been allocated to help meet limited demands that cannot reasonably be met from other sources.

Critical Needs Water

"Critical Needs" water was allocated in 1994 to both agricultural and M&I contractors north and south of the Delta. First, requests for critical needs water were solicited and screened. To be eligible, contractors had to have a current, approved water conservation plan on file with the Bureau of Reclamation. The total amount of critical needs water allocated was determined as an amount that could be made available within the context of forecasted CVP operations for the remainder of water year 1994. It was, in effect, a partial redistribution of water that had been withdrawn from water right settlement allocations when it was determined in May that 1994 would be a critical Shasta inflow year. A total of about 150,000 acre-feet was apportioned among those contractors whose critical needs requests were validated. Over 800,000 acre-feet was requested.

Water Allocation

In most years the combination of carryover storage and runoff into CVP reservoirs is sufficient to provide the water supply to meet contractors' demands. Since 1992, new constraints placed on operations by legislative and ESA requirements have removed some of the capability and operations flexibility required to actually deliver the water to the contractors. Water allocations south of the Delta have been most affected by changes in operations ensuing from passage of the CVPIA and the biological opinions covering protection of winter-run Chinook salmon and delta smelt.

The CVP water allocation process begins in the fall, when preliminary assessments are made of the next year's water supply possibilities given storage conditions and a range of hydrologic conditions. These preliminary assessments may be refined as the water year progresses. Beginning February 1, runoff forecasts are prepared using precipitation to date, snow water-content accumulation, and runoff to date. All CVP Sacramento River water right contracts and San Joaquin

Exchange contracts require that contractors be informed no later than February 15 of any possible deficiency in their supplies. In recent years, February 15 has been the target date for the first announcement of all CVP contractors' forecasted water allocations for the upcoming contract year.

The NMFS biological opinion requires the Bureau of Reclamation to use a conservative (at least 90% probability of exceedance) forecast as the basis of water allocations. Furthermore, NMFS reviews the operations plans devised to support the initial water allocation (and any subsequent updates to them) for sufficiency with respect to the criteria for Sacramento River temperature control.

Runoff forecasts and operations plans are updated at least monthly between February and May. Water allocations may or may not change as the year unfolds. Because a conservative runoff forecast is used, forecasted water supply will likely increase as the year progresses. Although this may result in increased allocations, it also means that knowledge of the final allocation may be delayed until April, May, or June. This adds to the uncertainty facing agricultural contractors, who need reliable forecasts of available supply as early as possible to assist in decision-making for farm management.

Carryover Storage

Providing the water needed for all the CVP's beneficial uses requires a strategy that recognizes two competing requirements:

- The need to retain sufficient carryover storage to reduce risks of future shortages and to ensure sufficient temperature control capability.
- The need to draw from storage in a given year to provide sufficient water delivery to avert health, safety, economic, and environmental hardship.

Since implementation of the NMFS biological opinion in 1993, CVP carryover storage is primarily an outcome of the annual balancing of the requirements to manage storage and releases to provide for upper Sacramento River temperature control, with the use of CVP storage, diversion, and conveyance facilities to make water available for other beneficial uses, including instream flows, water quality control, water delivery, and CVPIA purposes.

Individual CVP reservoirs must be operated to provide reasonable assurance that minimum storage, instream flows, diversion pools, and hydroelectric power pools can be sustained. These elements are also considered in determining water allocations. The CVPIA has required additional consideration by providing water for anadromous fish restoration and for providing fish and wildlife habitat.

Storage targets and release objectives are re-evaluated annually for Folsom Lake because of its high probability of refill and relatively small amount of usable conservation storage. Because of low refill probability at Clair Engle and New Melones reservoirs, long-term capabilities are more of a concern. For New Melones, water supply may already be over-allocated, so sustainable yield is a concern. For Clair Engle, releases in the current year to help meet water delivery, energy, and temperature control objectives must be balanced against retention of storage for use next year and beyond. Shasta's carryover is now mostly a byproduct of temperature control requirements on the upper Sacramento River, although use of Trinity Basin diversions can also affect Shasta carryover.

Even in above-normal runoff years, it may no longer be possible to meet all competing needs for CVP water, especially south of the Delta. However, if sufficient carryover storage is available, CVP water allocations may be met partly with withdrawals from reservoir storage, even in drier years. All beneficial uses of CVP water are adversely affected during prolonged droughts. Both environmental and economic systems are stressed by the cumulative impacts of dry conditions to a point where tolerance of continued drought is significantly weakened. When CVP storage is withdrawn to combat the effects of drought, the subsequent loss of carryover storage diminishes the capability of the system to mitigate the future impacts of a continuing drought.

Priorities and Categories

The water allocation process must consider various categories of CVP water demands and contractual amounts and deficiency criteria associated with each. These water demands can be categorized as:

- Water rights settlement agreements
- Municipal and industrial water service contracts
- Legislative mandates
- Agricultural water service contracts
- Delivery losses

Water rights settlement contracts and water service contracts are readily documented, consisting of agreements and contracts with specific terms and conditions. These terms and conditions may include deficiency provisions, terms for payment of water, repayment of capital obligations, *etc.* These terms and conditions vary depending on whether a contract is of a water rights, agricultural water service, or municipal and industrial type.

Legislative mandates are exemplified by PL 102-575, which specified increased levels of supply and maximum deficiencies for wildlife refuges and management areas.

Delivery losses are included as a category of demand, because such losses occur with the delivery of water and are in addition to contractual or other obligations.

The allocation of CVP water supplies can be portrayed as a two-tiered hierarchy, where all the categories of water demand fall into one of two "groups": Group I and Group II. Under this allocation system, Group I water demands must be met first.

Group I includes all demand categories with specifically defined minimum supplies. These include:

- Sacramento River water rights and San Joaquin Exchange contracts, with associated minimum rates of delivery in critical Shasta inflow years.
- Refuge water supplies, which must be provided a minimum of 75% supplies as prescribed in CVPIA.
- M&I water supplies, which are assumed to be sustained at 75% of maximum historical use, adjusted for growth.
- Conveyance, evaporation, and other such losses incidental to the delivery of contractual supplies.

Group II includes all other agricultural water service contracts, and allocations are made only after Group I obligations have been met. Further, the supplies available to Group II are then apportioned based on contract entitlements, which contain no minimum delivery provisions. Group II south-of-Delta water contracts amount to about 2 million acre-feet. Because of increases in certain Group I requirements over time (M&I and refuge water) and loss of some pumping opportunity due to recent changes in operations criteria, the potential for deficiencies to Group II exists every year.

San Luis Reservoir and O'Neill Forebay

There are two ways to move water from the Delta to San Luis Reservoir. One is Tracy Pumping Plant, which pumps water into the Delta-Mendota Canal. The other is Banks Pumping Plant, which pumps water into the California Aqueduct. Operations of the CVP and SWP must be closely coordinated to avoid inefficient situations, such as one project pumping water into the reservoir at the same time the other is releasing water.

San Luis Reservoir is usually filled during winter and early spring to ensure that contractual obligations can be met through summer. Surplus, uncontrolled water in the Delta is pumped into the California Aqueduct and Delta-Mendota Canal and flows by gravity to O'Neill Forebay. Here part of the water is pumped into San Luis Reservoir and the rest continues south to the San Joaquin Valley and Southern California. Beginning in May and continuing through summer, irrigation and urban requirements are substantially larger than the allowable Delta pumping, so water is released from San Luis Reservoir to satisfy requests from downstream water contractors.

Since San Luis Reservoir has little natural inflow, water must be stored when the two Delta pumping plants can export more water than is needed for contracted deliveries. Because the amount of water that can be exported from the Delta is limited, the fill and drawdown cycle of San Luis Reservoir is an extremely important part of both CVP and SWP operations.

A typical cycle starts with minimum reservoir storage at the end of August. Irrigation needs decrease in September, but the opportunity to begin refilling the reservoir depends on available water in the Delta and adequate capability at the pumping plants. CVP pumping continues at maximum until the end of April unless San Luis Reservoir is filled or the water is not available. In May and June, Decision 1485 standards limit export pumping, and irrigation needs begin to increase, so San Luis Reservoir storage begins to decline. In July and August, CVP pumping is again at maximum, plus up to 195,000 acre-feet of CVP water can be exported at Banks Pumping Plant to replace water that could not be pumped at Tracy during the May/June pumping restriction. Irrigation demands are still high during this period, and San Luis storage continues to decline until late August, when the cycle begins anew.

It is important to coordinate scheduling of San Luis Reservoir operations between the two projects. When the SWP pumps water required by Decision 1485 for the CVP, it may be of little consequence to SWP operations but critical to CVP operations. The amount of water in San Luis Reservoir may make it possible to "exchange" space or water to aid the operations of either project. Also, close coordination is required to ensure that water pumped into O'Neill Forebay by the two projects does not exceed the CVP's capability to pump into San Luis Reservoir or into San Luis Canal at the Dos Amigos Pumping Plant (Figure 5).

Coordinated operations are one method of ensuring that demands can be met while minimizing

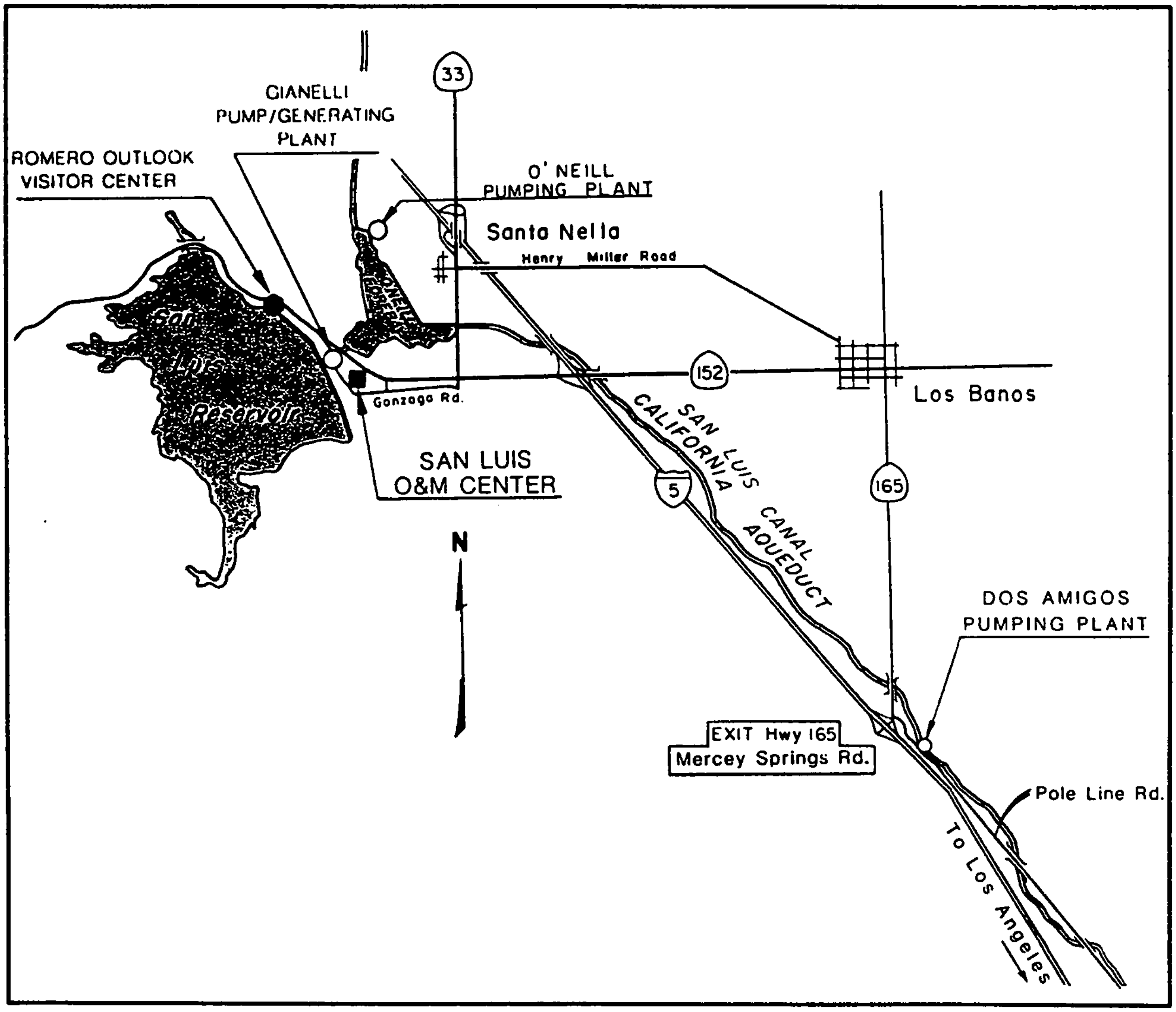


Figure 5
STATE WATER PROJECT AND CENTRAL VALLEY PROJECT JOINT FACILITIES AT SAN LUIS RESERVOIR AND O'NEILL FOREBAY

environmental impacts. This approach to operations allows the facility with the lowest impact to provide water to San Luis Reservoir for later delivery to water users.

John E. Skinner Fish Protective Facility

John E. Skinner Delta Fish Protective Facility began operating in 1968, using the same basic louver design as used at the CVP fish salvage facility. The louver system resembles venetian blinds and acts as a behavioral barrier. The slots are wide enough for fish to enter, but, at the correct water velocities, fish encountering the screens sense the turbulence and move along the screen face to the bypass.

Screens at Skinner Fish Facility separate fish from water diverted to Banks Pumping Plant through Clifton Court Forebay. The system consists of a series of primary V-shaped bays with louver fish screens that guide fish to a bypass at the apex of the "V" (Figure 6). Fish entering the bypass move via buried pipeline to a secondary screening system, where they are further concentrated. Exiting the secondary via another bypass, the screened fish enter holding tanks, where they are kept until they are trucked into the Delta and released. The release sites, Horseshoe Bend and Curtis Landing, are far enough from the pumps to reduce the chance of salvaged fish returning to the pumping plants. Releases are alternated between the two sites to reduce predation. Two CVP release sites are also available in emergencies.

In 1993, the State modified one of the fish hauling trucks so that fish could be released at boat ramps or docks or off the levee. The truck was modified to carry a portable water pump and four 10-foot sections of 10-inch-diameter flexible hose that can be attached to the release valve on the truck. The hose acts as a conduit for fish and allows the truck to reach the water from most road-accessible locations around the Delta. This tank truck feature allows releases at sites in addition to the permanent release facilities.

In the early 1980s, Water Resources installed center walls in the primary bays at Skinner Fish Facility to improve striped bass screening efficiency; opened new bays; built a new, perforated-plate screened secondary; and rescreened the holding

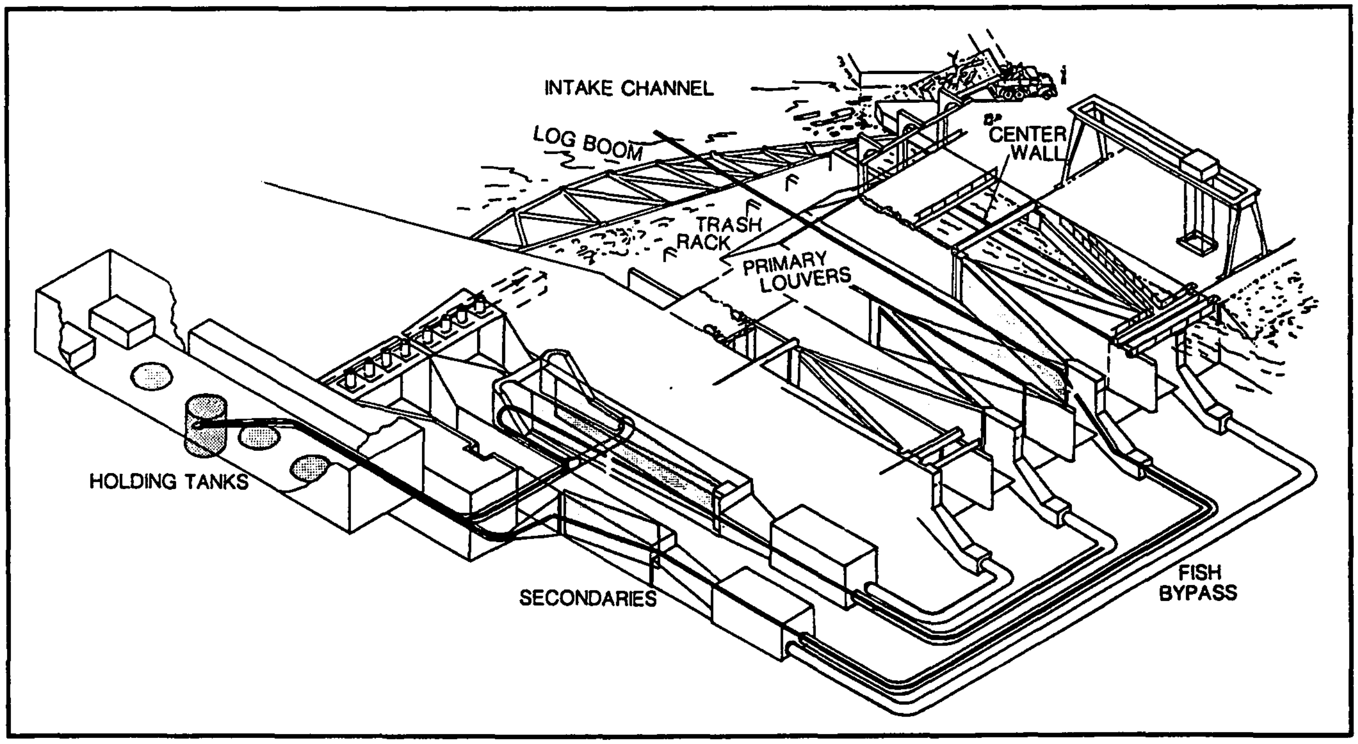


Figure 6
SCHEMATIC DIAGRAM OF THE JOHN E. SKINNER FISH PROTECTIVE FACILITY

tanks to help minimize fish losses. The new secondary is a positive-barrier screen, in that the small-diameter perforations prevent most fish greater than 20 mm TL from passing through the screen. This screen type is not designed to reduce entrainment of eggs or larvae.

In 1992, Water Resources completed three more holding tanks, which improve salvage efficiency for some species by allowing more efficient use of both secondary systems. In addition, the four new pumps at Banks Pumping Plant, in combination with the new holding tanks, allow better velocity control and increased salvage efficiency. The increased efficiency results from the capability to optimize water velocities for these species at any given pumping rate and from using both secondaries to ensure that flows through the holding tanks do not exceed fish protective criteria.

Fish salvaged at Skinner Fish Facility are subsampled periodically to obtain information on species composition, numbers, and lengths. Since operation began in 1968, the number and species composition of fish salvaged has been estimated by subsampling the fish entering the holding tanks. In 1992, the Department of Fish and Game took over the fish salvage and sampling operation under a contract with Water Resources. Fish and Game maintains the salvage data and reports monthly salvage estimates.

In the early 1970s, Water Resources and Fish and Game conducted an extensive evaluation of Skinner Fish Facility and have subsequently evaluated specific features such as trucking and handling losses, predation losses in Clifton Court Forebay, and losses in the holding tanks. Studies have generally been confined to a relatively few species, including fall-run Chinook salmon, striped bass, and American shad. Specific studies have not been conducted for delta smelt or splittail. However, recent experience of Fish and Game and the University of California, Davis, in handling and hauling delta smelt caught in the estuary indicates that species probably experiences high delayed mortality due to stress during handling and trucking.

Following are descriptions of each major feature of the SWP fish salvage system in the southern Delta, with special reference to delta smelt and splittail.

Clifton Court Forebay Gate Operations

Clifton Court Forebay is a 31,000-acre-foot regulating reservoir at the intake to the California Aqueduct (Figure 7). Inflows to the forebay are controlled by radial gates and are generally operated during high tide to reduce approach velocities and prevent scour in adjacent channels. The forebay is operated to minimize water level fluctuation in the intake by taking water in through the gates at high tide and closing the gates at low tide. When the gates are open at high tide, inflow can be as high as 15,000 cfs for a short time, decreasing as water levels inside and outside the forebay reach equilibrium. This flow corresponds to a velocity of about 2 feet per second in the primary intake channel. Figure 8 shows operation patterns of the radial gates. The schedule may vary from actual operations, depending on pumping restrictions for winter-run Chinook or delta smelt. Figure 9 shows predicted water surface elevations for a number of sites in the regions based on simulated operations.

Starting in May 1994, gate operation patterns were prioritized (as follows) to minimize entrainment of delta smelt into the forebay.

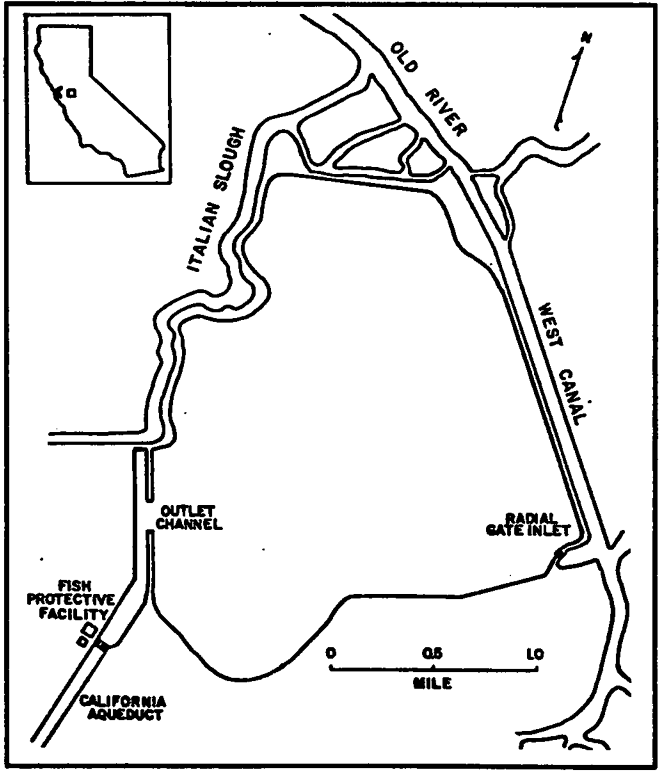


Figure 7
CLIFTON COURT FOREBAY

Priority 1

Intake gates open 1 hour after low-high tide, close 1 hour before high-low tide, open 1 hour after high-high tide, and close 2 hours before low-low tide (Figure 8, schedule D).

Priority 2

Intake gates open 1 hour after low-low tide, close 1 hour before high-low tide, open 1 hour before high-high tide, and close 2 hours before low-low tide (Figure 8, schedule B).

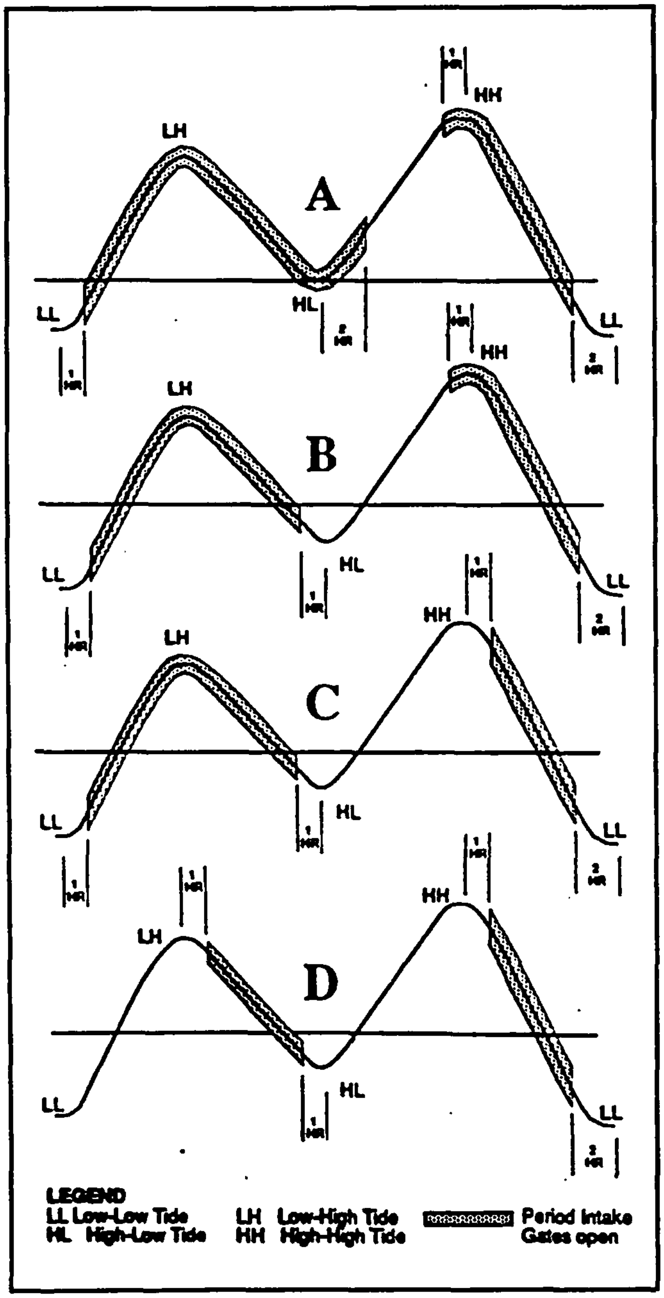


Figure 8
OPERATION PATTERNS OF
CLIFTON COURT FOREBAY RADIAL GATES

Priority 3

Intake gates open 1 hour after low-low tide, close 2 hours after high-low tide, reopen 1 hour before high-high tide, and close 2 hours before low-low tide (Figure 8, schedule A).

Priority 1 gate operation schedule was used as much as possible to reduce impacts to delta smelt and the southern Delta. If it appears that scheduled forebay inflow or Banks pumping cannot be met with priority 1 operation, then priority 2 is used; priority 3 is used in extreme cases.

Evaluations of juvenile salmon and striped bass survival across the forebay indicate predation in Clifton Court Forebay may be a significant source of juvenile fish mortality. In a series of Fish and Game studies, losses of marked fall-run hatchery salmon crossing the forebay were significant. Prescreen loss studies in 1976 to 1992 produced estimates of juvenile salmon mortality ranging from 68 to 99%. Losses were assumed to be largely due to striped bass predation, since the population of subadult striped bass in the forebay has been estimated to range between 35,000 and 945,000 (T. Tillman, DFG, pers comm; Kano 1990a). Fish and Game is using a juvenile salmon loss rate of 75% to calculate Chinook salmon losses at the SWP intake. No predation loss estimates have been established for either delta smelt or splittail.

Water Resources and Fish and Game are proposing an experimental predator removal program for 1994-95 in Clifton Court Forebay. The project will evaluate the effects of removing at least 75% of predator-size striped bass on prescreen survival of salmon and other juvenile fish entering the forebay. The experiment will address questions about the level of predation, recruitment of predators, and the amount of effort required to reduce predation in the forebay.

Given the relative success of salvage operations for salmonids, a reduction in predation across Clifton Court Forebay would help to minimize loss of winter-run Chinook and other salmon. Minimizing losses of delta smelt will require both a reduction in predation losses and improved survival of fish salvaged at the pumps and reintroduced to the western and central Delta. Efforts to achieve higher survival rates for salvaged fish are discussed in later sections.

Primary and Secondary Louvers

Salvage efficiencies for salmon, striped bass, and American shad at Skinner Fish Facility were evaluated in 1974. The following equations for combined efficiency of primary and secondary louver screens for the species of interest were derived as a result.

Length (mm)	Efficiency
Fall-Run Chinook Salmon	
1-100	0.630 + (0.0494 x Approach Velocity)
100	0.568 + (0.0579 x Approach Velocity)
Striped Bass	
21-30	0.935 - (0.149 x Approach Velocity)
31-40	0.806 - (0.0431 x Approach Velocity)
>41	0.945 - (0.0717 x Approach Velocity)
American Shad	
1-50	$(-65.8) - (0.0539)(\text{Length}^2) + (5.43)(\text{Length})$
>51	0.71

Screen efficiency is a function of fish length and channel (sweeping) velocity. Decision 1485 specifies the following velocities in both the primary and secondary channels:

- 3.5 feet per second from November 1 through May 14 for Chinook salmon.
- 1.0 foot per second from May 15 through October 31 for striped bass.

Channel velocity criteria are also a function of bypass ratios through the facility. Decision 1485 requires the following bypass ratios for salmon and striped bass.

For salmon:

- Maintain 1.2:1.0 to 1.6:1.0 bypass ratio in both primary and secondary channels.

For striped bass:

- Maintain 1.2:1.0 bypass ratio when operating Bay A only.
- Maintain 1.2:1.0 bypass ratio when operating Bay B only.
- Maintain 1.5:1.0 bypass ratio when operating both primary bays and when channel velocities are less than 2.5 fps.
- Maintain 1.2:1.0 bypass ratio in the secondary channel for all approach velocities.

How delta smelt and splittail react to these velocities or whether any of the criteria are appropriate for juvenile or adult smelt and splittail is not known.

The new secondary is a perforated-plate positive-barrier screen with 5/32-inch holes. The screen will exclude 100% of juvenile fish longer than about 20 mm. With appropriate channel (sweeping) and screen approach velocities, screening efficiency could also be this high for juvenile or adult delta smelt and splittail, depending on size and swimming ability. Efforts are now directed at determining approach velocities for delta smelt from the swimming stamina studies and screen mesh size from morphometric measurements.

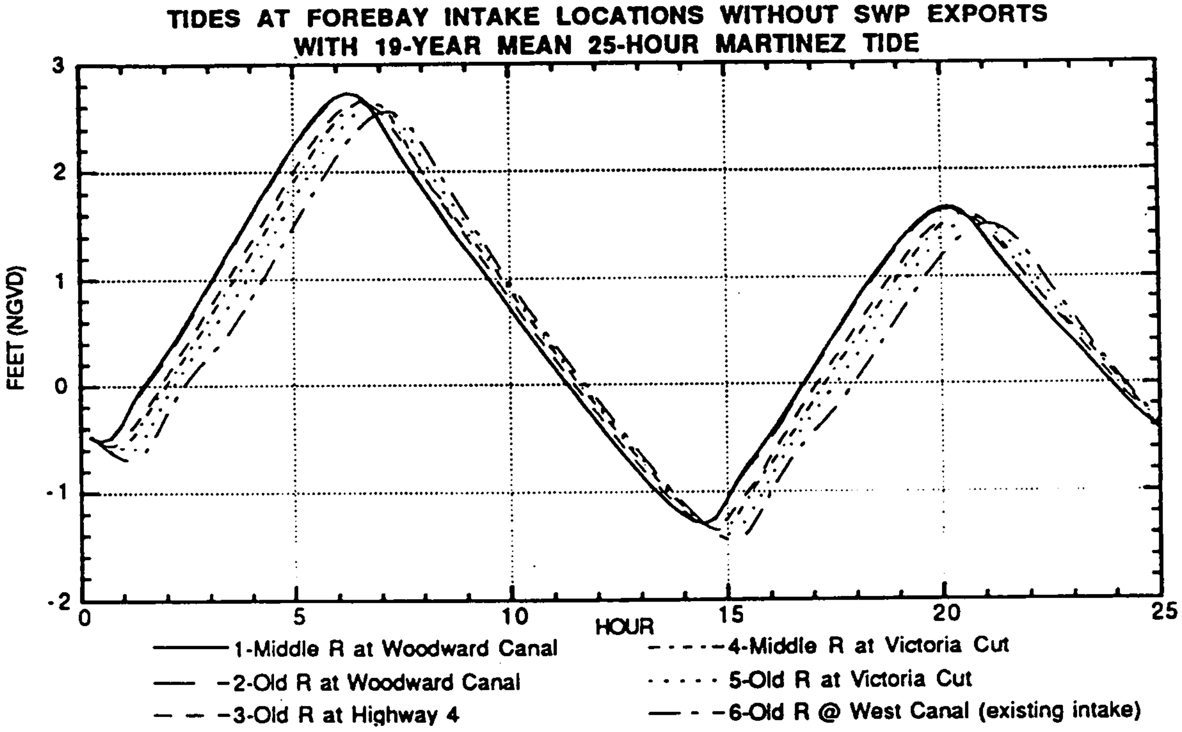
The Interagency Program's delta smelt work group is developing recommendations for screen criteria based on morphological and environmental tolerance tests and swimming stamina studies. The University of California, Davis, is under contract to Water Resources to study delta smelt swimming stamina, behavior, and environmental tolerance. This information will help establish screening requirements and flow velocity limits. Similar studies are being considered for splittail.

Striped bass and other predators can accumulate in the primary and secondary channels and prey on smaller fish moving through the salvage facilities. There are no reliable estimates of delta smelt losses to predation in this part of the system, but the potential for predation exists. The secondary channels are dewatered weekly during winter-run salmon periods and every other week through the year to reduce predator accumulation.

In June 1990, the secondary screening channels were drained to collect fish that had not entered the bypass and holding tanks. A total of 494 fish, representing 18 species, were salvaged, including:

Prickly sculpin	258
Striped bass	99
Chinook salmon	27
American shad	24
White catfish	11
Delta smelt	2

GATE OPERATION	TIMING
OPEN	1 HOUR BEFORE HIGH-HIGH TIDE
CLOSE	2 HOURS BEFORE LOW-LOW TIDE
OPEN	1 HOUR AFTER LOW-LOW TIDE
CLOSE	1 HOUR BEFORE HIGH-LOW TIDE


TIDES AT FOREBAY INTAKE LOCATIONS WITHOUT SWP EXPORTS WITH 19-YEAR MEAN 25-HOUR MARTINEZ TIDE

GATE OPERATION SCHEDULE

LOCATION	MODEL NODE	TIME IN HOURS OPEN	CLOSE	OPEN	CLOSE
1	117	5.00	12.25	15.25	24.25
2	82	5.00	12.25	15.25	24.25
3	79	5.25	12.50	15.50	24.50
4	113	5.50	12.50	15.50	24.50
5	75	5.75	12.75	15.75	24.75
6	72	6.00	13.00	16.00	25.00

Figure 9
WATER SURFACE ELEVATIONS FOR A SIMULATED
CLIFTON COURT FOREBAY GENERAL GATE OPERATION SCHEDULE

The Department of Water Resources has evaluated secondary bypass flows to assess bypass efficiencies under various operation criteria. Velocities into the bypass under existing striped bass flow criteria are not optimal to transport larger, strong-swimming fish through the bypass into the holding tanks. Designs are being reviewed to test modifications of the bypass entrance to increase velocities from the secondary channel into the bypass. With these modifications, bypass.efficiencies should increase significantly for larger, stronger predators such as striped bass and white catfish. The increased bypass efficiency should, therefore, reduce predation losses in the secondaries for all species of fish.

Holding Tanks

Decision 1485 specifies 10 cfs maximum flow through the six holding tanks. Due to flow imbalances, this criterion is met by average flows of 10 cfs for all tanks combined.

A number of factors influence short-term and long-term survival of fish in the holding tanks, including but not limited to:

- Predators.
- Stress related to extended periods of forced swimming against holding tank currents (a function of tank water levels).
- Salvage and handling.
- Water quality and temperature.

The holding tanks were rescreened in the mid-1980s to assure containment of fish diverted into the tanks. Fish are collected from the holding tanks into a crane-supported transfer bucket and moved to a tanker truck for hauling to the release sites.

In 1984 and 1985, tests were conducted to determine mortality associated with handling and trucking fish salvaged at Skinner Fish Facility (Raquel 1989). Six species were studied: Chinook salmon, striped bass, American shad, steelhead trout, threadfin shad, and white catfish. Mortality varied widely, depending on species, size of fish, and water temperature. Holding tank temperature and dissolved oxygen were the parameters most often significantly correlated with handling mortality. Holding tank flow, dissolved oxygen, and holding tank and trucking water temperature were most often significantly correlated with trucking mortality.

In 1994, the Bureau of Reclamation will evaluate the relationship between holding time and mortality rate for several fish species at Tracy Fish Facility. Water Resources will study those results for applicability to SWP operations.

Counting and Measuring

Since it is impractical to count all salvaged fish, estimates are made by subsampling periodically during the day and extrapolating results to the entire day. Typically, subsamples are collected every 2 hours by diverting flow from the secondary bypass into a "counting" tank. Sampling time varies with expected fish density but is normally about 10 minutes. Fish collected in each subsample are identified to species, counted, and returned to the holding tank. Four times each day (0300, 0900, 1500, 2100), the total length of each species from each subsample is measured to the nearest millimeter. Total daily salvage, by species and average length of each species, is then calculated by comparing the period subsampled with total pumping time.

All smelt collected during a counting period at Skinner Fish Facility are preserved for positive identification. This procedure was instituted after an adult Japanese pond smelt (wakasagi) was discovered during a salvage count in May 1993. Smelt are identified during the counting and rechecked by a DFG biologist. Those that cannot be positively identified as delta smelt are rechecked by Dr. Johnson Wang, an acknowledged expert. Positive identification of 20- to 40-mm juvenile wakasagi and delta smelt has been questioned due to overlapping or confounding characteristics previously thought to separate the two species. To address the identification problem, samples of both species have been collected and sent to UC-Davis for electrophoretic analysis. This work should help in determining whether the samples are genetically different and whether crossbreeding has occurred between the two species.

Hauling

Two stainless steel tank trucks operate at Skinner Fish Facility. Both are specially designed to reduce mortality associated with transporting fish to the release sites. The 2,500- and 1,200-gallon tanks reduce overcrowding, provide better temperature insulation, and are designed and loaded to reduce sloshing during transport. The smaller tank is fiberglass-insulated to help keep the water cool, and both tanks have oxygen injection systems.

Hauling frequency is based on estimated density of fish in the holding tanks. Guidelines for operating Skinner Fish Facility require that fish not be held longer than 8 hours, so salvaged fish are hauled to release sites at least three times a day; when large numbers are collected, hauls can be as often as five or six times a day. Also, hauls may be more frequent if only one truck is available, especially when operating only the 1,200-gallon truck.

Effects of handling and hauling on several fish species at Skinner Fish Facility were evaluated by Raquel (1989). Recommendations include adding 2 to 10 ppt salt to water in the tank trucks to reduce physiological stress of handling. Adding salt increased overall survival during transport (Raquel 1989). Under conditions of the 1994 biological opinion for delta smelt, 8 ppt of salt is added to the tank water before transport.

Although the studies did not specifically include delta smelt, data from Raquel (1989) are being reviewed for relevance to delta smelt and splittail survival. Delta smelt are apparently intolerant of handling and have high mortality rates under physically demanding conditions (Odenweller 1990, 1991; Sweetnam and Stevens 1991; R. Mager, UCD, pers comm).

There have been related concerns regarding long-term survival of salvaged delta smelt following release (Odenweller 1990, 1991; Sweetnam and Stevens 1991). Effects of transport and handling on survival of delta smelt have been documented during striped bass grow-out facility operations. Of 1,605,774 fish taken from the salvage facility to the grow-out facility in 1989, 111,093 (79%) did not survive; that number includes all of the 2,590 delta smelt taken incidentally (Odenweller 1990). Again in 1990, all 14,475 delta smelt taken were lost at the grow-out facility (Odenweller 1991). However, it is not clear how conditions at the grow-out facility compare to conditions salvaged fish encounter when they are returned to Delta channels.

Although it is not clear how conditions at the grow-out facility compare to conditions encountered by salvaged fish when they are returned to Delta channels, high losses must be assumed. This problem is being addressed both through efforts to reduce predation at Delta release sites and through research. Additional handling and trucking stress studies of delta smelt (or a surrogate species) and splittail are being discussed (Sweetnam and Stevens 1993; D. Hayes, DWR, pers comm).

Salvage Release Sites

The SWP maintains two permanent release site facilities, at Horseshoe Bend on the Sacramento River and on Sherman Island at Curtis Landing on the San Joaquin River. Two CVP release sites are also available in emergencies. Releases are alternated between sites over a 24-hour period. Normally, morning releases are at the Curtis Landing site, evening or night releases are at Horseshoe Bend, and afternoon releases are alternated between sites. Night releases are always at Horseshoe Bend because of protective fencing around the truck hookup. During delta smelt and splittail salvage operations in 1993, trucks made up to five releases a day to reduce holding time and exposure to predators in the holding tanks and in the trucks.

The 1993 delta smelt biological opinion required Water Resources to construct an additional release site. A thorough environmental evaluation of permanent release site options could not be completed and the necessary permits obtained by the January 1, 1994, deadline. Therefore, Water Resources modified one of its tank trucks so fish could be released at suitable sites in the upper Delta.

Facility Evaluations and Concurrent Studies

Water Resources, in cooperation with Fish and Game, is implementing studies for Skinner Fish Protective Facilities. Studies now planned include evaluations of:

Primary Intake Channel

Louver efficiency.

- Actual entrainment estimates data collection.
- Sample proportion of flow behind louvers and look at ratio of loss to estimate efficiency.
- Sieve net secondary channel to estimate louver screen efficiency.

Hydraulics and effects on guidance efficiency.

Secondary Intake Channel

Fish movement through secondary channels.

- Construct secondary channel covers to test effects of light and dark conditions on fish movement and salvage.
- Construct and test hydraulic effects of a ramp at the bypass entrance and influence on bypass flows and fish movement.

Fish Facility Predation

Pilot study to determine extent of predation and effects on fish salvage of weekly predator removal from secondary channels.

Draw down secondary channels and remove all predators to test effects on salvage.

- Introduce specific numbers and species of predator fish, and measure effects on fish salvage.

Hydroacoustic studies near trash racks and primary channel louvers to assess predator holding and foraging locations and predator numbers.

Holding Tank Operation Procedures

Evaluate different counting procedures, subsampling effects, sampling duration.

Develop equipment to better handle and transfer large numbers of fish to reduce fish stress and losses.

Study hydraulics to evaluate efficient holding tank flows for maximum fish salvage and survival.

Handling and Trucking

Conduct experiments to determine optimum procedures for delta smelt or a surrogate species.

Evaluate tank truck size and configuration on fish survival.

Release Sites

Study effects of predator populations, composition, and behavior on salvaged fish releases and survival.

Evaluate mobile release versus fixed-site release survival.

Evaluate use of holding pens for pre-release acclimation to local conditions.

These studies are being reviewed by an Interagency Program fish facilities work team and are being implemented on a priority basis. Fish and Game has developed draft work plans (DFG unpublished report).

As part of evaluations of predation impacts on released fish, the Bureau of Reclamation, Water Resources, and Fish and Game are planning a hydroacoustic and predator fish sampling study. The study will compare predator density at the permanent release sites under normal operations to predator density at multiple locations with infrequent releases. This evaluation was proposed to determine if permanent release facilities are returning fish to the Delta with minimal additional losses due to predation.

Tracy Fish Protective Facility

The Bureau of Reclamation completed Tracy Fish Protective Facility in 1958 to salvage fish that would otherwise be lost to Tracy Pumping Plant or entrained into Delta-Mendota Canal. Tracy Fish Facility is a louver structure based on a design developed by the U.S. Fish and Wildlife Service (Bates and Vinsonhaler 1956); it was the first full-scale louver fish screen ever built. The louver structure was specifically designed to intercept and salvage salmon smolts and 4-inch and larger striped bass. However, it also intercepts smaller striped bass and other species.

Tracy Fish Facility is at the intake to Tracy Pumping Plant, 2.5 miles downstream. Basic features are the system of primary and secondary louvers (Figure 10). The primary screening system is a single 320-foot-long louver array positioned at about a 15-degree angle to the direction of the flow. The louver slats are 25 feet high with a 1-inch space

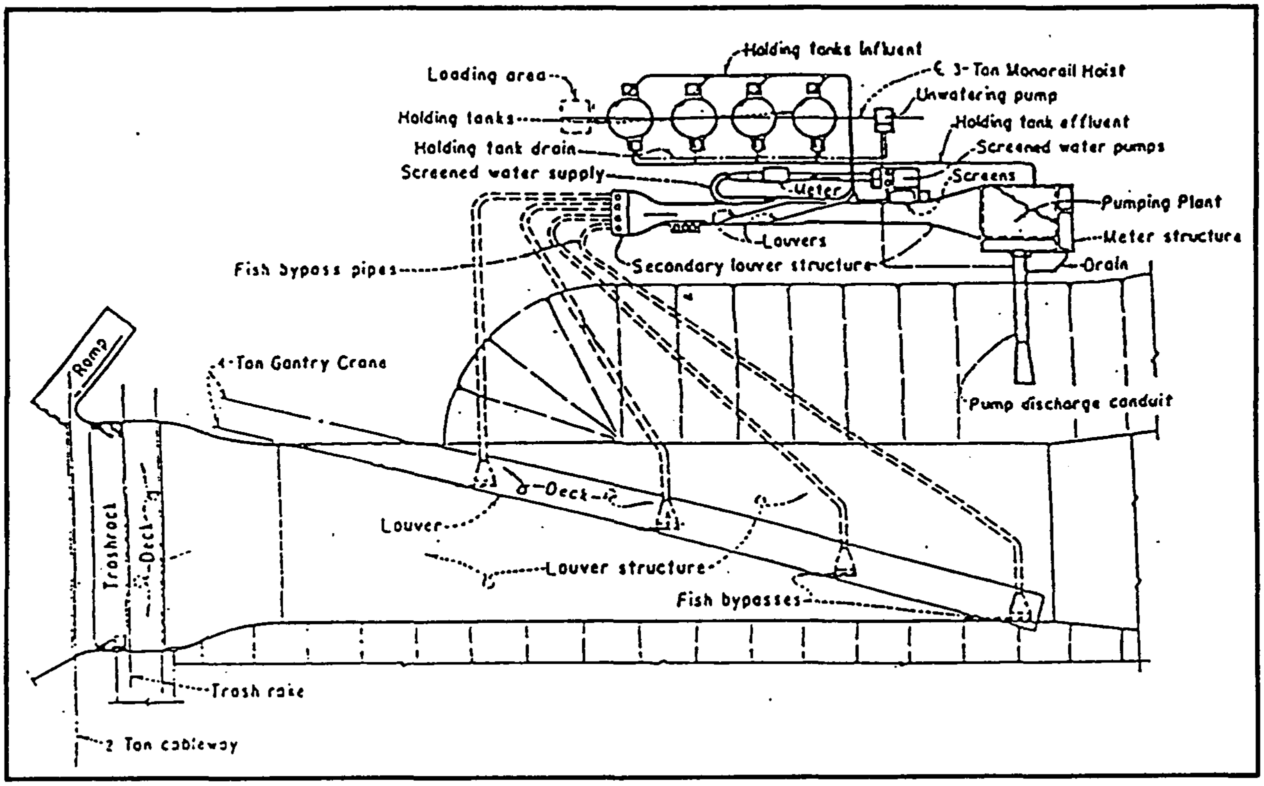


Figure 10
SCHEMATIC DIAGRAM OF CENTRAL VALLEY PROJECT TRACY FISH PROTECTIVE FACILITIES

between slats. Four 6-inch "bypass windows" along the primary louver face convey fish to the secondary louvers and on to the holding tanks. Salvaged fish are transferred to 2,000-gallon trucks and hauled to the Delta for release. The Bureau of Reclamation uses two release sites, one on the Sacramento River near Horseshoe Bend and the other on the San Joaquin River immediately upstream of the Antioch Bridge.

Changes in water surface elevation caused by tidal fluctuations affect operations at Tracy Fish Facility. High tide at the facility occurs about 8 hours after high tide at the Golden Gate Bridge, and tidal heights are about 70% of those at the Golden Gate. Typical tidal fluctuation at the fish facility is about 3 feet; maximum fluctuation is 6 feet. Since pumping at Tracy is generally constant over a 24-hour period, channel and approach velocities vary with tidal height.

Tracy Fish Facility is operated to achieve water velocity through the louvers specified in Decision 1485 for striped bass (about 1 foot per second) and for winter-run salmon (about 3 fps). However, tidal changes in water surface elevation can make this operation difficult, especially during low tide.

When the fish facility began operating, Tracy Pumping Plant was not operated year-round. Water was pumped to meet seasonal irrigation demand, generally April through October. With addition of San Luis Reservoir in 1967, the Tracy facilities began operating year-round. Pumping through winter affected fish species other than salmon and striped bass, especially smelt and other early spawners. This is documented by increased salvage of these species at the fish facility.

A complete field evaluation of Tracy Fish Facility is now underway to identify specific operational problems and possible improvements. The Bureau of Reclamation is also evaluating hydraulic conditions at the fish facility and periodically removing predators from the secondary bypass system.

Primary and Secondary Louvers

Initial evaluations of Tracy Fish Facility were conducted in the late 1950s by the Fish and Wildlife Service (Bates *et al* 1960) and Department of Fish and Game (Hallock 1968). The first study was not designed to measure efficiency at the primary louvers, but it did show a 90% salvage efficiency in the secondary louvers. The second study used paired fyke-nets upstream and downstream of the primary louvers and, based on striped bass, found that the primary louvers had a 71% efficiency in 1966 and a 91% efficiency in 1967. The difference between years was due to the size of captured striped bass. Data with striped bass showed a diversion efficiency of 5.4% for bass averaging 20 mm, 76% for 32 mm, 92.4% for 44 mm, and 99.4% for bass longer than 120 mm.

In day-versus-night comparisons, the primary louvers appeared to be more efficient during daylight hours, but the difference was minimal. At velocities of 2.2 to 3.9 feet per second, no significant difference in efficiency could be documented for bass. Other species captured in this study were too few to accurately determine louver efficiencies. Preliminary estimates of primary louver efficiency are 66% for delta smelt (161 fish), 89% for threadfin shad (159 fish), and 91% for American shad (1,223 fish). The 66% louver efficiency for delta smelt probably reflects a predominance of adults and sub-adults in the collections. Louver efficiency seems to be species or size dependent, based on these data. Further research is needed to document salvage efficiency at Tracy Fish Facility for delta smelt and splittail.

The current study to improve operations will examine how Tracy Fish Facility functions in relation to listed and candidate species, especially delta smelt and splittail. Discussions are continuing to determine interim screen criteria based on existing efficiency rates and to conduct swimming performance studies to develop specific delta smelt criteria.

Striped bass, white catfish, and other predators in the primary and secondary channels undoubtedly prey on delta smelt, but there are no reliable estimates of predation loss rates for smelt. Predation losses for smolt salmon are estimated at 15% based on losses at other fish screens.

Each month for the last 3 years, the Bureau of Reclamation has removed predators from the secondary louver channel. Large numbers of predators have been removed, and the number and size of predator fish seems to be decreasing with successive removal operations. Stomach analyses of striped bass and white catfish indicate small fish are the major food consumed, but a few delta smelt have been found. The Bureau of Reclamation plans to continue monthly predator removal from the secondary channel to reduce predation on smaller fish such as delta smelt. The Bureau also plans to study ways to reduce predators in front of the trash rack and in the primary louver channel.

Holding Tanks

There are two types of losses in the holding tanks, neither of which has been documented. The first type is predation losses, similar to those in the louver channels. The second type is loss due to stress and fatigue from fighting a current. Both types would increase as length of holding time increased. The 1993 and 1994 biological opinions for delta smelt recommended holding times of no more than 8 hours to help reduce these losses. The Bureau of Reclamation complied with this request before the opinion was released and continues to do so.

There is concern that delta smelt do not reach the release sites alive and that salvage operations are ineffective for this species. Bureau of Reclamation personnel have indicated that delta smelt survive the screening and holding procedure and are in good shape when placed into transport trucks. Adult delta smelt are generally seen in the loading bucket, in groups of 5 to 10 near the surface. Studies are needed to confirm that salvage operations are functioning properly or to design methods to improve delta smelt survival through the salvage facilities.

The Bureau of Reclamation has proposed a study to determine how holding time influences mortality rates for several fish species. However, documenting the health or condition of fish before they enter the holding tanks will be difficult. The added handling stress involved in determining their condition before they enter the holding tank will affect interpretation of results. Work on this study is proposed to begin in 1994.

Counting and Measuring

It is not practical to count all salvaged fish, so estimates are made by sampling every 2 hours and extrapolating the results to the entire day. Sampling typically represents one-twelfth of the total salvage. Fish are measured at two counts every day. Counting and identifying fish results in additional handling, so these fish are more stressed than the typical fish going through the salvage operations.

When salvage operations began at Tracy Fish Facility, salmon and striped bass were the species of interest, and delta smelt were lumped in a class called "others". When enumeration of smelt began in the 1960s, longfin and delta smelt were both in one category, "smelt", but the two species have been identified separately since 1969.

A concern with the data is that delta smelt may have been misidentified in these early years. Adult delta smelt are fairly easy to identify, and identification has likely been accurate for many years. Larval delta smelt closely resemble longfin smelt, and until recently it was not possible to separate the two. Also, juvenile delta smelt can be easily confused with juvenile threadfin shad and American shad. These younger stages must be preserved to be positively identified, which would be counterproductive for a salvage facility.

In 1994, wakasagi were found among the salvaged fish. Some specimens could not be identified conclusively as either wakasagi or delta smelt. Efforts are underway to identify separating characteristics.

The Bureau of Reclamation has hired a fisheries biologist expressly for Tracy Fish Facility and has contracted with a consultant as part of a long-range improvement of taxonomic identification for several species. Studies so far indicate fish facility workers are nearly 100% accurate at identifying adult delta smelt and about 80% accurate at identifying juvenile longfin and delta smelt. Salvage personnel are not expected to become proficient at identifying larval smelt less than 15 mm. This work is now done by a contractor.

Bureau of Reclamation biologists are studying splittail distribution and movement through the fish facility. Radio-tag tracking of adult splittail is providing preliminary information on activity of these fish in and near the facility.

Hauling

Hauling losses for delta smelt are unknown. Stress and predation are the obvious concerns. The large hauling trucks (2,000 gallons) are built and loaded in such a way as to reduce sloshing. These large tank trucks are believed to provide the best conditions for transport of fish that can reasonably be developed. Tests have shown that water temperature changes are less than one degree in the hottest part of summer. In addition, salt is added to the tanks to create an 8-ppt solution to reduce stress and disease associated with handling and transport.

Hauling fish in tanker trucks during foggy weather is a major problem. Because of dense fog in the Delta during winter, often for long periods, personnel safety is a concern. These conditions also increase the time of the hauling trip, possibly exposing delta smelt to additional stress and predation.

Salvage Release Sites

The 1993 delta smelt biological opinion indicated that Tracy Fish Facility had a single release site for salvaged fish, because the other site had a nonfunctional pump and was under repair. At a meeting on June 2, 1993, a representative of the Fish and Wildlife Service Endangered Species Office indicated that completing repairs at the second release site would fulfill the requirement for a second CVP release site. Repairs have been completed, and two sites are now being used.

During the winter of 1992-93, thousands of adult delta smelt were salvaged at the CVP and SWP fish facilities. These smelt were moving from rearing areas near the confluence of the Sacramento and San Joaquin rivers to upstream spawning areas and were drawn to the export pumping plants. Once salvaged, the fish were returned to release sites in the lower Delta and had to repeat the upstream migration. The Bureau of Reclamation is proposing to acquire a third release site, designed for use by both CVP and SWP trucks. The third site would be chosen and designed exclusively to enhance salvage and survival of delta smelt by allowing them to be released near their spawning areas. This would reduce the chance of salvaged delta smelt being re-entrained.

Suisun Marsh Facilities

Suisun Marsh is in southern Solano County, west of the Delta and north of Suisun Bay (Figure 11). This tidally influenced marsh is a vital wintering and nesting area for waterfowl of the Pacific Flyway, and it represents about 12% of California's remaining wetland habitat.

The *Suisun Marsh Plan of Protection*[1] and *Suisun Marsh Preservation Agreement*[2] were developed to assure that a dependable water supply is maintained in Suisun Marsh to offset diversions by the CVP, SWP, and others.

Suisun Marsh facilities are operated to minimize marsh salinity only so far as operations do not create a need for additional upstream releases, do

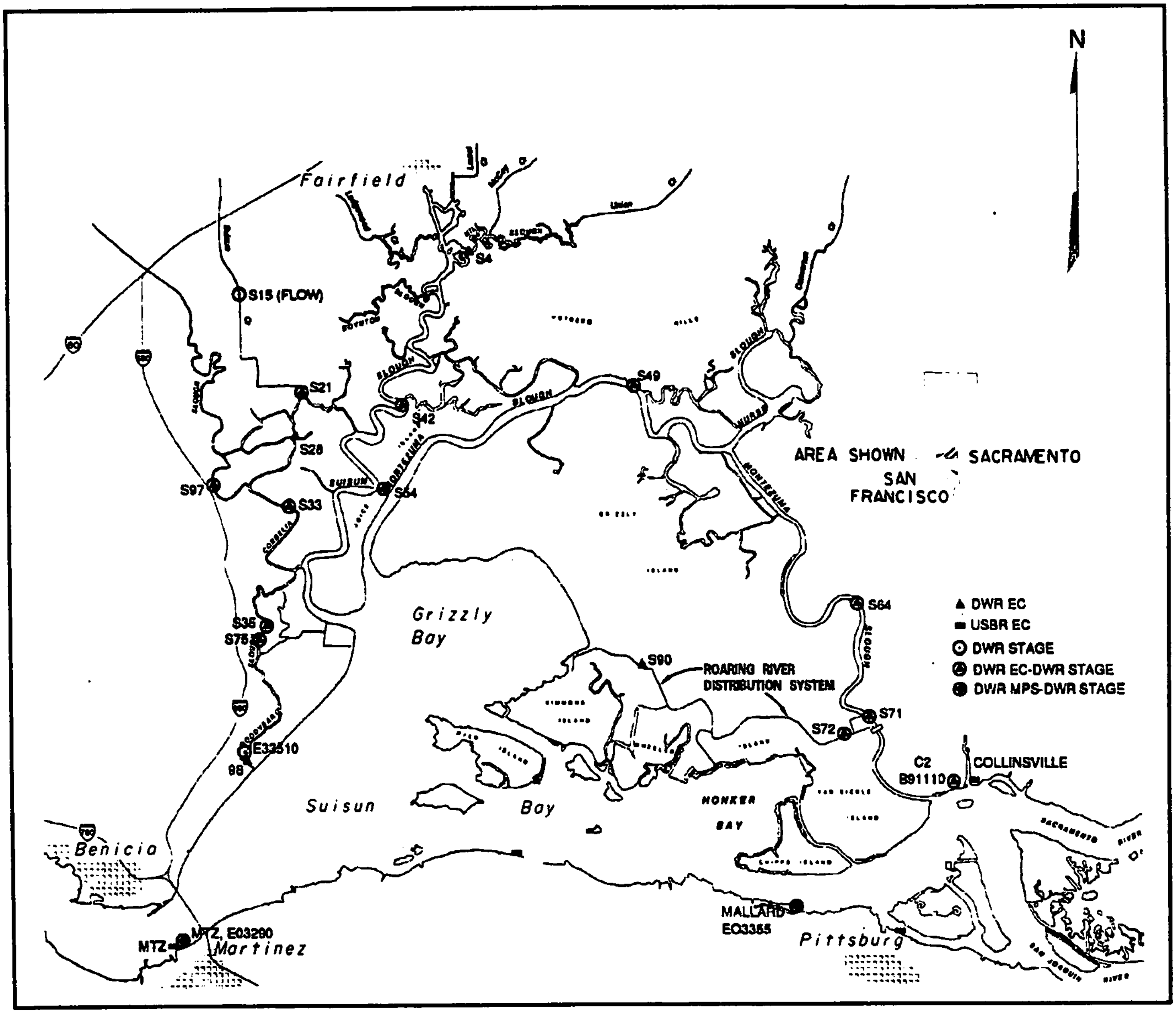


Figure 11
SUISUN BAY AND SUISUN MARSH

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[1] In 1984, the Department of Water Resources published the *Plan of Protection for the Suisun Marsh including Environmental Impact Report* in response to Order 7 of Decision 1485.

[2] The U.S. Bureau of Reclamation, Department of Water Resources, Department of Fish and Game, and Suisun Resource Conservation signed the *Suisun Marsh Preservation Agreement* in 1987.

not limit exports, do not harm fish, do benefit wildlife habitat, and do not require the Suisun Marsh Salinity Control Gate flashboards to remain in place beyond the time otherwise required to meet Decision 1485 standards.

Areas for compliance with the revised Decision 1485 salinity standards are being phased in over time. Since October 1988, compliance has been required for the eastern and northeastern regions of the marsh at Collinsville (C-2), National Steel (S64), and Beldons Landing (S49). Compliance for the northwestern region of the marsh began in October 1993 in Chadbourne Slough (S21) and Cordelia Slough (S97).

The schedule for future compliance is:

- October 1994 — Southwestern marsh in Goodyear Slough near Pierce Harbor (S75).
- October 1997 — Suisun Slough, 300 feet south of Volanti Slough (S42).

Phase I, Initial Facilities, of the Plan of Protection was completed in 1980, and Phase II, Suisun Marsh Salinity Control Gates[1], began operating in November 1988. Phases III and IV have been combined into the Western Suisun Marsh Salinity Control Project. Environmental documentation for the project is a joint effort by the Bureau of Reclamation and Department of Water Resources, and a draft EIS/EIR is scheduled for October 1995. If needed, Phase V, the Grizzly Island Distribution System, will provide a dependable water supply for the central region of the marsh; project planning and environmental documentation work is scheduled to begin after the conclusion of the Phase III/IV project. Phase VI, Potrero Hills Ditch, will be initiated if field monitoring indicates additional salinity control is necessary. DWR and USBR will initiate separate ESA consultations for these new facilities.

The Department of Water Resources started meeting southwestern marsh salinity standards on October 1, 1993. Salinity control is expected at all compliance sites using a combination of Delta outflow, Suisun Marsh Salinity Control Gate operation, and augmentation of creek flows from watersheds along the northwestern perimeter of the marsh. Lake Berryessa or North Bay Aqueduct water may be used in 1995 to control salinity in the western marsh if natural creek flows are insufficient. If 1995 is as dry as 1990, then an estimated maximum average daily flow of 50 cfs of augmentation water will be needed for January-March and 30 cfs for April-May 1995 to meet Decision 1485 standards in the western marsh. Model studies are in progress to refine the estimate of needed augmentation water. The refined estimate will reflect water year 1992 hydrologic and salinity conditions in the marsh and Suisun Bay as affected by conditions of the biological opinions for winter-run salmon and delta smelt.

In planning for the Western Suisun Marsh Salinity Control Project, Water Resources and the Bureau of Reclamation conducted a test in January-May 1994 to identify relationships between creek flow tributary to the northwestern marsh and channel water salinities in the same region. During the test, velocity, water level, and salinity instruments were deployed in northwestern marsh channels. Flow augmentation from the North Bay Aqueduct was intended to be used to reduce channel salinity in Cordelia Slough if natural flows from the Green Valley watershed were unable to control salinity. Natural flows were sufficient, and North Bay Aqueduct water was not needed. The test was a success; under test conditions, natural flows to Cordelia Slough were found to adequately control salinity in this part of the marsh. Specific information on the likely region of influence and residence time of augmentation water are needed for the EIS/EIR.

The Bureau of Reclamation and Water Resources are scheduling another test that will expand the scope of the first test that will run from September 1994 through May 1995. Additional instruments have been installed, and Green Valley Creek flow may be augmented. Marsh channel water salinities are expected to be higher than in early 1994 because 1994 runoff was so low (Sacramento River Index of 8 million acre-feet).

Facilities of the *Plan of Protection* that could affect delta smelt are discussed in the following sections. Diversions by private landowners, which could also affect delta smelt, are discussed as well.

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[1] Also referred to as Montezuma Slough salinity control gates.

Suisun Marsh Salinity Control Gates

The Suisun Marsh Salinity Control Gates are about 2 miles northwest of the eastern end of Montezuma Slough, near Collinsville. The structure spans Montezuma Slough, a width of 465 feet. A schematic of the structure (Figure 12) shows the southern, or upstream, side. From left (west) to right (east), the structure consists of the following components:

- A permanent barrier, 89 feet across, extending from the western levee to the flashboard module.
- The flashboard module, which provides a 66-foot-wide maintenance channel through the structure that can be closed September 1 through May 31. The flashboards can be removed if emergency work is required downstream of the gates, but removal requires a large barge-mounted crane.
- The radial gate module, 159 feet across, containing three radial gates, each 36 feet wide.
- The boat lock module, 20 feet across, which is operated when the flashboards are in place.
- A permanent barrier, 131 feet across, extending from the boat lock module to the eastern levee.

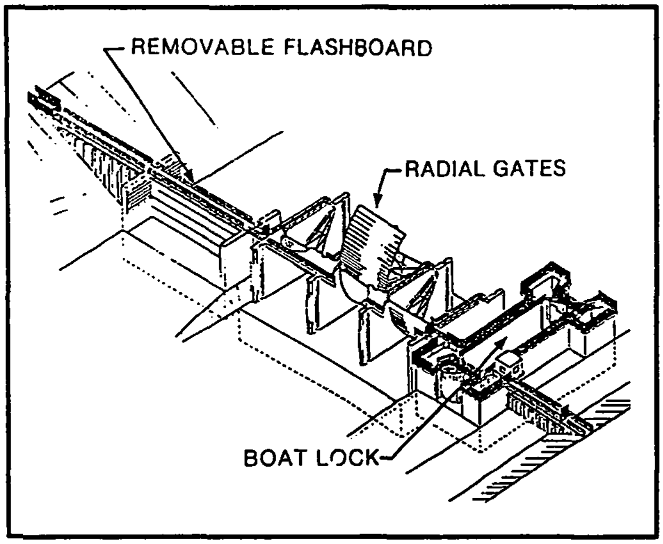


Figure 12
SUISUN MARSH SALINITY CONTROL GATES

An acoustic velocity meter is located about 300 feet upstream (south) of the gates to measure water velocity in Montezuma Slough near the structure. Water level recorders on both sides of the structure allow operators to determine the difference in water level above and below the gates. The three radial gates open and close automatically, using the water level and velocity data.

The Suisun Marsh Salinity Control Gates may be operated from September 1 through May 31 to hold less-saline water originating in the Sacramento River near Collinsville in eastern end of Montezuma Slough and reduce the amount of more-saline Grizzly Bay water from entering the western end. Gate operation is necessary during the marsh control season (October-May) of below-normal, dry, and critical water years. The gates can be operated full time to divert the maximum quantity of water from the Sacramento River or intermittently to divert only the quantity needed to meet Decision 1485 standards.

During full-bore operation, the gates open and close twice each tidal day (about 25 hours). The gates are open during the two ebb tides, when the water level is higher on the Collinsville (upstream) side, and remain open about 7 hours. The gates are closed during the two flood tides, when water in Montezuma Slough begins to flow upstream toward Collinsville.

The quantity of Sacramento River water "tidally pumped" by the gates is primarily a function of the shape and sequence of ocean tides and hydrologic conditions in the Delta. Instantaneous flows past the gates vary from no flow when the gates are closed to about 8,000 cfs with all three gates open. During full-bore operation, the net flow through the gates is about 1,800 cfs when averaged over one tidal day. When the gates are not operating (June-August) and the flashboards are removed, net flow in Montezuma Slough over one tidal day is low, and often in the upstream direction (as estimated by hydrodynamic model simulations).

Water is diverted from Montezuma Slough at individual diversion points onto Fish and Game and private land along the slough and at the Roaring River Distribution System intake.

In spring 1992, the biological opinion for winter-run Chinook salmon dramatically changed operation of the Suisun Marsh Salinity Control Gates over that which would have normally occurred in a critically dry year. The National Marine Fisheries Service ordered the gates closed from March 1 to March 27. A return to full gate operation was allowed beginning March 27 provided individual owners did not divert water through unscreened diversions. Because Roaring River is the only screened intake, most duck clubs were unable to divert water until May 1, 1992, when permit conditions in the opinion ended.

Because of the western Suisun Marsh salinity compliance sites (S-21, S-97, S-75), Water Resources expects to operate the Suisun Marsh Salinity Control Gates full bore from September 1, 1994, through May 31, 1995.

Roaring River Distribution System

The Roaring River distribution system is one of the initial facilities of the *Plan of Protection.* The Roaring River diversion and distribution system intake is the largest diversion point on Montezuma Slough. The intake consists of eight 60-inch culverts just to the north of the original Roaring River Slough confluence with Montezuma Slough. A 40-acre intake (peaking) pond, constructed west of the new intake culverts, supplies water to Roaring River Slough.

Flows through the culverts into the pond are controlled by motorized slide gates on the Montezuma Slough side and flap gates on the pond side. The motorized gates are adjusted depending on tide levels, the amount of diversions from Roaring River Slough, and the season. The original confluence of Roaring River Slough consists of a manually-operated flap gate that allows drainage back into Montezuma Slough for flood protection. Water Resources owns and operates this drain gate to ensure that the Roaring River levees are not compromised during extremely high tides.

Water is diverted into the Roaring River intake pond on high tides to raise the water surface elevation in Roaring River Slough above the adjacent marshlands. Wetlands south and north of Roaring River Slough receive water from the slough at a steady flow, as needed. The pond is used to supplement the water supply in Roaring River Slough. In most cases, the wetlands continue to drain to Grizzly, Suisun, and Honker bays and Montezuma Slough using existing facilities.

Wetland management operations and water demand from Roaring River and Montezuma Slough are discussed in the next section, "Discrete Diversions from Montezuma Slough".

The intake to Roaring River Slough is screened to prevent entrainment of fish larger than about 25 mm. Water Resources designed and installed the screens using Fish and Game criteria. The Bureau of Reclamation and Water Resources provide routine screen maintenance.

The screen is a stationary, vertical screen constructed of continuous slot, stainless steel wedge wire. One screen panel is constructed of copper-nickel alloy as a test of anti-biofouling materials (D. Hayes, DWR, pers comm). All screens have 3/32-inch slot openings. Design approach velocity is 0.5 foot per second, the through-screen velocity specified by Fish and Game to protect juvenile salmon and striped bass, but during routine operation, velocity is usually below this value. Flow through the fish screen is controlled by motorized slide gates on each culvert (maximum design flow occurs briefly, only at high-high tide, with all slide gates open).

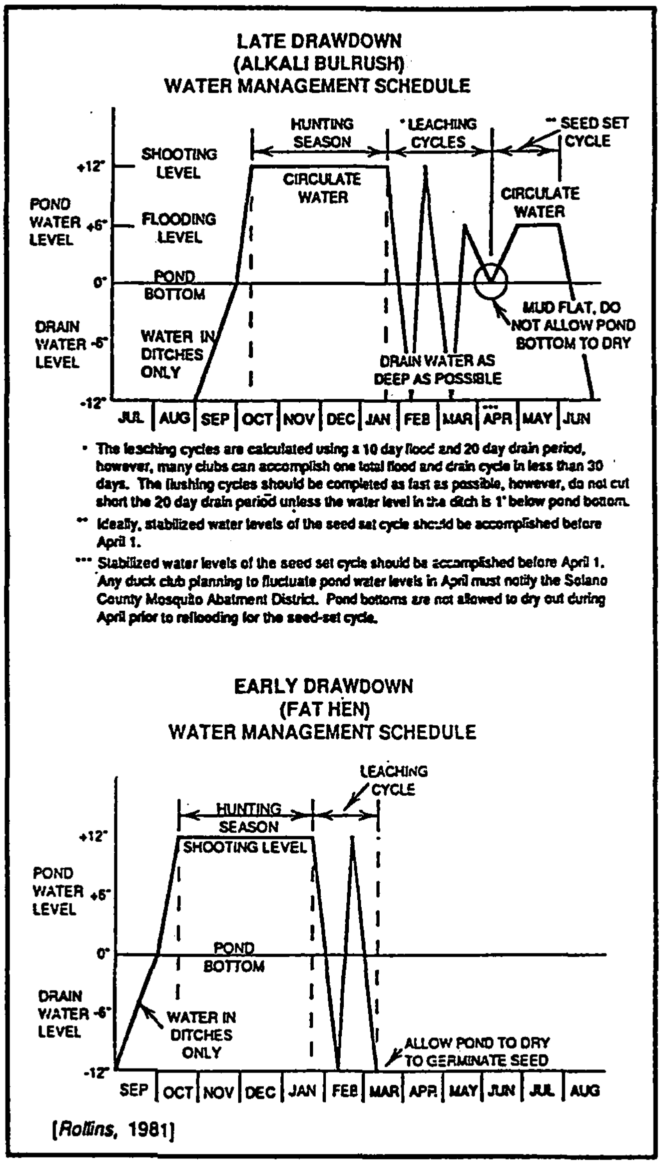
This year the Roaring River intake flows at Montezuma Slough will be modified by adjusting the slide gates to reduce entrainment losses of adult and juvenile delta smelt. At this time, the procedure will be to calculate the flow rate (cfs) through the fish screens based on the difference in water level in Montezuma Slough and the peaking pond and the position of the slide gates. Then, using the fish screen area through which water will flow (based on the water level in Montezuma Slough), the approach velocity will be calculated by dividing the flow by the area. If too high a velocity is calculated, then the slide gates will be lowered until the approach velocity is within the 0.2 fps criterion. In compliance with the 1994 delta smelt biological opinion incidental take term and condition 4, if new information on a more appropriate velocity becomes available, it shall be approved by the Fish and Wildlife Service and implemented. Initially, slide gate adjustments are expected to be made only during periods of higher-high tides. In addition, a close estimate of the required gate position can be achieved based on forecasting water levels in Montezuma Slough. To meet delta smelt biological opinion requirements, Water Resources is participating in developing recommended screen criteria for delta smelt as part of addressing Roaring River diversion concerns.

UC-Davis, under contract with Water Resources, is evaluating environmental tolerances and effects on swimming ability for delta smelt. Recent efforts have focused on morphometric measurements of preserved and live specimens of delta smelt. Preserved specimens were obtained from UC-Davis, the Bureau of Reclamation, and Dr. J. Wang. Live smelt from samples at SWP and CVP salvage facilities are measured when available. The measurements will help define the size of screen opening necessary to exclude a given life stage based on average morphometric dimensions. These data will be used in developing screening criteria for delta smelt. Additional studies going on at UC-Davis include environmental tolerance and swimming performance evaluations for juvenile and adult splittail and development of culturing techniques and early life history characterization.

Discrete Diversions from Montezuma Slough

The Department of Fish and Game and more than 30 private owners along Montezuma Slough divert water from the slough through more than 60 unscreened culverts of varying diameters. Most of these diversions are used to convert adjacent land areas to ponds for waterfowl management and hunting. Diversion rates are usually highest during October, when the managed wetlands are flooded for the first time each year. Initial flooding requires about 3 weeks.

Water management practices vary greatly in Suisun Marsh, but Suisun Resource Conservation District is working to update and enforce efficient management schedules for the private owners. During the control season, water is diverted from Montezuma Slough during initial flooding in October, for water circulation in November to mid-January, and during leach cycles in February to May (Figure 13).



- * The leaching cycles are calculated using a 10 day flood and 20 day drain period, however, many clubs can accomplish one total flood and drain cycle in less than 30 days. The flushing cycles should be completed as fast as possible, however, do not cut short the 20 day drain period unless the water level in the ditch is 1" below pond bottom.

** Ideally, stabilized water levels of the seed set cycle should be accomplished before April 1.

*** Stabilized water levels of the seed set cycle should be accomplished before April 1. Any duck club planning to fluctuate pond water levels in April must notify the Solano County Mosquito Abatment District. Pond bottoms are not allowed to dry out during April prior to reflooding for the seed-set cycle.

[*Rollins*, 1981]

Figure 13
TWO OPERATIONAL SCENARIOS FOR MANAGED WETLANDS IN SUISUN MARSH

In 1995, Water Resources will install screens for culverts diverting water onto Grizzly Island Wildlife Refuge to offset fish losses at Banks Pumping Plant. Water Resources is also considering screens for two culverts at the Lower Joice Island Fill/Drain Facility by 1995.

In summary, a number of efforts are underway to avoid or minimize impacts to delta smelt related to operations in the Suisun Marsh area, including controls on unscreened diversions, screen operations at the intake to Roaring River Slough, modified operations at Montezuma Slough, and screens at Grizzly Island Wildlife Refuge to mitigate for fish losses at Banks Pumping Plant.

Delta Cross Channel and Georgiana Slough

The Delta Cross Channel is a gated diversion constructed in 1951 by the Bureau of Reclamation to augment the natural transfer of water from the Sacramento River near Walnut Grove into the central and southern Delta. Water diverted into the Delta Cross Channel flows into Snodgrass Slough, then the Mokelumne River, San Joaquin River, and various channels in the central and southern Delta, providing a more direct path for high quality Sacramento River water to the pumping plants in the southern Delta. The Cross Channel gates are also operated for fish protection, flood control, water quality control, and recreational boat traffic.

Flows into the Delta Cross Channel are controlled by two 60- by 30-foot radial gates at the Sacramento River end of the mile-long cross channel. In accordance with Decision 1485, the gates are closed to avoid diverting salmon whenever the daily Delta Outflow Index exceeds 12,000 cfs from January 1 to April 15. From April 16 to May 31, the gates may be closed for up to 20 days, at the discretion of Fish and Game, to avoid diverting striped bass if the Delta Outflow Index exceeds 12,000 cfs. Such closures are not required to be more than 2 of 4 consecutive days. To reduce scour on the downstream side of the gate structure and to limit high flows and velocities on the Mokelumne River side of the Cross Channel, the gates are also closed when sustained flows in the Sacramento River at Sacramento exceed about 25,000 cfs. On occasion, the gates may be operated to regulate flow in the Sacramento River to help meet the Decision 1485 salinity standard at Emmaton.

The "reasonable and prudent alternatives" in the biological opinion for Chinook salmon require closing the Delta Cross Channel gates from February 1 to April 30 to avoid diverting juvenile winter-run salmon. Also, the gates must be operated to minimize diversion of juvenile winter-run based on real-time monitoring for their presence in the lower Sacramento River from October 1 to January 31.

Georgiana Slough, just south of the Delta Cross Channel, is a natural channel and, by virtue of its location, is the main channel for water moving from the Sacramento River to the San Joaquin River, central Delta, and the pumping plants in the southern Delta. This natural channel is used by salmon during migration. Juvenile salmon using this route are believed to have higher loss rates than those that stay in the Sacramento River.

Experiments have been performed at Georgiana Slough during spring 1993 and 1994 to investigate the effectiveness of an acoustic (underwater sound) barrier in guiding Chinook salmon smolts away from Georgiana Slough as a means of increasing juvenile salmon survival. Results of guidance efficiency are not yet available. The 1994 tests will also be used to evaluate potential acute and delayed effects of exposure to the sound pressure levels. Adult delta smelt were incidentally collected during trawling at the site, and juvenile splittail were collected in beach seines.

Contra Costa Canal

The Contra Costa Canal, which began operating in 1940 and was completed in 1947, originates at Rock Slough, about 4 miles southeast of Oakley. Water for irrigation and M&I use is lifted 127 feet by a series of four pumping plants. The 47.7-mile canal terminates in Martinez Reservoir. Two short canals, Clayton and Ygnacio, are integrated into the system. The initial diversion capacity of 350 cfs gradually decreases to 22 cfs at the terminus. Historically, pumping has ranged from about 50 to 250 cfs, and varies seasonally (Figure 14).

The Bureau of Reclamation, Contra Costa Water District, National Marine Fisheries Service, and Fish and Wildlife Service have developed a monitoring program to determine whether fish species of concern are being entrained into Contra Costa Canal and, if so, the levels of entrainment. Of principal concern are winter-run Chinook salmon and delta smelt, with slightly lesser concerns for Sacramento splittail and longfin smelt. The monitoring program began as a pilot program in 1994.

In compliance with the incidental take term and condition 5 to minimize take of delta smelt in the unscreened Rock Slough intake, the Bureau of Reclamation will use monitoring information described in the reporting requirements to determine reduction in diversion of water at the Rock Slough and Mallard Slough intakes. The intent is to minimize take of delta smelt adults, juveniles, or larvae

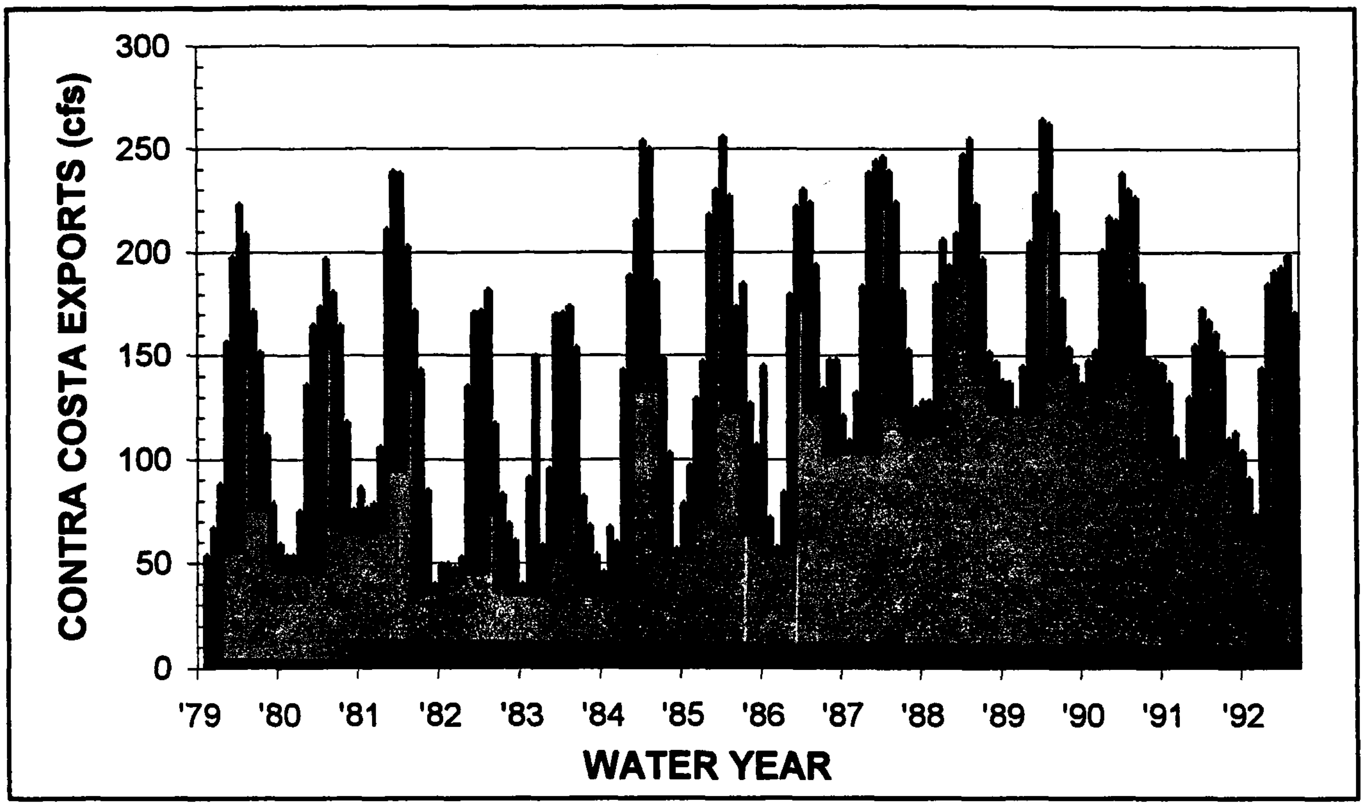


Figure 14
AVERAGE MONTHLY CONTRA COSTA CANAL PUMPING, WATER YEARS 1978 TO 1992
From the DAYFLOW Database.

that are exposed to pumping and diversion during the spawning and rearing interval from January through August. Notification of proposed reduction of diversion to reduce take of delta smelt will be submitted to the Fish and Wildlife Service for approval, and monitoring results will also be submitted in the twice-monthly reports.

Contra Costa Canal originally had a screen at its entrance, but it has been removed. The screen prevented fish from using 4 miles of the canal that contained no pumps. Biologists probably believed the unrestricted rearing habitat and production of fish in that stretch of canal was more valuable than a fish screen to prevent losses. Section 3406(b)(5) of the CVP Improvement Act and the Los Vaqueros Project biological opinion require construction and operation of screening and recovery facilities to mitigate for fishery impacts at the Rock Slough intake.

North Bay Aqueduct

In 1987, the SWP began pumping from Barker Slough through the North Bay Aqueduct to meet project entitlements in Napa and Solano counties (Figure 1, Chapter 1). Ultimate scheduled deliveries are expected to be about 67,000 acre-feet annually. Maximum pumping capacity is about 175 cfs (pipeline capacity). Daily pumping rates have ranged between 0 and 90 cfs (Figure 15). Average annual pumping rate is 35 cfs.

Water diversion to the North Bay Aqueduct has improved water clarity and dissolved oxygen and decreased specific conductance due to downstream water being drawn into the Barker/Lindsey Slough complex (Kano 1990). Pumping rates could increase by 30 to 50 cfs in dry years when additional water may be needed to help meet new water quality standards in western Suisun Marsh.

Water use in the North Bay Aqueduct service area is increasing as population grows in Napa and Solano counties. Current demands result in

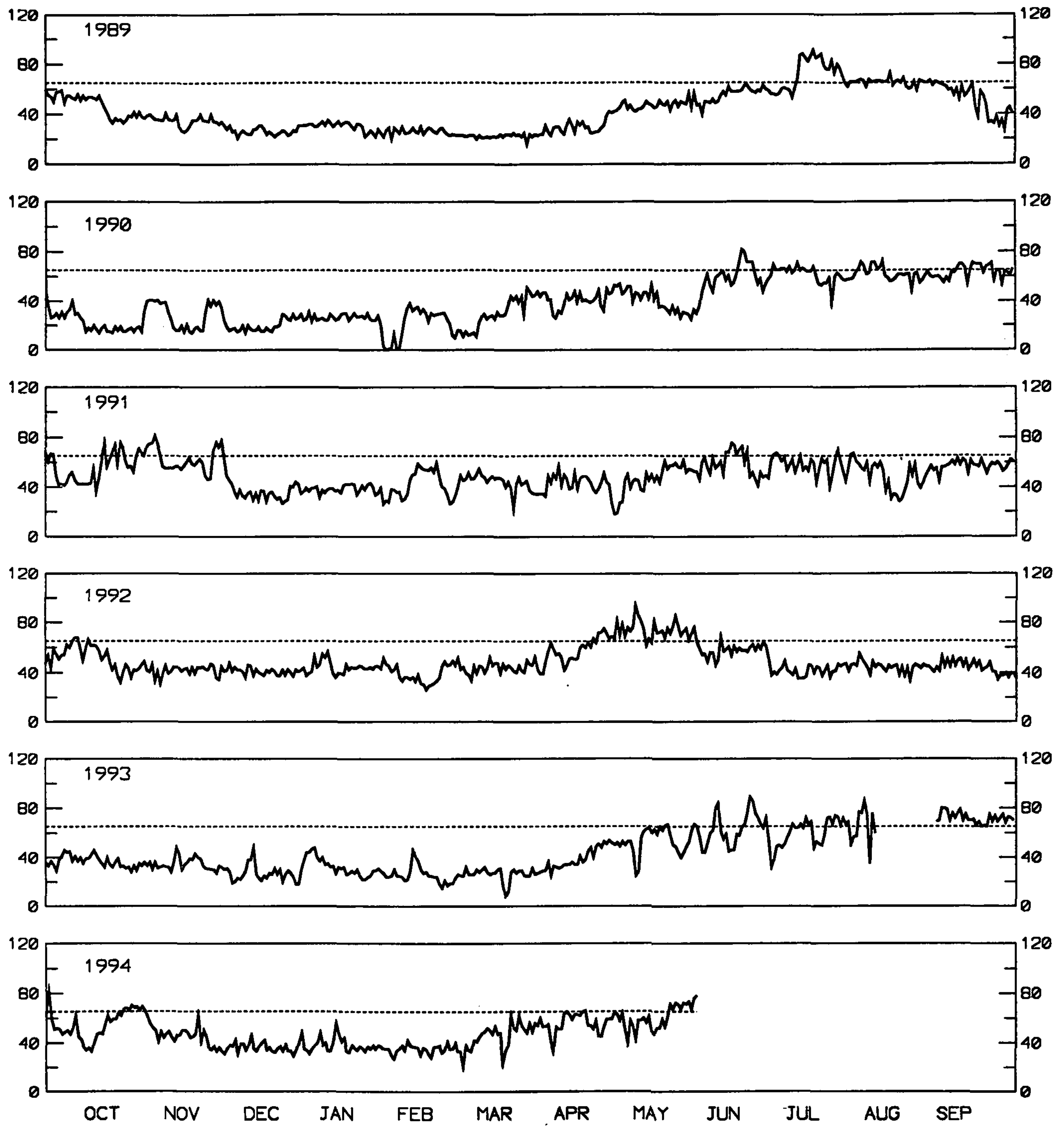


Figure 15
NORTH BAY AQUEDUCT DAILY EXPORTS FOR WATER YEARS 1989 TO 1994
(In Cubic Feet per Second)
NOTE: The 1993-94 delta smelt biological opinion restricts exports to below 65 cfs when delta smelt are in the area (65 cfs is shown as a reference point in the figure).

pumping less than 65 cfs during the early part of the delta smelt spawning period. Until April, demands are usually less than 65 cfs, but in the future the 65-cfs threshold will be reached earlier in the year.

In response to fisheries concerns, the Department of Water Resources constructed a state-of-the-art positive barrier fish screen at the Barker Slough intake. The screen consists of a series of flat, stainless steel, wedge-wire panels with a slot width of 3/32 inch designed to exclude fish 25 mm or larger from being diverted. A low approach velocity (0.5 fps) prevents them from being impinged onto the screens. The screens are routinely cleaned to prevent head loss across the screen face, which would result in increased approach velocities. Screen design and maintenance were developed in cooperation with and final design was approved by Fish and Game.

Fish and Game now uses an approach velocity of 0.33 fps for continuously cleaned screens and 0.0825 fps for non-continuously cleaned screens. Non-continuously cleaned screens require cleaning before through-screen velocities exceed 0.33 fps (DFG 1993). The effectiveness of this criterion to screen delta smelt adults or juveniles is not known, because no data are available to define screening criteria for delta smelt. In absence of specific approach velocity criteria for delta smelt, the Fish and Wildlife Service has used a 0.2-fps criterion established for American shad (FWS 1993a).

Fish and Game conducted pre- and post-installation monitoring to evaluate impacts of the North Bay Aqueduct on fish. Results of these studies are discussed in Chapter 5.

In compliance with the incidental take term and condition 3, when monitoring at Barker Slough (stations 720 and 721) indicates the presence (as defined in reasonable and prudent alternative 2) of delta smelt less than 20 mm, diversions from Barker Slough will be reduced to a 3-day running average rate of 65 cfs for a minimum of 2 weeks, at which time presence of delta smelt will be reassessed. The averaging period for the 65 cfs will begin 48 hours after delta smelt are detected. The Fish and Wildlife Service will be notified within 48 hours when diversions are reduced due to presence of delta smelt juveniles and larvae and when diversions are subsequently increased due to absence of delta smelt juveniles and larvae.

South Delta Temporary Barriers Project

The existing South Delta Temporary Barriers Project consists of installation and removal of temporary rock barriers at the following locations:

- Middle River near Victoria Canal, about 0.5 mile south of the confluence of Middle River, Trapper Slough, and North Canal.
- Old River near Tracy, about 0.5 mile east of the Delta-Mendota Canal intake.
- Head of Old River near San Joaquin River, within 0.1 mile west of the confluence of the two rivers.

The barriers on Middle River and Old River near Tracy are tidal control facilities designed to improve water quality and water levels in southern Delta channels during irrigation season. The barrier at the head of Old River near San Joaquin River is designed to improve conditions in the San Joaquin River during fall-run Chinook salmon migration.

Although the barriers are temporary structures, some variation of the project will likely be in place through 1995. Figure 16[1] shows the original barrier schedule and when each barrier has been in place from 1987 to 1993. Variations such as hydrology and endangered species constraints have modified the installation schedule each year.

Installation of the Old River near San Joaquin River barrier is permitted by the Corps of Engineers from 1968 until 1997. In 1993, the Middle River and Old River near Tracy barriers were permitted to be in place from June 1 to September 30 until 1995.

If the barriers prove effective in helping San Joaquin River salmon and enhancing southern Delta farmers' ability to manage their water supply, and if

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[1] Figure 16 includes a fourth barrier, on Grant Line Canal, which has never been installed and, therefore, is not included in this discussion of existing facilities. DWR will be requesting that the existing permits be amended to allow installation of this barrier in 1994. This request will be addressed in a separate Section 7 consultation.

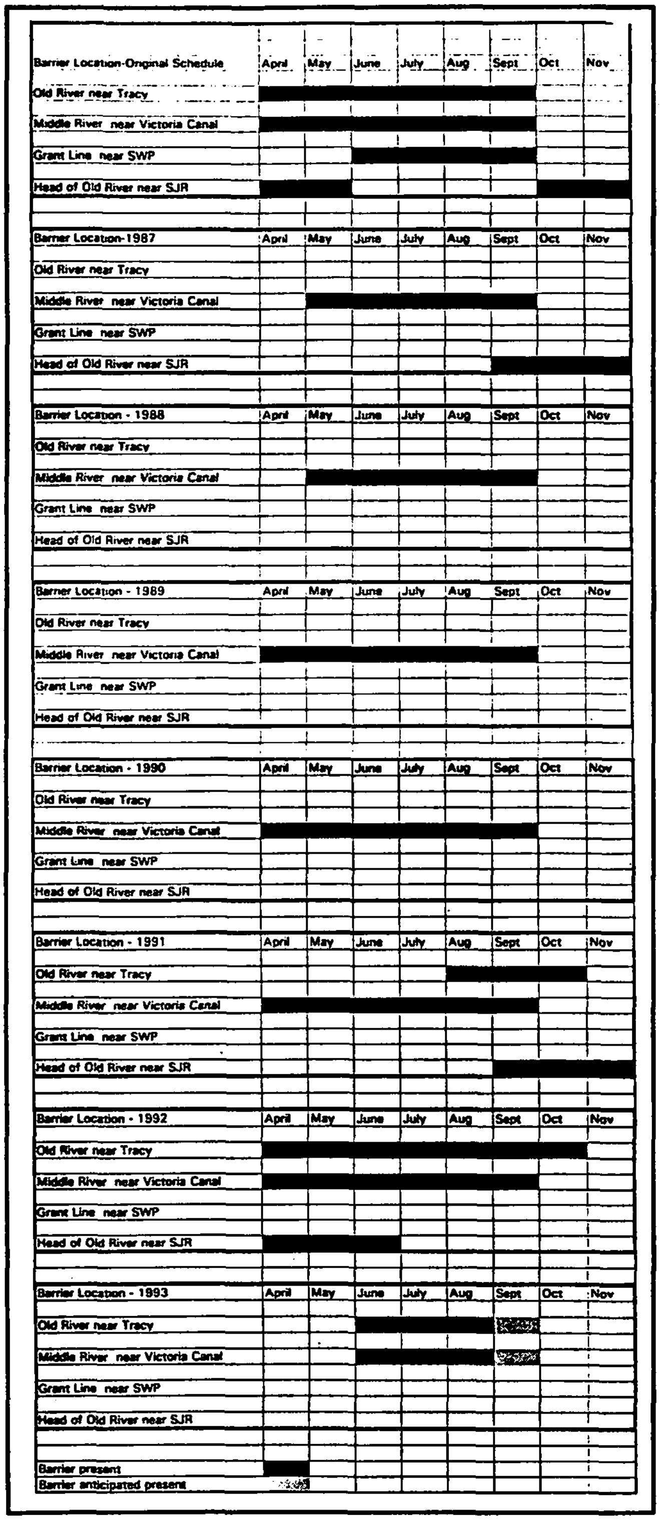

Figure 16
SOUTH DELTA TEMPORARY BARRIER SCHEDULE
1987 TO 1993

they are shown to have minimum negative impacts, the goal will be to install them routinely during spring and summer. Should this occur, barrier design will be changed to a permanent structure such as a radial gate. A biological monitoring program has been designed and initiated as part of the barrier evaluation. Studies are also underway by Fish and Game to evaluate barrier effectiveness in increasing San Joaquin salmon smolt survival.

Following are general descriptions of the three temporary barriers.

Head of Old River near San Joaquin River

The barrier at the head of Old River consists of about 1,800 cubic yards of rock and sand placed across Old River about 0.5 mile west of its confluence with the San Joaquin River. The barrier is about 200 feet long, and 50 feet at its widest point. Side slopes are 1.5 vertical to 1 horizontal. Although the barrier is designed to allow no flow of water over it, it is notched to allow passage of any adult salmon that may be migrating through Old River to the San Joaquin River. The fall barrier does not have boat portage facilities.

When the barrier period is over, rock is removed and stockpiled for future use. The barriers are designed not to impede floodflows, and installation should not compromise channel integrity.

Old River near Tracy

The proposed temporary tide control facility is in the same location as a temporary barrier installed for 3 months during the drought in 1977 and for about a month in 1991. In 1993 this barrier was installed on June 5. Water Resources will propose to amend existing permits to allow installation of this barrier as early as April 1, 1994.

About 5,700 cubic yards of rock and sand is placed across Old River near Tracy about 0.5 mile west of the Delta-Mendota Canal intake. The barrier is about 250 feet long and 100 feet at its widest point. Nine 48-inch pipes, each 56 feet long with flapgates, are placed in the barrier to permit flow in one direction. Crest elevation is +2.0 feet, which allows water to flow over the top of the barrier during flood (incoming) tides. During ebb tides, the crest elevation will retain the tidal volume below the +2.0-foot elevation.

The invert of the pipes is at –6.0 feet elevation (NGVD). The structure allows tidal flows to enter the channel upstream of the barrier and be retained as the tide ebbs, so agricultural pumps can divert water with less probability of pump damage. Also, the barrier changes circulation flows and may dilute return agricultural drainage to improve the quality of local agricultural diversions.

Boat portage facilities consist of two boat launching ramps and an operated vehicle that tows a universal boat trailer. Boats are loaded onto the trailer and towed up one side of the barrier and lowered to the other side. Six marking buoys are placed about 70 feet apart, three upstream and three downstream, about 200 feet from the centerline of the barrier. Two signs on top of the barrier provide notice to boaters.

When the barrier period is over, rock is removed and stockpiled for future use. The barriers are designed not to impede floodflows, and installation should not compromise channel integrity.

Middle River near Victoria Canal

The Corps of Engineers authorized annual placement of a barrier at this location until 1992. It was installed seasonally from April through September. In 1993, this barrier was incorporated into the South Delta Temporary Barrier Project permit and was installed on June 15.

About 4,800 cubic yards of rock and sand is placed across Middle River to construct a 270-foot-long berm with a removable center section. Each end of the barrier, near the abutments, contains three 48-inch pipes with flapgates. The barrier ends and pipes remain in place all year. The tide gates are tied open when the center section is removed. The center section is 140 feet long with side slopes of 2 horizontal to 1 vertical. Crest elevation of the center section is 2 feet lower than the abutment, allowing some flow over the barrier, even at times other than high tide. The boat portage facility at this site is a gravel ramp that can be used to carry or drag a small boat across the barrier.

Friant Division of the Central Valley Project

Friant Dam regulates and diverts the flow of the upper San Joaquin River. Millerton Lake, behind Friant Dam, has a maximum storage capacity of 520,500 acre-feet. Average annual runoff of the upper San Joaquin River is 1.8 million acre-feet. The Bureau of Reclamation has contracts to deliver 2.2 MAF per year in the Friant service area, which extends from Madera County to Kern County. About 0.8 MAF of the total water contracted is Class I, about 1.4 MAF is Class II, the difference being reliability of the water supply. In all but the driest years, 100% of Class I water is allocated, whereas the amounts of Class II water that can be regulated for delivery depend on the magnitude and timing of runoff and regulation of the runoff by reservoirs upstream of Friant.

Madera Canal and Friant-Kern Canal originate at Friant Dam and convey water north and south, respectively, to CVP contractors in the Friant service area. Capacity of Friant-Kern Canal is about 5,300 cfs at the headworks. Capacity of the Madera Canal is about 1,250 cfs at the headworks.

Operation of Friant Dam focuses on regulation and conservation of the water supply to maximize the amount of water available for delivery each year. Because of the relatively small amount of conservation storage available in Millerton Reservoir compared to the typical runoff, emphasis is on ensuring that enough water is available for delivery in a pattern consistent with contractors' needs.

Southern California Edison Company operates a system of reservoirs, powerplants, and water conduits in the upper San Joaquin basin that significantly regulates inflows to Millerton Lake. An operating contract between the Bureau of Reclamation and Edison is the basis for ongoing coordination of Friant operations with the operation of Edison's system. This so-called "Mammoth Pool Contract" was intended to reconcile the rights of the two parties to use San Joaquin River water. The agreement was entered in 1957, before construction of Mammoth Pool reservoir.

Friant Dam is also operated for flood control. Up to 170,000 acre-feet of space may be reserved to regulate inflows. Snowmelt flood control releases may be required in years when the combination of reservoir storage and water deliveries is not sufficient to safely regulate peak snowmelt runoff. To evacuate the flood control pool at Friant, releases may be made into Madera Canal or Friant-Kern Canal if the water is needed; otherwise the water is discharged to the San Joaquin River.

The Bureau of Reclamation releases water into the San Joaquin River to provide a minimum flow of 5 cfs at Gravelly Ford. This ensures that water will be available for diversion by water right holders on the San Joaquin River between Friant Dam and Gravelly Ford. These releases vary seasonally from a few cubic feet per second in winter to 100 cfs during peak irrigation season. No other releases are made to the San Joaquin River except those required for flood control. Beyond Gravelly Ford, the San Joaquin River has little or no flow until Mendota Pool.

When flood control releases are made from Friant, excess flow in the San Joaquin River may reach Mendota Pool, where it can be diverted for use by San Joaquin River Exchange Contractors.

Concerns about levee scouring in the San Joaquin River downstream of the bifurcation structure for Chowchilla Bypass have restricted flow to only about 1,300 cfs in that section of the river. However, flows in excess of that are rare, not well forecastable, and of short duration.

Excess flows entering Chowchilla Bypass are the only other means by which releases from Friant Dam can reach the Delta. Such a condition last occurred in March-June 1993.

Effects of the Friant Division service area were addressed in the Fish and Wildlife Service's 1991 Friant consultation. At that time, the Bureau of Reclamation agreeded to address listed species effects in the remaining service areas in future consultations.

New Melones Dam and Reservoir

New Melones Dam, on the Stanislaus River about 35 miles northeast of Modesto, is an earth and rockfill structure 625 feet high with a capacity of 2.4 million acre-feet, 450,000 of which is reserved for flood control. The dam was built by the Corps of Engineers and transferred, when completed in 1979, to the Bureau of Reclamation for operation and maintenance as the key feature of the East-Side Division of the CVP.

Project purposes are flood control, power generation, irrigation supply, water quality control, fishery enhancement, and recreation. Under an agreement with Tri-Dam Project, operations of New Melones and Tulloch reservoirs are coordinated, with Tulloch Reservoir operated as an afterbay. Goodwin Dam, just downstream of Tulloch, acts as a diversion structure to provide irrigation water to Oakdale Irrigation District and South San Joaquin Irrigation District to meet water rights under an agreement with the Bureau of Reclamation.

Under terms of State Water Resources Control Board Water Right Decision 1422, water quality objectives for New Melones are:

- Dissolved oxygen of 7.0 mg/L or higher at all times at Stanislaus River at Ripon.
- Total dissolved solids of 500 mg/L (monthly average) at San Joaquin River near Vernalis.

Decision 1422 calls for up to 98,000 acre-feet to be released for maintenance of fish and wildlife. The fishery enhancement is mainly flow augmentation, including spring pulse flows in April and May, fall attraction flows in October, and minimum flows in other months. The spring pulse flows have been intended in the past to assist outmigrating salmon smolts, but they also contribute to San Joaquin River pulse flows for delta smelt and other species. The fall attraction flows also tend to increase the dissolved oxygen level at Stockton, but they are relatively inefficient because much of the flow released to the San Joaquin River is lost to Old River and, therefore, does not support the flow past Stockton.

In addition, special consideration is given each fall to releases required to meet the 56°F target on the lower Stanislaus River.

Coordinated Operation Agreement

The CVP and SWP use the Sacramento River and Delta as common conveyance facilities. Reservoir releases and Delta exports must be coordinated to ensure that each of the projects retains its portion of the shared water and bears its share of the obligation to protect beneficial uses.

The Coordinated Operation Agreement between the Bureau of Reclamation and the Department of Water Resources became effective in November 1986. The agreement defines rights and responsibilities of the CVP and SWP regarding Sacramento Valley and Delta water needs and provides a means to measure and account for those responsibilities. The Coordinated Operation Agreement includes a provision for its periodic review.

Obligations for In-Basin Uses

The Coordinated Operation Agreement defines in-basin uses as "legal uses of water in the Sacramento Basin including the water required under the Delta standards found in SWRCB Decision 1485". The CVP and SWP are obligated to ensure that water is available for these specific uses, but the degree of obligation depends on several factors and changes throughout the year.

Balanced water conditions are defined in the Agreement as periods when the two projects agree that releases from upstream reservoirs plus unregulated flows are about equal to the water supply needed to meet Sacramento Valley in-basin uses plus exports. ***Excess water conditions*** are periods when the CVP and SWP agree that releases from upstream reservoirs plus unregulated flow exceed Sacramento Valley in-basin uses plus exports.

During excess water conditions, sufficient water is available to meet all demands and requirements; under these conditions, the CVP and SWP store and export as much water as possible.

During balanced water conditions, the two projects share in meeting in-basin uses. Balanced water conditions are further defined according to whether water from upstream storage is required to meet Sacramento Valley in-basin use or if unstored water is available for export.

When water must be withdrawn from storage to meet Sacramento Valley in-basin uses, 75% of the responsibility for withdrawing water is borne by the CVP and 25% is borne by the SWP. When unstored water is available for export (*ie*, balanced water conditions and exports exceed withdrawals), the sum of CVP stored water, SWP stored water, and the unstored water for export is allocated 55% to the CVP and 45% to the SWP.

Accounting and Coordination of CVP and SWP Operations

With daily coordination, the Bureau of Reclamation and Water Resources determine the target Delta outflow for water quality, reservoir releases to meet in-basin needs, and schedules to use each project's facilities for pumping and conveyance.

To show CVP and SWP accumulated obligations during balanced water conditions, a daily accounting is maintained according to the sharing formulas in the Agreement. This allows flexibility in operations by allowing either party's share to vary on a daily basis, thereby avoiding the need to make daily changes in reservoir releases that originate several days' travel time from the Delta. During balanced conditions, adjustments can also be made afterward rather than by predicting the variables of reservoir inflow, storage withdrawals, and in-basin uses on a daily basis.

Releases are one means of adjusting to changing in-basin conditions. During balanced water conditions, outflow can be increased almost immediately by reducing project exports.

Decision 1485 standards require that the CVP and SWP each limit pumping to an average of 3,000 cfs during May and June. This is particularly constraining for CVP operation, because its annual exports are limited by the capacity of Tracy Pumping Plant and Delta-Mendota Canal. The Coordinated Operation Agreement and Decision 1485 allow as much as 195,000 acre-feet to be pumped at Banks Pumping Plant to replace this lost CVP export. If this water is pumped during balanced water conditions, the CVP is responsible for supplying the water at Banks Pumping Plant.

When real-time operations dictate CVP and SWP actions, an accounting procedure tracks the water obligations of the two projects. When the difference between obligations is sufficient, adjustments may be made in reservoir releases to allow the project that has carried more than its obligation to recoup the water while the other project compensates for its deficient contribution.

During any given year, water conditions can go in and out of balance. Account balances continue from one balanced water condition through an excess water condition and into the next balanced water condition. If, however, the project with a positive balance (*ie,* the party that has provided more than its accumulated share of water) enters into flood control operations, the accounting is reset to zero.

Limitations of the Present Coordinated Operation Agreement

Current Endangered Species Act operational restrictions in the Delta are not addressed in the Coordinated Operation Agreement. The two ESA restrictions that have affected coordinated operations between the CVP and SWP are the QWEST standard and the take limitations at the export pumping facilities.

The QWEST standard is a CVP/SWP operational limitation from the long-term winter-run Chinook salmon biological opinion. Technically, QWEST is an index of reverse flow in the lower San Joaquin River. QWEST regulates the amount of CVP/SWP export capability based on hydraulic conditions of the San Joaquin River, eastside streams (Mokelumne, Cosumnes, and Calaveras rivers), Delta precipitation and estimated local consumptive use, Sacramento River flow, and Delta Cross Channel operations. QWEST conditions can be operationally influenced through three controllable mechanisms: Delta Cross Channel operations, Sacramento River flow, and total CVP/SWP export pumping.

QWEST is *not* a constraint that was considered or even contemplated in negotiations and studies that led to the Coordinated Operation Agreement. The Decision 1485 standards contained in the Agreement are water quality and outflow standards, not export restrictions based on Delta hydraulic conditions. Imposition of QWEST on combined project operations has created a number of key coordination issues:

- The definition of balanced water conditions is not appropriate when QWEST is the controlling criterion.
- The priority of CVP or SWP export pumping during periods when QWEST is the controlling constraint is not defined.
- The responsibility for satisfying QWEST with releases from upstream reservoirs when both projects continue exports is not defined.
- How the benefits of Delta Cross Channel operations are now to be applied to CVP or SWP export capability has not been determined.

The long-term winter-run Chinook salmon biological opinion and the 1994 delta smelt biological opinion both contain provisions for incidental take limitations at the combined CVP/SWP export facilities. Neither opinion addresses operation of the individual export facilities; rather they require coordinated operation of the CVP and SWP to address endangered species take. The Coordinated Operation Agreement has no provision to address individual project responsibility for endangered species take.

As a result of QWEST and take limitations, the Coordinated Operation Agreement relationship between the CVP and SWP has been clouded to the point that individual project operations cannot be forecast satisfactorily on a long-term basis. The operational relationships between the water projects are complex and cannot be fully addressed until all operational and regulatory issues are firm. Operations required by the Endangered Species Act affect the Coordinated Operation Agreement and, in turn, the COA affects ESA operations.

In 1993, the CVP and SWP were not operated in strict accordance with the Coordinated Operation Agreement concerning sharing the available water supply. By mutual agreement, in light of ESA requirements, the Bureau of Reclamation and Water Resources have apportioned the water supply and responsibility for Delta standards between the projects. Operations in 1993 were complicated by problems meeting the QWEST standard, take limits for winter-run Chinook salmon and delta smelt, and CVPIA operational prescriptions. A wet winter in 1993 provided the flexibility for the projects to operate in this manner without severe COA problems. Operational flexibility is reduced as a direct result of low water supplies in 1994, a critically dry year.

Regulatory Requirements for Delta Water Quality, Flow, and Operations

Delta water quality standards and the beneficial uses they protect are defined in Decision 1485, which also addresses minimum flow requirements.

Beneficial uses protected by Decision 1485 include agriculture, M&I, and fish and wildlife. Delta standards apply throughout the year but become more critical whenever balanced water conditions exist, typically from April through November but varying depending on hydrologic and storage conditions.

In addition to Decision 1485 water quality standards, CVP and SWP operational decisions are based on the current water supply and hydrologic conditions and impacts and benefits to fisheries, recreation, and power. The uncontrollable variables of tide, wind, barometric pressure, river depletion, and agricultural drainage affect the ability of the CVP and SWP to comply with the water quality standards.

Operational actions initiated to maintain Delta water quality are based on past experience and empirical studies, used as guides for determining initial responses to Delta conditions. Operations are changed according to varying conditions, and they provide a reasonable level of protection against noncompliance with the standards.

Depending on the water year classification[1], complying with Decision 1485 water quality standards and fishery flows requires from 3.0 to 5.5 million acre-feet annually, as measured by the Delta Outflow Index.

Because of Delta hydraulic characteristics, some standards are managed more efficiently through export curtailments; others are managed more efficiently through flow increases. For example, the Contra Costa and Jersey Point standards are managed more efficiently by export curtailments. While complying with these standards, CVP and SWP operators also target a Delta Outflow Index and salinity levels in the western Delta. These levels are expected to provide a reasonable margin of error against noncompliance with Decision 1485 should adverse or unforeseen conditions arise.

In typical or full delivery years, a curtailment at Tracy Pumping Plant will likely adversely affect CVP water supply availability south of the Delta. During such times, the SWP usually makes short-term curtailments, because its ability to recover from such curtailments is significantly greater than that of the CVP.

In contrast, the Decision 1485 Emmaton water quality standard is more efficiently managed by flow increases. In most instances, salinity levels at Emmaton react proportionately to increases in flow in the Sacramento River along Sherman Island, where the Emmaton recorder is located. Closing the Delta Cross Channel increases flow in the Sacramento River and reduces flows in the lower San Joaquin River. Without additional outflow water, reverse flows on the San Joaquin side of the Delta result in increased salinity in the central and southern Delta. For this reason, the Delta Cross Channel gates can usually be closed for only a day or two before water quality on the San Joaquin River side of the Delta begins to deteriorate.

Another way to increase flows on the Sacramento River is to increase releases from the CVP and SWP reservoirs. Approximate lag times for releases from the two projects to reach the Delta are shown below.

Dam	River	Lag Time
Nimbus (Folsom)	American	1 day
Oroville	Feather	3 days
Keswick (Shasta)	Sacramento	5 days

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[1] Decision 1485 defines water year classifications.

In a typical water year, releases may be increased simultaneously on all three rivers. The largest initial release increase would be on the American River. Then, as increased releases in the Feather and Sacramento rivers reach the Delta, the American River release would be decreased accordingly.

Winter-Run Chinook Salmon Biological Opinion

On February 12, 1993, the National Marine Fisheries Service released the *Biological Opinion for the Operation of the Federal Central Valley Project and the California State Water Project*, concerning Sacramento River winter-run Chinook salmon. The opinion contains "reasonable and prudent alternatives" to be implemented by the Bureau of Reclamation, Department of Water Resources, and other agencies to avoid jeopardizing winter-run Chinook salmon in the long-term operation of the water projects. It also contains an "incidental take" statement with terms and conditions to monitor and/or minimize the incidental take of winter-run Chinook salmon. Actions identified in the reasonable and prudent alternatives and in the reasonable and prudent measures in the incidental take statement are discussed below.

Reasonable and Prudent Alternatives

Actions 1-6 concern the Shasta/Trinity and Sacramento River Divisions of the CVP.

> 1. The Bureau must make its February 15 forecast of deliverable water based on estimates of precipitation and runoff at least as conservatively as 90% probability of exceedence. Subsequent updates of water delivery commitments must be based on at least as conservative as a 90% probability of exceedence forecast.

The purpose of this action is to reduce the risk of adverse temperature conditions for winter-run salmon on the upper Sacramento River that might be caused by an over-commitment of water due to a forecast that is too high. This action, because of its conservative nature, may affect the forecasted capability of the CVP to meet other system demands and may present conflicts with meeting possible demands for delta smelt.

> 2. The Bureau must maintain a minimum end-of-water-year (September 30) carryover storage in Shasta Reservoir of 1.9 million acre-feet.

The purpose of this action is to assure the maintenance of a cold-water pool in Shasta Lake to meet temperature requirements on the upper Sacramento River. This action reduces the capability of the CVP to meet other system demands and may present conflicts with meeting possible demands for delta smelt.

> 3. The Bureau must maintain a minimum flow of 3,250 cfs from Keswick Dam to the Sacramento River from October 1 through March 31.

The purpose of this action is to provide for safe rearing and downstream passage and to protect against the stranding of juvenile winter-run Chinook. This condition may require a redistribution of releases from storage in Shasta Lake, thereby creating conflicts with other demands, but it is difficult to assess its potential impact.

> 4. (This condition specifies the rates at which changes to releases from Keswick Dam are to be made.)

The purpose of this condition is to prevent stranding of juvenile winter-run Chinook salmon. This condition will not affect delta smelt.

> 5. The Bureau must maintain daily average water temperature in the Sacramento River at no more than 56°F within the winter-run Chinook salmon spawning grounds below Keswick Dam as follows:
>
> (Four conditions specifying temperatures and locations.)
>
> The February 90% exceedence forecast of runoff, or an exceedence forecast at least as conservative, must be used to determine the operational environment and associated temperature compliance points. Any modifications to the February allocation must comply with the above requirements.

The purpose of this condition is to prevent mortality to winter-run Chinook salmon eggs and preemergent fry by providing water temperatures below 56°F at specified points on the Sacramento

River. This condition is a companion to Condition 2 and essentially requires that Shasta Reservoir be held at higher levels than would otherwise be required. This condition will reduce the capability of the CVP to meet other system demands and may present conflicts with meeting possible demands for delta smelt.

> 6. Pursuant to the following schedule, the gates of the Red Bluff Diversion Dam must remain in the raised position to provide unimpeded upstream and downstream passage for winter-run Chinook salmon.
>
> (Schedule for gate openings.)
>
> NMFS will review proposals for intermittent gate closures of up to 10 days one time per year on a case-by-case basis.

The purpose of this condition is to reduce the adverse effects to the upstream and downstream passage of winter-run Chinook salmon caused by operation of Red Bluff Diversion Dam. This condition will not affect delta smelt.

Actions 7-13, concerning the Delta Division of the CVP and the SWP, are discussed below.

> 7. The Bureau must maintain the Delta Cross Channel Gates in the closed position from February 1 through April 30 to reduce the diversion of juvenile winter-run Chinook salmon emigrants into the Delta.

The purpose of this action is to improve overall survival of the winter-run emigrant population by reducing the number of fish exposed to adverse conditions in the central Delta. Sampling indicates that February-April is the primary period of winter-run emigration through the Delta. This action will reduce flow in the lower Mokelumne River and lower San Joaquin River and, therefore, QWEST.

> 8. Based on the observations of a real-time monitoring program in the lower Sacramento River, the Bureau must operate the gates of the Delta Cross Channel during the period of October 1 through January 31 to minimize the diversion of juvenile winter-run Chinook salmon into the central Delta. The Bureau must develop the real-time monitoring program and fisheries criteria for gate closures and openings in coordination with the National Marine Fisheries Service, U.S. Fish and Wildlife Service, California Department of Fish and Game, and the California Department of Water Resources by August 1, 1993. The Bureau must ensure that continuous real-time juvenile Chinook salmon monitoring is conducted between October 1 and January 31 of each year commencing in 1993.

Monitoring for winter-run Chinook will not directly aid delta smelt. To the extent that such a monitoring program will indirectly collect information about the presence and distribution of delta smelt, it will contribute to the body of knowledge on delta smelt.

> 9. Based on 14-day running average of QWEST in cfs, the Bureau and the California Department of Water Resources must operate the Delta water export facilities to achieve no reverse flow in the western Delta from February 1 through April 30. The 7-day running average, if negative, must be within 1,000 cfs of the applicable 14-day running average during this period.

Eliminating reverse flows in the western Delta in February-April may reduce losses of winter-run juveniles in the Delta. As discussed in Chapter 5, the influence of reverse flows on survival of delta smelt and other species is inconclusive.

> 10. Based on the 14-day running average of QWEST in cfs, the Bureau and the California Department of Water Resources must operate the Delta export water facilities to achieve flow in the western Delta greater than negative 2,000 cfs from November 1 through January 31. The 7-day running average, if negative, must be within 1,000 cfs of the applicable 14-day running average during this period.

Maintaining lower reverse flows in the lower San Joaquin River may reduce losses of juvenile winter-run pre-smolts from October through January. The effect of this standard on delta smelt, although not well understood, is discussed in Chapter 5.

> 11. Continue and expand monitoring of winter-run Chinook salmon in the lower Sacramento River and Sacramento-San Joaquin Delta to

> establish their presence, residence time, and serve as a basis for the real-time management of Delta Cross Channel gate operation.

Monitoring for winter-run salmon will not directly aid delta smelt. To the extent the monitoring will indirectly collect information about the presence and distribution of delta smelt, it will contribute to the body of knowledge on delta smelt. Incidental capture of delta smelt in the FWS Chipps Island salmon trawls and other fish sampling programs may be sufficiently high to adversely impact the population.

> 12. The Bureau in coordination with the Contra Costa Water District must develop and implement a program to monitor entrainment loss of winter-run Chinook salmon juveniles at the Rock Slough intake of the Contra Costa Canal.

A program to monitor winter-run salmon at the Contra Costa Canal is underway. Monitoring for delta smelt is required by a biological opinion for the Los Vaqueros Project.

> 13. The Bureau and Department of Water Resources in cooperation with California Department of Water Resources (actually meant DFG) must monitor the extent of incidental take associated with operation of the Tracy and Byron (Banks) pumping facilities.

The Bureau of Reclamation and Department of Water Resources have instituted measures and procedures to better monitor for winter-run salmon and delta smelt at CVP and SWP facilities.

Reasonable and Prudent Measures in the Incidental Take Statement

Measures 1-8 concern operation of the Shasta, Trinity, and Sacramento River division. These actions will not directly affect delta smelt.

Measures 9-13 concern CVP and SWP Delta operations.

> 9. The DWR and the Bureau are authorized to take up to 1 percent of the estimated number of out migrating smolt winter-run incidental to the operation of the Delta pumping facilities at Byron and Tracy.

In 1993, these incidental take limitations significantly reduced the export capability of the water projects, particularly the SWP. (In 1993, exports were reduced by 525,000 acre-feet due to winter-run smolt take at SWP facilities.) This will reduce incidental take of delta smelt, particularly in winter and summer. The potential effect of export reductions on delta smelt is discussed in Chapter 5.

> 10. The California Department of Water Resources in coordination (with) the Bureau must develop and implement a program of Chinook salmon investigations at the Suisun Marsh Salinity Control Structure and within Montezuma Slough.

The Department of Fish and Game has continued a sampling program to monitor and assess the effects of Montezuma Slough gate operations on juvenile and adult salmon migration and predation levels near the gates. This program was a permit requirement for construction and operation of the salinity control gates under the Suisun Marsh Plan of Protection, which is coordinated between Water Resources and the Bureau of Reclamation.

> 11. The Bureau and California Department of Water Resources must ensure that the fish collection facilities are fully staffed for monitoring incidental take and the screens fully operated whenever Tracy and Banks pumping plants are in operation from October 1 through May 31.

CVP and SWP fish collection facilities are fully staffed, and screens will be operated in accordance with the agreed salmon criteria. Salvage procedures used during the 1993-94 season were developed by the Interagency Program[1] work group on winter-run loss, salvage, and monitoring. These procedures were in place October 1, 1993. Fish facilities operation is critical for compliance with

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[1] The Interagency Ecological Program for the Sacramento-San Joaquin Estuary was formed in 1970 as the Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. In 1994, member agencies are the California Department of Water Resources, U.S. Bureau of Reclamation, California Department of Fish and Game, U.S. Fish and Wildlife Service, U.S. Geological Survey, State Water Resources Control Board, U.S. Army Corps of Engineers, and U.S. Environmental Protection Agency.

take limitations for winter-run Chinook salmon and delta smelt.

> 12. The Bureau in coordination with the California Department of Water Resources must develop and implement a demonstration screening program designed to promote the advancement of state-of-the-art positive-barrier screening technology at small unscreened diversions along the Sacramento River and within Delta waterways.

The Bureau of Reclamation sponsored a screening workshop in spring 1993. A fish screen demonstration program has been implemented, and Water Resources is testing a rotating drum screen for agricultural diversions as part of the Interagency Program agricultural diversion studies.

> 13. The Bureau in coordination with the California Department of Water Resources must submit daily, weekly, and annual reports to the National Marine Fisheries Service regarding operation of project facilities, temperature and hydrological conditions, and the results of monitoring programs.

Reporting procedures are in place and data are routinely transmitted to the National Marine Fisheries Service, Fish and Game, and Fish and Wildlife Service, as appropriate.

> 14. The Bureau must establish a working operations and management group that includes the National Marine Fisheries Service to address the implementation of the reasonable and prudent alternative.

The operations and management group was convened in June 1993 and will continue to meet as necessary to consider issues involving implementation of the reasonable and prudent alternative.

> 15. The Bureau, in coordination with Water Resources, must develop new sampling and analytical methodologies for estimating winter-run Chinook salmon salvage and loss numbers at the fish collection facilities that is acceptable to the National Marine Fisheries Service.

The Bureau of Reclamation and Water Resources have adopted procedures for estimating winter-run salvage and losses based on recommendations by the loss, salvage, and monitoring work group. The procedures have been reviewed by Fish and Game statisticians. Sampling and analysis may be limited by the scarcity of winter-run Chinook, by uncertainties inherent in their identification, and by factors used to expand observations to estimated losses. Experience and further experimentation may help resolve some of the uncertainty.

> 16. The Bureau must develop, in consultation with the National Marine Fisheries Service, a winter-run Chinook population model that can be used to evaluate the long-term effects of CVP operations plans on the winter-run Chinook salmon survival and recovery.

Several salmon population models exist, but none specifically for evaluating the effects of CVP/SWP operations on winter-run Chinook.

Delta Smelt Biological Opinion

On February 4, 1994, the Fish and Wildlife Service released a biological opinion, *Formal Consultation on the Operation of the Central Valley Project and State Water Project: Effects on Delta Smelt*. This opinion was the result of an October 5, 1993, request by the Bureau of Reclamation for a formal consultation pursuant to Section 7 of the Endangered Species Act.

This biological opinion addresses effects on delta smelt of proposed operations and planning of the CVP and SWP from February 15, 1994, to February 15, 1995, which include modifications that will result from the long-term opinion for winter-run Chinook salmon.

Reasonable and Prudent Alternatives

The biological opinion established the following reasonable and prudent alternatives. Each criterion is briefly described below, followed by a discussion of how it was met in 1994.

(1) Transport and Habitat Flows

> (a) USBR/DWR shall ensure that the 2-ppt isohaline is placed downstream of Collinsville for at least one day between February 1 and June 30 in all but critically dry years. In critically dry years, the 2-ppt isohaline shall be placed down-

stream of Collinsville for at least one day between April 1 and April 15. Table 3a (below) lists the required number of days that USBR/DWR shall provide a minimum of 6,800 cfs and/or 12,000 cfs outflow for the period beginning February 1 through June 30. The number of days required at each flow need not be consecutive within the period specified. In all water-year types, except for critically dry years, counting of days shall commence with placement of the 2-ppt isohaline at Collinsville. In critically dry years, counting of the required 18 days at 12,000 cfs may precede placement of the 2-ppt isohaline at Collinsville. In critically dry years, the requirement for outflows of 6,800 cfs shall be provided for a minimum period of 40 days starting between April 1 and April 15 and extending through June 30, once the 2-ppt isohaline has reached Collinsville. In all water-year types, the minimum number of days of 6,800 cfs and 12,000 cfs flows may be concurrent.

This criterion was met in 1994, which was critically dry. Therefore, this criterion called for the 2-ppt isohaline to be placed downstream of Collinsville for one day between April 1 and April 15. This was accomplished April 1. The criterion also called for outflow of 6,800 cfs for 40 days and 12,000 cfs for 18 days. Beginning April 1, the 6,800 cfs outflow was met for 43 days. Beginning February 1, the 12,000 cfs outflow was met for 34 days.

(b) The computation of salinity at Collinsville shall be based on a mean daily average electroconductivity at the Collinsville gage. The 2-ppt isohaline is defined to be met with a mean daily surface electroconductivity of 3.0 millisiemens/cm.

This method of computation was followed.

(c) Delta outflows shall be computed from the daily Delta Outflow Index as reported each day by the operations offices of the CVP/SWP. A minimum net Delta outflow of 3,500 cfs shall be maintained from February 1 to June 30.

This requirement has been followed. Mean Delta outflow has been 9,675 cfs (as of June 23) for this period; minimum daily Delta outflow was 3,699 cfs on June 16.

(d) Water-year classifications shall be based on the forecasted (90% probability of exceedence) Sacramento River Index as defined in SWRCB Decision 1485. Decision 1485 defines a split classification for water-year type based on agricultural, municipal and industrial, and fish and wildlife uses in years following a critical year. Since 1993 was not a critically dry year, this split classification will not affect the designation of water-year type in this biological opinion. DWR Bulletin 120 published forecasts will be used to initially classify the water year in February and to update the classification in March, April, and May. The May Bulletin 120 forecast will finalize the classification of the water year. Until publication of the February Bulletin 120 forecast (about February 10), a preliminary forecast of the Sacramento River Index will be used. If deemed acceptable by the Working Group (defined in the Reporting Requirements section), a sliding scale (to allow a smooth transition between water-year types) will be developed and incorporated into the long-term biological opinion. In the event that the water-year classification changes to a wetter year, which

Table 3a. Minimum number of days that net Delta outflows of 6,800 cfs and 12,000 cfs must be provided (based on Delta outflow from DWR's DAYFLOW for 1955-1991).

	Wet	Above Normal	Below Normal	Dry	Critically Dry
6,800 cfs	150 days	150 days	114 days	109 days	40 days
12,000 cfs	150 days	150 days	85 days	64 days	18 days

Table 3b. Minimum average San Joaquin River flow (calculated at Vernalis) component of 6,800 cfs and 12,000 cfs required flows listed in Table 3a.

	Wet	Above Normal	Below Normal	Dry	Critically Dry
San Joaquin River Component	2000 cfs	2000 cfs	1500 cfs	1200 cfs	800 cfs

> requires more days of compliance than remain in the period, then the flow need only be maintained to June 30.

This requirement has been followed. There has been no agreement on a sliding scale, and that part of this criterion has not been adopted.

> (e) In the period beginning February 1 through June 30, a minimum average San Joaquin River flow component as calculated at Vernalis and shown in Table 3b shall be provided in every water-year type for the number of days indicated in Table 3a.

The requirement for 1994 was 800 cfs. Mean daily San Joaquin flow has been 1,874 (as of June 23) and minimum daily San Joaquin flow was 973 cfs on June 16.

> (f) The Fish and Wildlife Service recognizes that strict adherence to the required transport and habitat flows may not be reasonable and prudent under certain adverse hydrologic conditions, such as those experienced in the 1976 and 1977 critically dry years. If, under adverse operational or hydrologic conditions, USBR and DWR determine that meeting these criteria would result in a conflict with protection of other threatened and endangered species, a conflict with the project's capability to meet requirements, or otherwise require actions that would not be reasonable or prudent, then USBR and DWR may immediately reinitiate consultation to determine appropriate modifications.

This was not invoked in 1994.

> (g) If monitoring indicates that the flows specified are not sufficient to transport delta smelt away from the southern and central delta and into adequate rearing habitat, then the Working Group will convene and recommend to project operators any actions that may be appropriate to protect delta smelt. Based on these recommendations, USBR and DWR will reinitiate section 7 consultation, if it is deemed necessary.

Discussions of the delta smelt Working Group did not conclude that transport flows were inadequate and further consultations were not held.

(2) San Joaquin River Transport Flows

> (a) USBR and DWR proposed operations shall ensure that there will be a net positive flow in the lower San Joaquin River, as indexed by the 14-day running average of QWEST, from February 1 through April 30.
>
> (b) If monitoring indicates that adult delta smelt are present (an average of one or more adult delta smelt at all San Joaquin River sampling stations 802-912 and captured in any one month's sampling period) in the San Joaquin River or its tributary sloughs from January through March, USBR shall provide the following additional 30-day average flows at Vernalis for a 30-day period from April 1 through May 15: 2,400 cfs in critical years, 2,600 cfs in dry years, 3,200 cfs in below normal years, 3,600 cfs in above-normal years, and 5,200 cfs in wet years. An amount of water sufficient to provide these flows through May 15 shall be held in storage until monitoring shows that adult delta smelt were not present in the San Joaquin River or its tributary sloughs from January through March.

Monitoring during 1994 did not indicate the presence of delta smelt at levels that would have required the specified flows.

(3) Presence of Delta Smelt Upstream of the Confluence in July-August as a Result of a Late Spawning Period

> If the summer tow-net survey shows that delta smelt are not found distributed in 3 of 7 Suisun Bay stations 405-515, 3 of 6 Montezuma Slough/Sacramento River stations 604-709, and 3 of 5 north-central Delta stations 802-904, then the following measure shall be implemented. The Working Group and Management Group will convene, recommend and decide, respectively, what actions are appropriate to protect delta smelt larvae and juveniles in the San Joaquin River; and USBR/DWR will reinitiate section 7 consultation if it is deemed necessary.

Surveys to determine the distribution and age composition of the delta smelt population are underway concurrent with preparation of this biological assessment.

(4) Suisun Marsh Salinity Control Structure

DWR, in coordination with USBR, shall develop and implement a program of investigations designed to evaluate the effects of operation of the Suisun Marsh Salinity Control Structure on delta smelt. The investigations will seek to address the diversion rate of adult delta smelt into Montezuma Slough and predation at the control structure. The proposed evaluation program will be submitted to the Fish and Wildlife Service and the Working Group for review and approval by October 1, 1994. Investigations will be initiated during the spring of 1995. During the interim, DWR will operate the gates only as required to meet existing Suisun Marsh salinity standards. When not operating, the gates shall remain in the raised position.

A study is being developed to evaluate operations on delta smelt. Until the study is completed, the gates will be operated only as required.

Reasonable and Prudent Measures

The Fish and Wildlife Service established the following reasonable and prudent measures to minimize the impact of incidental take.

(1) Improve salvage operations at Tracy and Skinner fish protective facilities during the spawning interval.

DWR and DFG are planning and implementing fish facility operation evaluations and efficiency studies. USBR is also conducting efficiency evaluations of fish salvage at Tracy Fish Facility. Other cooperative studies are underway to evaluate several alternative release sites. The studies are mainly focused on whether existing sites have the potential for harboring large predator populations that would be predators on the released fish. There are also concerns that release sites in this area may subject the salvaged fish (juvenile Chinook salmon in particular) to a second trip and subsequent jeopardy at the export pumps and that other sites farther downstream are more suitable. Other planning work concerns access to electrical power, the physical arrangement of the facilities at the site, and security for the personnel. Permits will be required from the Corps of Engineers and State Lands Commission, as well as environmental documentation for NEPA compliance. Construction costs for facilities at the site chosen are expected to be about $200,000. It is not expected that this site will be operational until 1998. In the meantime, USBR is planning to establish a temporary release site (with only limited facilities) that would be operational next year.

The specified conditions concerning transport of salvaged fish have been met.

(2) Minimize take at the Tracy and Skinner fish protective facilities.

The 1994 (critically dry) incidental take limits for the CVP/SWP are listed below. Take limits are a 14-day running average.

February-March — 755 (fall midwater trawl x 0.7)

April-June — 755 (fall midwater trawl x 0.7)

July — 1,078 (tentative; fall 1993 midwater trawl)

USBR and DWR modified project operations to accommodate these take limits. However, on May 24 the 14-day average was exceeded, and on May 27 the 14-day average went above 1,000. This exceedance was due to a combination of pumping levels and unexpectedly high densities of delta smelt. Emergency meetings of the Working Group and the Management Group resulted in a modification of the take limit computation and establishment of export limitations and outflow levels for June 1-14. Combined export pumping was kept below 2,000 cfs, and outflow was kept above 4,000 cfs. On June 14, the 14-day average was 441.

The July incidental take limit is based on the summer tow-net survey. If results of that survey are greater than the mean of dry and critical years, the fall midwater trawl for the previous year will be the limit, otherwise the limit is 300. Results of the summer tow-net survey indicate this value will be greater than the average, and the limit will be 1,078.

(3) Minimize take at the North Bay Aqueduct Intake on Barker Slough during the spawning interval.

Monitoring took place every other day from February 11 to July 13, 1994. Delta smelt were first detected on April 16. Since the pumping restriction is effective for a minimum of 2 weeks after presence is detected, the pumping restriction extended continuously from April 16 to May 17. Sampling results are:

	April 16-30	May 1-31	June 1-27
Sampling Days	8	13	14
Days Delta Smelt Averaged 1/Station	3	1	0

No additional water was necessary to meet western Suisun Marsh salinity standards during 1994.

(4) Minimize take at the Roaring River diversion in Montezuma Slough.

In 1994, DWR initiated a program to collect velocity data at the Roaring River Slough fish screen. The data will be used to develop alternative operation plans for this facility and the marsh facilities it serves. A report covering this program is in preparation.

(5) Minimize take at Contra Costa Water District diversions.

A pilot monitoring program was developed and begun. Reports have been submitted to the Fish and Wildlife Service. During this period (January 1 through June 17, 1994) only two delta smelt were caught. Diversions were not reduced as a result of these two fish.

Terms and Conditions

The term and condition implementing reasonable and prudent measure (1) is shown in an accompanying table (reproduced below). "Latest available", as used in the table, means the current year's or month's index value, to be updated with the next year's or month's value. An example would be the fall midwater trawl index, sampled in September-December, where the "latest available" value on December 1 would be the additive value of September, October, and November.

Month	Wet, Above-Normal, Below Normal	Dry, Critical
December January	100, if fall midwater trawl index is 0-250. 200, if preceding fall midwater trawl index is 250-500. 300, if preceding fall midwater trawl index is 500-1000. 400, if preceding fall midwater trawl index is 1000-1500. 500, if preceding fall midwater trawl index is greater than 1500.	100, if fall midwater trawl index is 0-250. 200, if preceding fall midwater trawl index is 250-500. 300, if preceding fall midwater trawl index is 500-1000. 400, if preceding fall midwater trawl index is 1000-1500. 500, if preceding fall midwater trawl index is greater than 1500.
February March	Fall midwater trawl index (latest available) x 0.7.	Fall midwater trawl index (latest available) x 0.7
April May June	Previous year's fall midwater trawl index x 0.7 (the number may not be greater than 755) or 600, whichever is greater.	Previous year's fall midwater trawl index x 0.7 (the number may not be greater than 755) or 400, whichever is greater.
July	Previous year's fall midwater trawl index or 600. Use greater value unless this year's summer tow-net survey is less than mean of wet, above-normal, and below-normal years from 1959 to 1993, then use lesser value.	Previous year's fall midwater trawl index or 300. Use lesser value unless this year's summer tow-net survey is greater than mean dry and critically dry years, then use greater value.
August	Previous year's fall midwater trawl index or 300. Use greater value unless this year's summer tow-net survey is less than mean of wet, above-normal, and below-normal years from 1959 to 1993, then use lesser value.	Previous year's fall midwater trawl index or 200. Use lesser value unless this year's summer tow-net survey is greater than mean of dry and critically dry years from 1959 to 1993, then use greater value.
September October November	The lesser value of: (1) previous year's fall midwater trawl index; or (2) the latest value for this year's fall midwater trawl index; but (3) the value cannot be less than 100.	The greater value of: (1) 100; or (2) the latest value for this year's fall midwater trawl index.

Other terms and conditions implementing the reasonable and prudent measures have been detailed with the specific facilities and operations that are affected.

Los Vaqueros Biological Opinion

At the request of USBR, on September 9, 1993, FWS released the *Formal Consultation of Effects of the Proposed Los Vaqueros Reservoir Project on Delta Smelt*. The Los Vaqueros project is being undertaken by Contra Costa Water District, and when completed, will be operationally integrated into the CVP. The biological opinion describes actions to be undertaken by USBR and CCWD. The reasonable and prudent alternatives contained in the opinion generally relate to operation of Los Vaqueros Reservoir, which has not been constructed. Only those reasonable and prudent alternatives and measures that have been done in 1994 are discussed below.

> (1)(c) A study plan to determine the presence of delta smelt at the Old River and Rock Slough intakes shall be submitted to FWS within 90 days of the issuance of this opinion and the study commenced within 4 months of its approval by FWS.

A pilot monitoring program began in 1994 to collect information and to determine the nature and scope of a long-term monitoring program, expected to begin in 1995.

> (1)(d) During the interval January 1 to August 31, monitoring shall be undertaken to determine an index for the abundance of delta smelt at current and future CCWD intakes.

A pilot monitoring program began in 1994 to collect information and to determine the nature and scope of a long-term monitoring program, expected to begin in 1995.

> (2)(a) CCWD shall collaborate with USBR to ensure that screening of the Rock Slough intake in accordance with the CVPIA is completed by October 1998.

The monitoring program discussed above and the data collected will be used with other information to determine the feasibility and design of a fish screen at Rock Slough. USBR and CCWD are negotiating a cost-sharing agreement for the monitoring program and subsequent fish-screen studies.

Chapter 3

BASIC BIOLOGY AND LIFE HISTORY OF DELTA SMELT

The biology and life history of delta smelt are not well understood for several reasons. First, they were not identified as a separate species until 1961, and confirming electrophoretic studies were not completed until 1993 (Stanley *et al* 1993). Delta smelt were not specifically identified as a component of CVP salvage until 1980. Second, there have been many changes in the Bay/Delta ecosystem since the early 1960s, including introduction of predatory and competing species; the observed behavior and life history of the species may, thus, reflect adaptation to these changes and may not reflect its behavior under natural conditions. Third, based on preliminary data from ongoing studies of sampling gear, the species may not be well sampled by gear currently used in a number of sampling programs. As a result, data about the distribution of delta smelt may not be entirely reliable. Fourth, delta smelt are highly sensitive to handling, and the standard mark/recapture studies needed to estimate population size have not been performed.

Basic life history is, however, reasonably well known. Delta smelt are euryhaline, with their distribution apparently affected by outflow and related entrapment zone phenomena. They spawn in tidally-influenced rivers and sloughs, with the spawning period beginning in December and ending in June, a strategy probably dictated by the highly variable hydrologic conditions in the watershed. They tolerate a wide range of conditions such as temperature and salinity and utilize both shallow-water and deep-water habitat. The species has relatively low fecundity and is a broadcast spawner; survival of (adhesive) eggs and larvae, therefore, is probably significantly influenced by hydrology at the time of spawning.

Taxonomy

Delta smelt have been described by Moyle *et al* (1989) as follows:

> Delta smelt (Hypomesus transpacificus) are slender-bodied fish that typically reach 60-70 mm standard length (SL), although a few may reach 120 mm SL. The mouth is small, with a maxilla that does not extend past the mid-point of the eye. The eyes are relatively large, with the orbit width contained approximately 3.5-4 times in head length. Small, pointed teeth are present on the upper and lower jaws. The first gill arch has 27-33 gill rakers and there are 7 branchiostegal rays. The pectoral fins reach less than two-thirds of the way to the bases of the pelvic fins. There are 9-10 dorsal fin rays, 8 pelvic fin rays, 10-12 pectoral fin rays, and 15-17 anal fin rays. The lateral line is incomplete and has 53-60 scales along it. There are 4-5 pyloric caeca.
>
> Live fish are nearly translucent and have a steely-blue sheen to their sides. Occasionally there may be one chromatophore between the mandibles, but usually there is none.

Like other members of the Osmeridae family, delta smelt possess an adipose fin and have a distinct odor of cucumbers when fresh (Moyle 1976, Wang 1986).

Until 1961, the delta smelt was considered to be the same species as the widely distributed pond smelt (*Hypomesus olidus*). Under this assumption, pond smelt were introduced in 1959 from Japan into several California lakes and reservoirs as a forage fish for trout (Wales 1962). Delta smelt and pond smelt were first recognized as distinct species by Hamada (1961, cited by Moyle *et al* 1989). The delta smelt retained *H. olidus*, while the pond smelt was renamed *H. sakhalinus*. A few years later, McAllister (1963) determined that *H. olidus* was not present in California waters and named *H. transpacificus*, which he described as having California (*H. t. transpacificus*) and Japanese (*H. t. nipponensis*) subspecies. Further studies have shown these two subspecies should be recognized as distinct species: *H. transpacificus* (delta smelt) and *H. nipponensis* (wakasagi) (Moyle 1980). Results from recent electrophoretic studies indicate that delta smelt and wakasagi are distinct species (Stanley *et al* 1993).

Life Cycle

The delta smelt is a euryhaline species found only in the Sacramento-San Joaquin Estuary. Much of the information available on the life history of delta smelt has been derived from the sampling programs described in Chapter 4. A simplified life cycle is shown in Figure 17. Figure 18 is a periodicity chart illustrating the timing of each life stage.

Delta smelt commonly occur, presumably in schools, in the surface and shoal waters of the lower reaches of the Sacramento River below Isleton, the San Joaquin River below Mossdale, through the Delta, and into Suisun Bay (Moyle 1976, Moyle *et al* 1992) (refer to Figure 1). Adult delta smelt were present in trawl samples in Georgiana Slough and the Sacramento River near Walnut Grove in 1994 (Hanson, pers comm). Delta smelt have been found as far upstream on the Sacramento River as the mouth of the American River (Stevens *et al* 1990). In high flow years, delta smelt may also be washed temporarily into San Pablo Bay, as in the winter of 1992-93 (D. Sweetnam, pers comm, cited by Moyle *et al* 1993). When not spawning, they tend to concentrate just upstream of the entrapment zone (described in Chapter 5; Moyle *et al* 1989). When the entrapment zone is in Suisun Bay and both deep and shallow water exists, delta smelt are caught most frequently in shallow water (Moyle *et al* 1992). However, as described in Chapter 5, delta smelt geographic distribution is not always a function of outflow.

Adults migrate in winter and spring from brackish water to fresh water, where they spawn from about February through June (Wang 1986). Ripe female smelt have been collected as early as December and into April, but are most abundant in February and March (Moyle 1976). Data for 1989 and 1990 indicate spawning occurred from mid-February to late June or July, with peaks in April and early May (Wang 1991). Past research indicates an almost complete spawning failure is possible in some years (Erkkila et al 1950, cited by Sweetnam and Stevens 1993).

Wang (1991) suggests the long spawning season (at least 4 or 5 months) indicates delta smelt may spawn more than once during the spawning season, or individuals may mature at different times and spawn only once. Based on findings by Moyle et al (1992), the latter may be more likely. Eggs removed from females collected in mid-January and early March 1973 were about the same size in each ovary, indicating each fish probably spawned over a relatively short period. If delta smelt were multiple spawners, eggs would be at various stages of development and size. Also, since collections were made a month and a half apart, individuals may mature at different times during the spawning season. Recent histological analyses further support this spawning theory, because all the eggs develop synchronously (S. Doroshov, pers comm, cited by Sweetnam and Stevens 1993).

Recent culturing efforts by BioSystems Analysis, Inc., and University of California, Davis, indicate spawning success in the laboratory appears to vary depending on whether fish are captured early or late in the season. Gonadal development occurs from October to April, especially in March and April. Development is asymmetric, with the left gonad being considerably larger (Mager 1993). A ripe gonad may have 1,000-1,400 eggs. However, fertility and percent hatch ranged from zero to 80% and was poorer in late spring. In collections of adult fish, females were more common than males later in the spawning season (mid-April) (88.5% females, n=140) (Lindberg 1992).

Moyle *et al* (1992) found no correlation between female length and fecundity. Females of 59-70 mm SL[1] ranged in fecundity from 1,247 to 2,590 eggs per fish, with an average of 1,907. Delta smelt fecundity is relatively low in comparison to longfin smelt (*Spirinchus thaleichthys*), the other euryhaline smelt present in the Delta, which has fecundity of 5,000 to 25,000 eggs per female (Moyle 1976).

Spawning has been reported to occur at about 45-59°F (7-15°C) in tidally-influenced rivers and sloughs, including dead-end sloughs and shallow edge-waters of the upper Delta and Sacramento

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[1] FL = Fork Length; SL = Standard Length; TL = Total Length. See list of abbreviations inside the back cover.

River above Rio Vista (Radtke 1968, Wang 1986). Evidence of some spawning has also been recorded in Montezuma Slough and, more recently, in Suisun Slough (P. Moyle, unpubl data). However, typical April-June water temperatures in the Delta are 59-70°F (15-23°C), which are higher than the reported spawning range. Initial results from UC-Davis provide an indication of environmental tolerances of delta smelt (Cech and Swanson 1993). The study found that although delta smelt tolerate a wide range of water temperatures (<8°C to >25°C), warmer temperatures apparently restrict their distribution more than colder temperatures. Posthatch larvae of 5.0 mm TL were collected in 1991 at

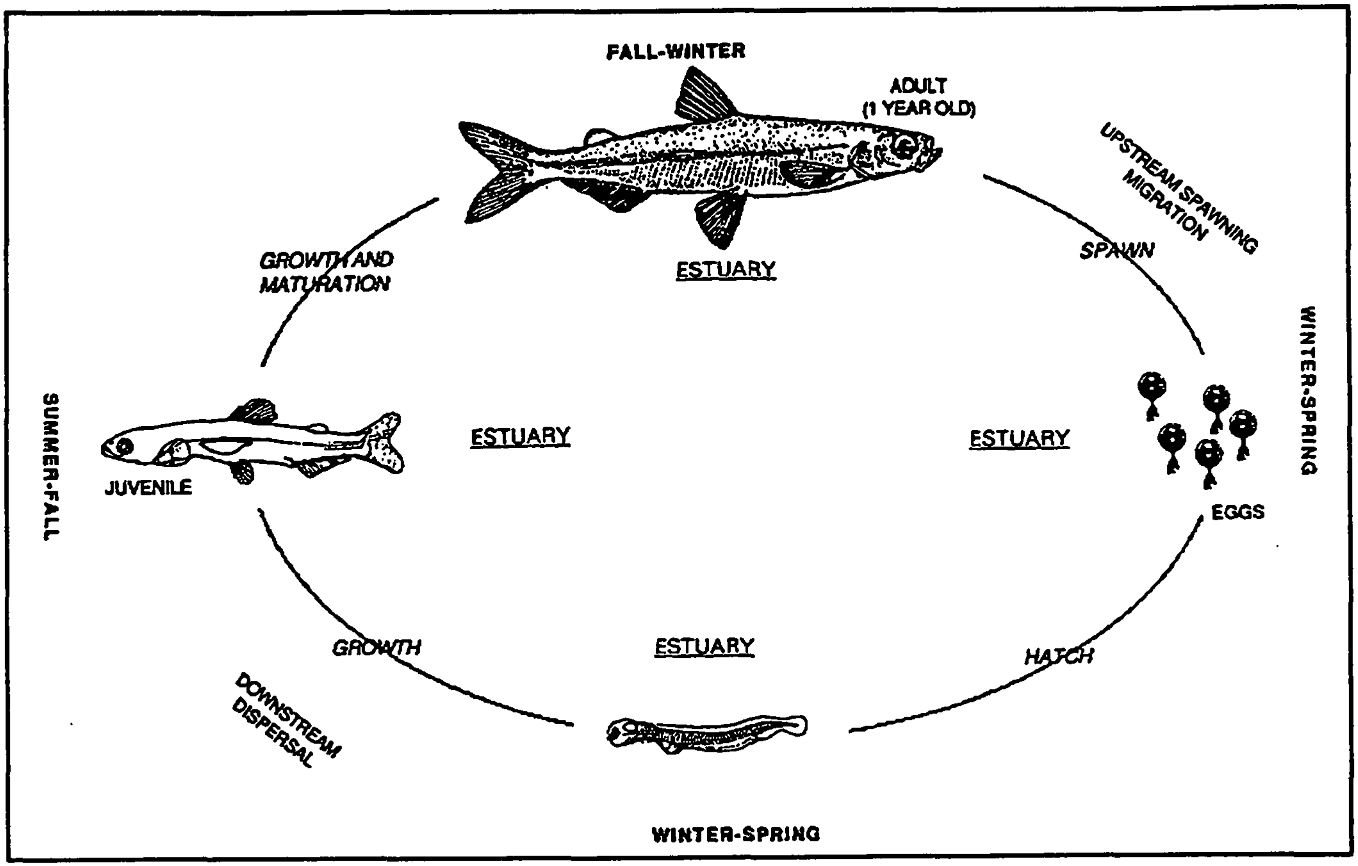


Figure 17
LIFE HISTORY OF DELTA SMELT
Adapted from Jones & Stokes (1993).

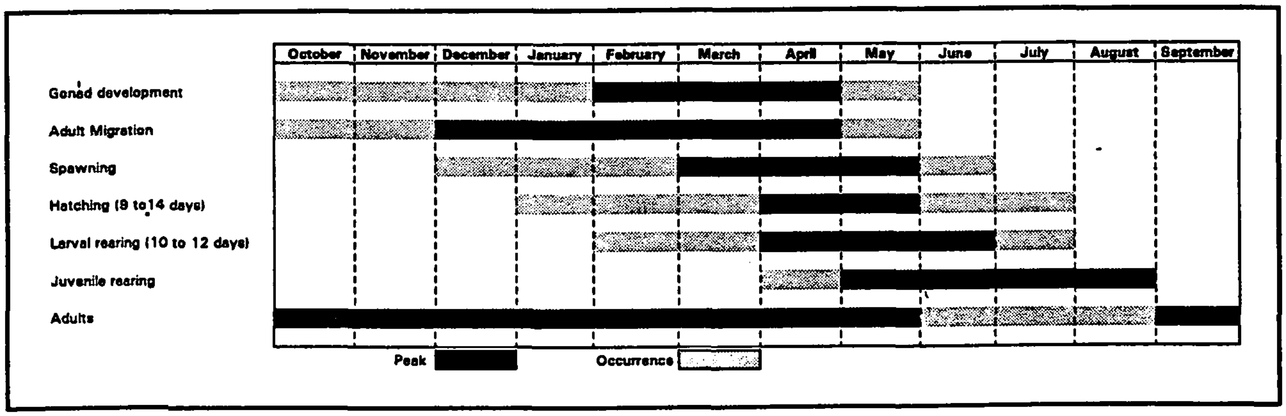


Figure 18
PERIODICITY CHART FOR DELTA SMELT

73°F (22.8°C), while water temperatures for the previous 7-14 days at the same location were 69.5-70°F (20.8-21.7°C). However, the larvae may have been spawned and carried in from an area of cooler temperatures (Sweetnam and Stevens 1993).

Most spawning occurs in fresh water, but some may occur in brackish water in or near the entrapment zone (Wang 1991). The demersal, adhesive eggs sink and attach to hard substrates, such as submerged tree branches and roots, gravel or rocks, and submerged vegetation (Moyle 1976, Wang 1986).

Laboratory observations indicate that delta smelt are broadcast spawners that spawn in a current, usually at night, distributing their eggs over a local area (Lindberg 1992, Mager 1993). The eggs (1.0 mm) form an adhesive foot that appears to stick to most surfaces. Eggs attach singly to the substrate, and few eggs were found on vertical plants or sides of the culture tank (Lindberg 1992). Mager (1993) found that larvae hatched in 10-14 days under laboratory conditions, with absorption of the yolk-sac in 150 hours and of the oil droplet in 200 hours. Larvae began feeding on phytoplankton on day 4, rotifers on day 6, and Artemia nauplii at day 14. They did best on a rotifer diet until day 10-15 but were not selective when fed a mixed diet. Little digestion was observed until day 8. Lindberg (1992) found that hatch occurred at 9 days, yolk absorption at 4 days post hatch, exogenous feeding at 4-5 days post hatch, and oil globule absorption at 10 days post hatch (at 17°C).

Newly hatched larvae are planktonic and drift downstream near the surface in inshore and channel areas to the upper end of the entrapment zone (Wang 1986, Moyle *et al* 1992). In the laboratory, yolk-sac fry were found to be positively phototaxic, swimming to the lightest corner of the incubator, and negatively buoyant, actively swimming to the surface. The behavior of post-yolk-sac fry was more variable; they were more evenly distributed throughout the water column (Lindberg 1992).

A recent study of delta smelt eggs and larvae by Wang and Brown (1994) suggests that spawning may occur from February through June, with a peak in April and May. From 1988 to 1990, Bradford Island was a major spawning area. Delta smelt spawned farther inland in 1991, perhaps because of low flows. Key spawning areas in 1991 included the eastern Delta toward the Mokelumne River and Venice Island and the mid-Sacramento River area near Isleton. Spawning activity was also noted in the Mokelumne River and Cache Slough. Slough habitat of the Delta appears to have been the most important nursery area from 1988 to 1991. Spawning appears to have been more systemwide in 1993, including the San Joaquin River, Mokelumne River, and Montezuma Slough (D. Sweetnam, pers comm).

Juvenile and adult delta smelt commonly occur in the surface and shoal waters of the lower reaches of the Sacramento River below Isleton, the San Joaquin River below Mossdale, through the Delta, and into Suisun Bay (Moyle 1976, Moyle *et al* 1992). Growth is rapid through summer, with juveniles reaching 40-50 mm FL by early August (Radtke 1966). Growth slows in the fall and winter, presumably to allow for gonadal development. Adult smelt reach 55-70 mm SL in seven to nine months, and those that survive spawning may grow as large as 120 mm SL (Moyle 1976). Most delta smelt do not grow larger than 80 mm FL (Moyle *et al* 1992). The largest recorded smelt was 126 mm FL (Stevens *et al* 1990).

Length/frequency distribution of the short life-span of delta smelt indicates most fish live only one year and die after spawning (Stevens *et al* 1990, Moyle *et al* 1992); however, some do apparently survive for two years (Moyle 1976). Recent culturing work indicates that after spawning, males die off more rapidly in May and June (Mager 1993). Smelt larger than 50 mm FL become increasingly rare in March through June samples (Moyle *et al* 1992), and by late summer, the young of the year dominate trawl catches (Moyle *et al* 1989). There is generally an abrupt change from a single-age adult cohort during spring spawning to a dominance of juveniles in the summer (Radtke 1966).

Chapter 4

HISTORICAL ABUNDANCE AND DISTRIBUTION OF DELTA SMELT

Several surveys have collected data on delta smelt as part of larger sampling programs. Some surveys focused on specific species such as striped bass or salmon; others were designed to monitor fish populations in specific areas. During the past few years, sampling programs have been modified and expanded substantially to provide more information on delta smelt.

Information on delta smelt is included in databases from the summer tow-net survey, fall midwater trawl survey, Delta Outflow/San Francisco Bay Study, Chipps Island trawl survey, beach seine survey, Suisun Marsh survey, and fish salvage operations at the SWP and CVP. Although these programs were not designed to measure delta smelt distribution and abundance, the databases provide the best information available on delta smelt abundance, distribution, and trends. Each sampling program has relative strengths and weaknesses, associated with such factors as gear types (biases, net efficiencies), channel area sampled, seasonal timing of survey, and geographic area covered. Although the size of the delta smelt population cannot be accurately estimated from the available data, the data do provide indices of general population trends. Figure 19 shows trends in delta smelt populations as indexed by the seven databases. This chapter briefly describes each of the databases and the observed trends.

Pre-CVP abundance and distribution of delta smelt is unknown, and pre-SWP information is based on relatively few years of data. In the highly altered Bay/ Delta ecosystem, delta smelt are believed to utilize habitat from eastern San Pablo Bay (rare) to the lower Sacramento and San Joaquin rivers. Their distribution within their overall range appears to vary significantly from year to year, apparently influenced by hydrology and availability of food.

Almost all indices of relative abundance suggest a substantial decline in abundance of the species beginning in the late 1970s, although there have been apparent resurgences in the early 1980s and early 1990s. Smelt abundance appears to be lowest in dry periods, such as 1976/1977 and 1985-1992, and to rebound following and during wet periods, such as following 1978 and 1983.

The data from the seven indices have implications for CVP and SWP operations. First, they suggest that salvage at the pumps, an indicator of the influence of pumps on delta smelt, is not consistently related to the other indices. For example, SWP salvage did not increase in 1993 as did most of the other indices.

The change in distribution of delta smelt during dry and wet years has the potential to affect take of the species at the CVP and SWP pumps. If delta smelt are concentrated in upstream areas in dry years, as fall midwater trawl data suggest, then there is opportunity for them to be taken at the SWP or CVP pumps. During wet years, when the species appears to be more widely distributed due to better overall habitat conditions, take at the pumps may be reduced.

Although the population trends suggested by the various abundance indices are generally consistent, there are several indications in the various indices that suggest estimates of abundance are being influenced by distribution. The relationship between distribution and take raises the issue of the significance of take. In years when most of the population is outside the influence of the project pumps, the small incidental take recorded may have an insignificant impact on the overall population. When improved conditions result in a broader distribution of the population and bring the delta smelt into habitat where they can be affected by the pumps, it is less likely that higher levels of take affect a significant portion of the population. Because there are differences in the various indices of abundance, it is important to consider all indices in the evaluation of trends.

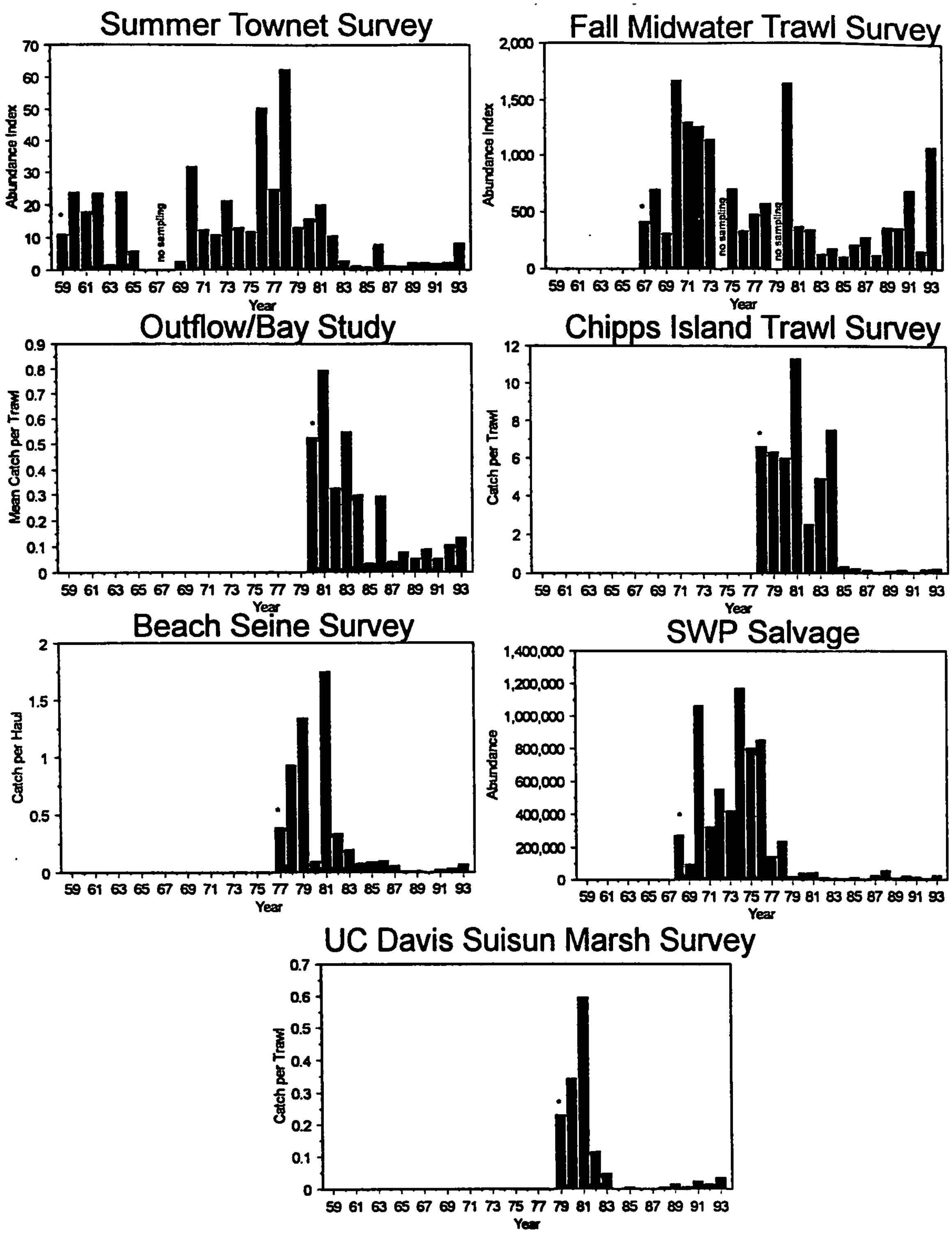


Figure 19

TRENDS IN DELTA SMELT POPULATIONS, AS INDEXED BY SEVEN INDEPENDENT SURVEYS

Note that not all surveys were conducted in all years shown.

Source: Department of Fish and Game, updated from Stevens *et al* 1990.

Summer Tow-Net Survey

The Department of Fish and Game has conducted the tow-net survey each summer since 1959 (except 1967 and 1968), primarily to provide an abundance index for young striped bass. About 30 sites in San Pablo Bay and the Delta (Figure 20) are now surveyed for five days at 2-week intervals from June until the average size of young bass is 38 mm, in July or August.

Although the tow-net survey was primarily designed to sample striped bass abundance, data have also been collected on other species, including delta smelt. Two to five sampling runs have been completed each survey year; for consistency, the smelt index is based only on the first two sampling runs of each year. Abundance indices for each sampling run are calculated as the product of the total catch at each site and the estimated water volume (in acre-feet) for the site divided by 1,000, a convenient scaling factor. A mean site index for the two sampling runs is calculated, with the annual Delta/Estuary index representing the sum of all sites (Stevens *et al* 1990).

The tow-net index is considered one of the best measures of delta smelt abundance, because it covers much of the species' habitat and represents the longest historical record. However, the index may underestimate abundance in high flow years, when many fish are carried to San Pablo Bay (Moyle *et al* 1992). The study demonstrated that a tow-net caught relatively few smelt and may have produced a biased distribution of abundance. Also, some potentially important habitat such as Cache Slough is not sampled. To maintain survey continuity with respect to the tides, additional stations were not added for areas such as Cache Slough. A larval purse seine has been added to the study to sample this area, but results are not yet available. Another concern is that the timing of delta smelt spawning varies (Wang 1991), so the size and associated catchability of young fish by the onset of tow-net sampling may change from year to year. Above-average mortality of early-spawned delta smelt could also result in an underestimate of year-class strength (Dale Sweetnam, pers comm).

Results of the summer tow-net surveys are summarized in Figures 21 and 22. Abundance indices vary considerably but values have generally remained low from the 1980s until 1993 (Figure 21). The 1993 index was the highest since 1982, and delta smelt appeared to be much more widely distributed than in recent years. The 1994 index of 13 indicates population levels have continued to increase. The reduced population levels during the 1980s appears to have been consistent throughout

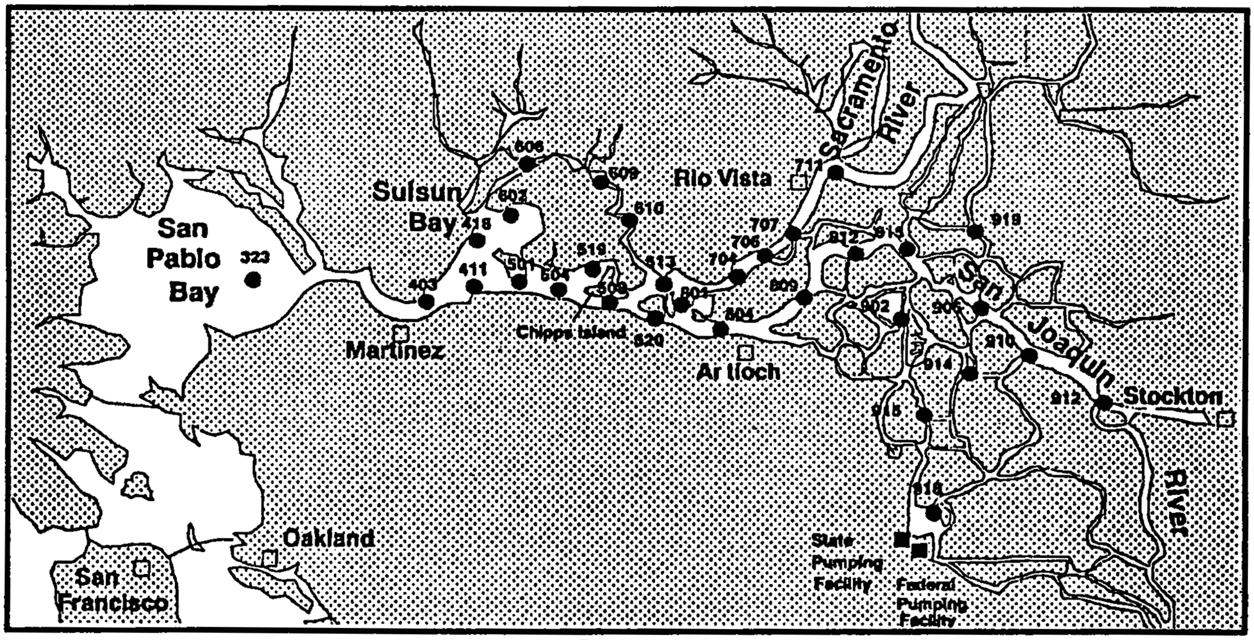


Figure 20
SUMMER TOW-NET SURVEY SAMPLING SITES IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

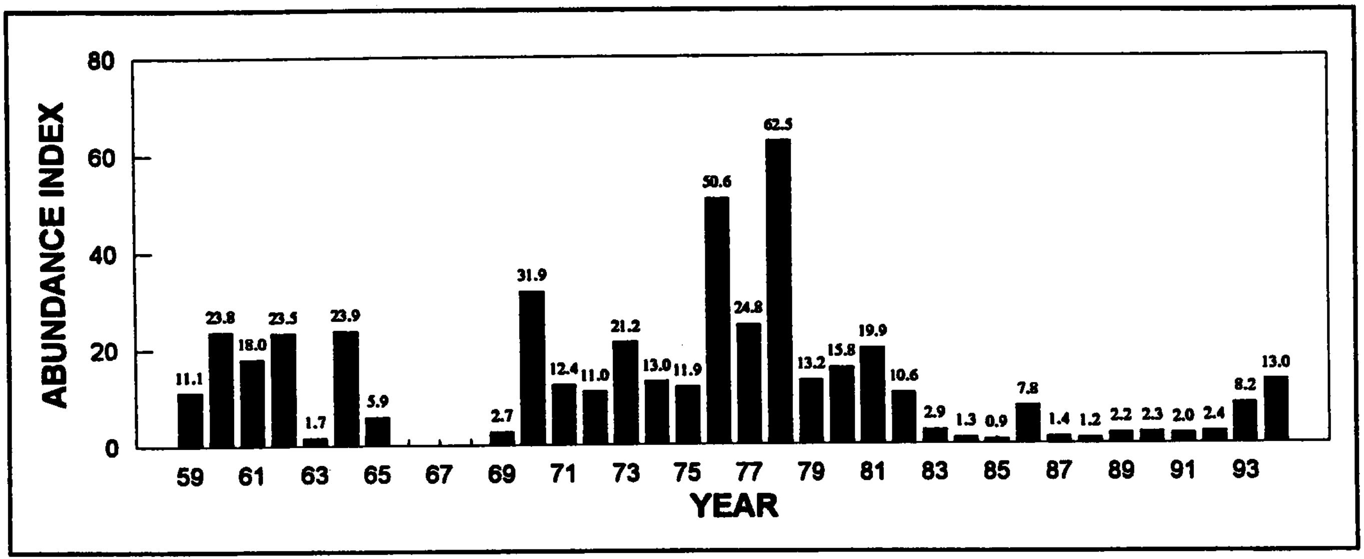


Figure 21
DELTA SMELT SUMMER TOW-NET INDEX, 1959-1994

the Delta and Suisun Bay (Figure 22), but declines may have occurred as early as the mid-1970s in the eastern and southern portions of the Delta.

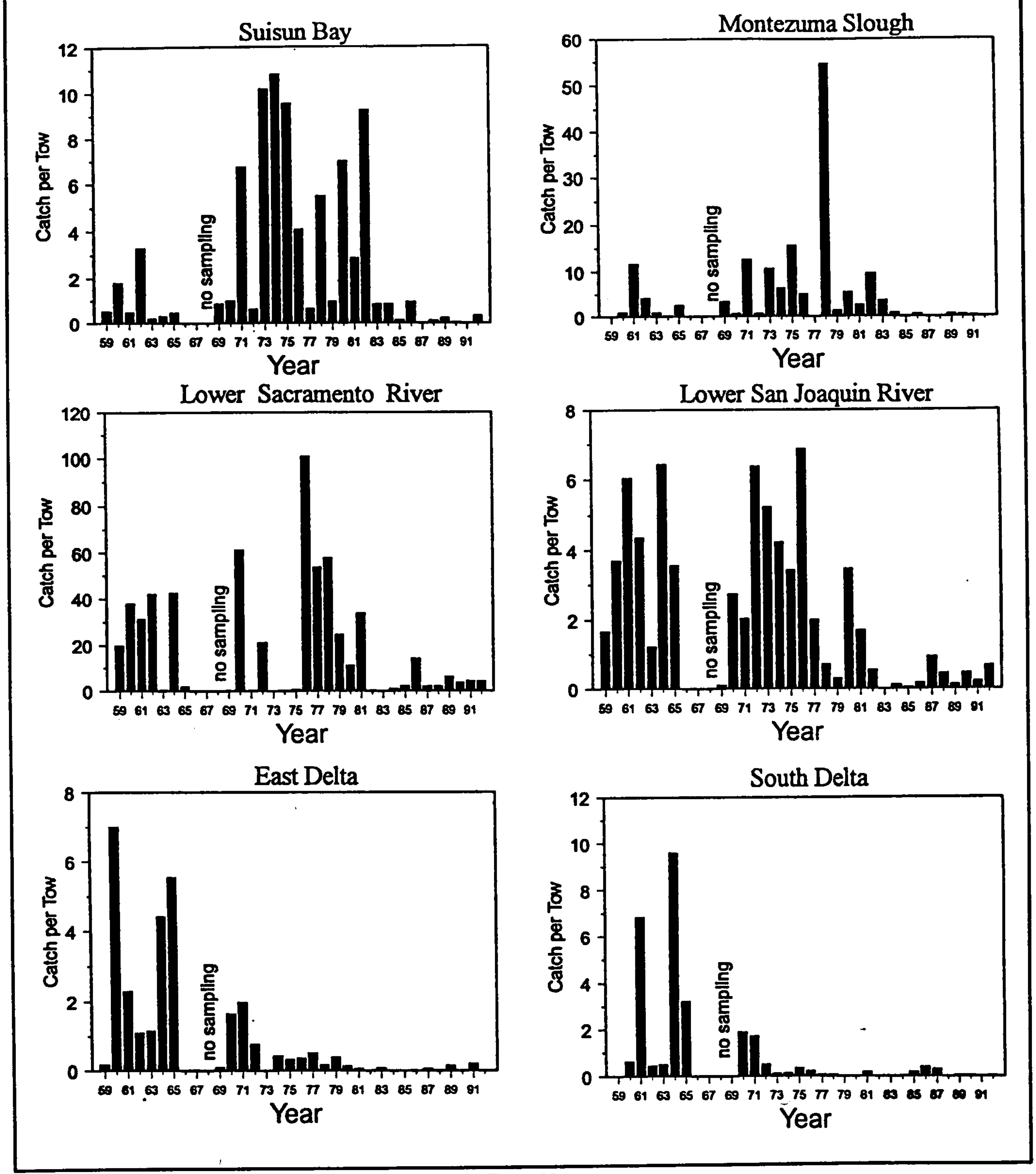
Fall Midwater Trawl Survey

Since 1967, the Department of Fish and Game has conducted a fall midwater trawl survey to determine abundance of striped bass and other species. The survey area includes about 87 sites from the Delta to San Pablo Bay (Figure 23). Additional stations have recently been added to improve coverage for delta smelt, but they are not used to develop the index for delta smelt (Sweetnam 1992). Until 1980, the survey lasted from late summer through the following March but now is from September through December. No sampling was conducted in 1974 and 1979, nor in November 1969 and September and December 1976. Additional months were included in 1991, 1992 (January-March), and 1993 (January-August) to increase sampling for delta smelt.

Monthly delta smelt indices are calculated for 17 subareas of the estuary as the product of the mean catch from each subarea and a weighting factor that is proportional to the estimated volume in each subarea. An annual index is calculated as the sum of monthly indices from each subarea from September through December. Missing data for 1969 and 1976 were estimated from interpolation or extrapolation (Stevens *et al* 1990).

Abundance indices have also been developed using the surface area of each site rather than the volume. The rationale was that delta smelt frequently school near the water surface, so dividing by the total volume may not be an accurate indication of abundance, particularly when sampling in narrow channels. However, indices based on volume were similar to those developed by surface area, so the index remains based on volume (Dale Sweetnam, DFG, pers comm).

The midwater trawl provides one of the best indices of smelt abundance because it covers most of the range of delta smelt. However, for several reasons, the index is not an actual measure of total population size. Samples are collected principally from higher-velocity, midchannel areas and only during daytime, causing unquantified levels of gear selectivity and sampling bias. As evidence, efficiency of the midwater trawl in catching delta smelt appears to change over the course of the year. Sweetnam and Stevens (1993) reported that the midwater trawl was about 2.6 times more effective at sampling striped bass than delta smelt in August 1991 and 1.8 times more effective in January 1992. Hence, population size estimates based on the ratio of delta smelt to striped bass in the fall midwater trawl were recognized by Stevens *et al* (1990) to be imperfect. Other potential sources of error in the



Suisun Bay

Montezuma Slough

Lower Sacramento River

Lower San Joaquin River

East Delta

South Delta

Figure 22

MEAN CATCH PER TOW OF DELTA SMELT, BY AREA, FROM THE SUMMER TOW-NET SURVEY

Note differences in the scale used for each area.

Source: Sweetnam and Stevens 1993.

survey, including non-random distribution of sampling stations, tidal and temporal effects, patchiness in smelt distribution, and skewness and non-homogenous variations in the data, were reviewed in detail by Buell (1994a). Although the midwater trawl data do not produce satisfactory estimates of stock size, calculated indices remain reasonable evidence of abundance trends (Sweetnam and Stevens 1993).

Results of the midwater trawl surveys are presented in Figure 19. While indices have been highly variable, abundance was generally low from 1981 to 1988. Except in 1992, there appears to be a general increase in abundance since 1988. This trend has culminated in the 1993 index, the sixth highest on record. Indices were also low in 1967, 1969, 1976, and 1977, but they rebounded more quickly than in the 1980s.

The midwater trawl also indicates changes in population distribution. Figure 24 presents distribution trends for eastern Delta, lower San Joaquin River, lower Sacramento River, Montezuma Slough/ Grizzly Bay, eastern Suisun Bay, and western Suisun Bay. In drought years such as 1976-1977 and 1987-1992, the population was concentrated in upstream channels in the lower Sacramento River. In wetter years, the population was more broadly distributed, extending into Montezuma Slough/ Grizzly Bay, eastern Suisun Bay, and occasionally western Suisun Bay. Survey results from September 1993 are consistent with this pattern.

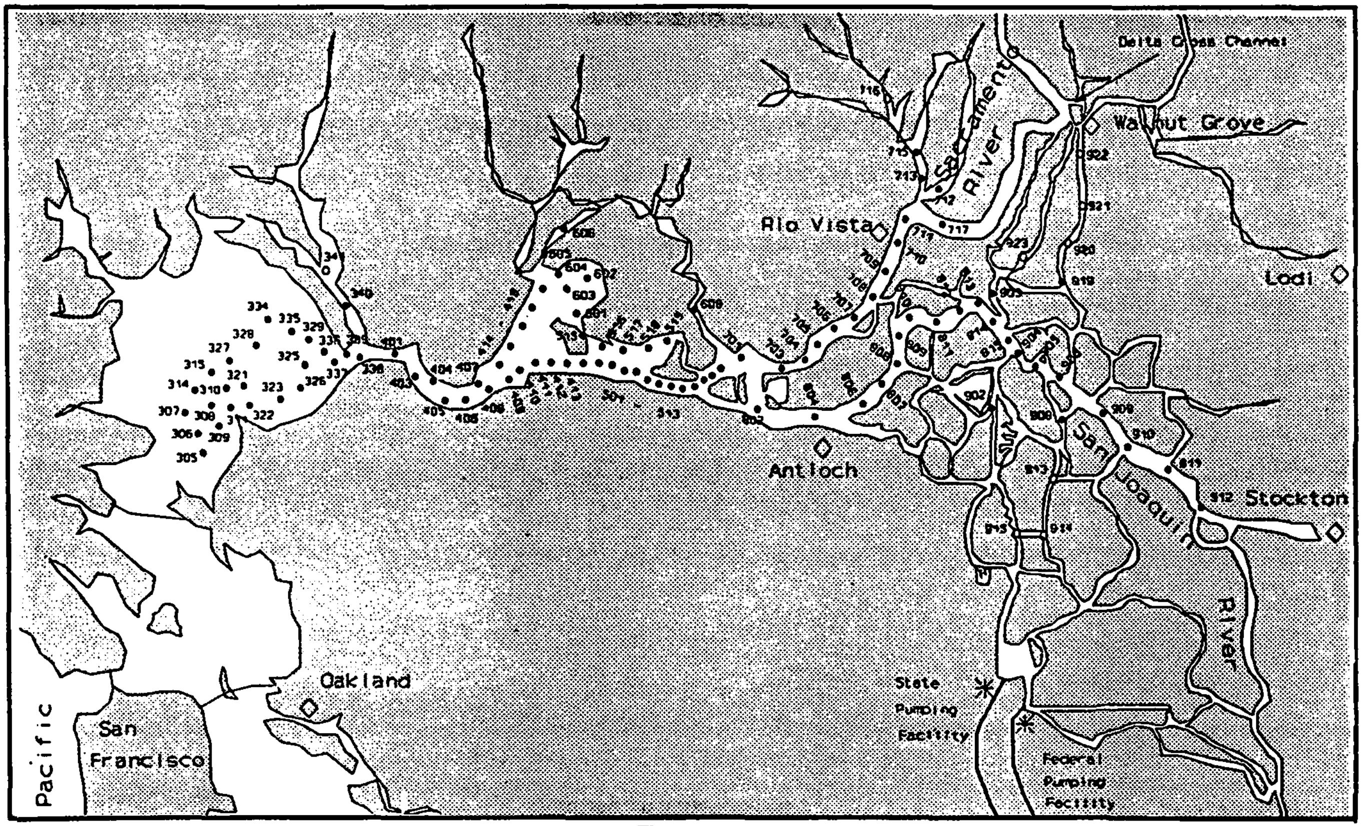


Figure 23

FALL MIDWATER TRAWL SAMPLING SITES IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

● Original striped bass stations. ○ Added delta smelt stations.

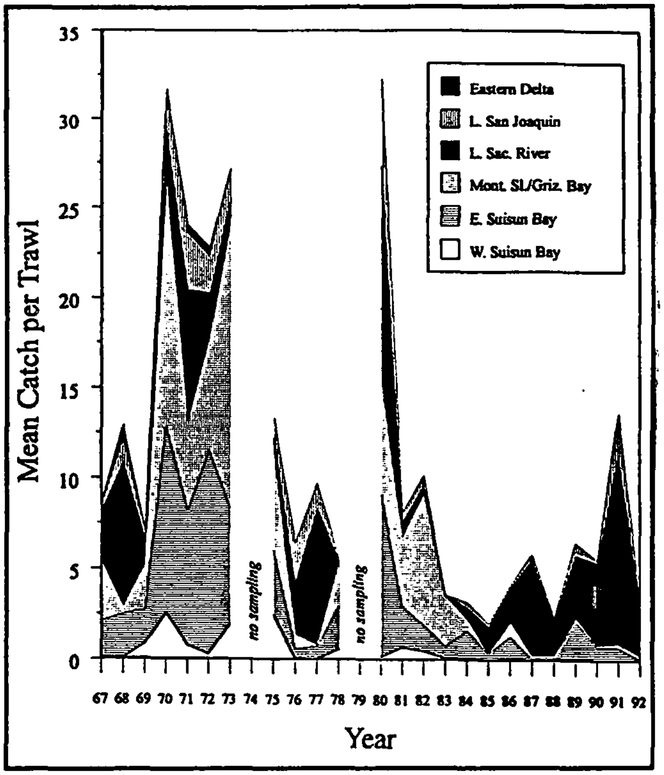


Figure 24
MEAN CATCH PER TRAWL FROM THE
FALL MIDWATER TRAWL SURVEY FOR SPECIFIC AREAS OF
THE SACRAMENTO-SAN JOAQUIN ESTUARY
Source: Sweetnam and Stevens 1993.

Delta Outflow/ San Francisco Bay Study

Since 1980, the Delta Outflow/San Francisco Bay Study of the Interagency Program has sampled 42 locations from South San Francisco Bay to the western Delta. Catch per unit effort is calculated based on monthly 12-minute net tows. The survey is conducted year-round and reveals gross trends in fish and invertebrate abundance. This study collects both juvenile and adult delta smelt.

A major drawback of delta smelt data collected in the Outflow/Bay study is that the area east of Antioch is not sampled, so an important part of the species' range is excluded. Hence, while Figure 19 shows a dramatic decline in delta smelt during the 1980s, the trend may be largely a result of an upstream shift in distribution during the drought. Abundance levels appear to be improving, based on the 1992 and 1993 indices.

Chipps Island Trawl Survey

The Interagency Program's annual midwater trawl surveys at Chipps Island, in upper Suisun Bay, are primarily to capture released coded-wire-tagged salmon, but they also measure abundance of outmigrating Chinook salmon. The survey has been conducted in April through June since 1976. Numbers of delta smelt captured incidentally in the trawl are recorded, allowing an index to be calculated based on catch per trawl. The major deficiency with this index is that only one location is sampled, so the index is strongly affected by changes in delta smelt distribution. Hence, the significantly lower catch-per-trawl levels after 1986 (Figure 19) could be partly a result of a distribution shift during the drought. An additional concern is that data are from relatively high-velocity, midchannel areas, where delta smelt may not necessarily be abundant during April through June. A slight increase in abundance was noted in 1993.

Beach Seine Survey

The Interagency Program has conducted a beach seine survey at 23 sites from the Delta and Sacramento River upstream to the mouth of the American River. Since 1977, surveys have been performed several times each month from January to April, May, or June. This survey samples low-velocity water near the shoreline rather than high-velocity, midchannel areas. This survey reflects the numbers of adult smelt, which select shallow water as they move upstream to spawn. However, 20- to 30-mm juvenile smelt have also been taken. Results are consistent with general declines in the 1980s followed by an increase in 1993 shown for other indices (Figure 19).

Suisun Marsh Survey

Under contract to Water Resources, students and staff at the University of California, Davis, have sampled the interior channels of Suisun Marsh since 1979. Otter trawl samples are taken monthly at a number of sites, including two in Montezuma Slough. An abundance index is calculated for delta smelt based on catch per tow (Figure 19). This sampling program also may not represent trends in overall abundance. The decline in catch per tow in the 1980s is consistent with other surveys, although the trend may be partly due to an upstream shift in distribution during the recent drought. Like the other surveys, abundance levels increased in 1993.

SWP and CVP Fish Salvage Operations

Fish salvage data from the SWP and CVP facilities provide a useful, long-term record for delta smelt juveniles and adults) However, utility of the database is limited because of inconsistencies in the taxonomic identification and enumeration of delta smelt. Salvage data before 1979 are particularly suspect because of identification and other data quality problems. Also, the fish screens are relatively inefficient for fish less than 25 mm. The databases are also probably poor indicators of population abundance because annual salvage varies depending on seasonal and annual shifts in geographic distribution. Annual variations in water export rates also affect the numbers of fish diverted and efficiencies of the fish screens. Salvage values represent estimated delta smelt collected at the fish screens, not losses of smelt to the water diversions. Nonetheless, salvage may provide an index of the timing and magnitude of losses.

At the CVP, the annual salvage estimate was about 45,000 delta smelt in 1979 and 1980, when smelt species identification began (Stevens *et al* 1990) (Figure 25). Salvage increased to about 275,000 delta smelt in 1981, and has been very low since 1982, ranging from 2,000 to 34,000.

At the SWP, less than 300,000 delta smelt were salvaged in 1968 and 1969, the initial years of sampling (Stevens *et al* 1990). From 1970 to 1974, salvage ranged from about 300,000 to more than 1 million delta smelt. Results from subsequent years are shown in Figure 25. Delta smelt salvage declined dramatically in 1977 (146,000) and 1978 (238,000). Relatively few delta smelt have been salvaged since 1979.

Kodiak Trawl Surveys

Kodiak trawls were used to sample for delta smelt to evaluate the relationship between distribution and salvage at the pumps. Results from the Georgiana Slough acoustic barrier study showed that the Kodiak trawl was highly efficient for catching a variety of juvenile fish.

To compare the relative efficiencies of the tow-net and the Kodiak trawl, side-by-side comparison trawls were conducted over 6 days. Preliminary results are that the Kodiak trawl appears to have a lower detection limit; that is, it consistently catches fish in areas where the tow-net did not. This aspect of the trawl is significant, particularly in light of the fact that recovery criteria for the species, current reasonable and prudent alternatives, and possibly future take provisions depend on the presence or absence of delta smelt at specific locations. However, further analytical and sampling work is needed to determine whether the Kodiak trawl is more efficient than the tow-net on a catch-per-unit-effort basis.

Comparative sampling is planned for early fall, and results should be available by late fall 1994.

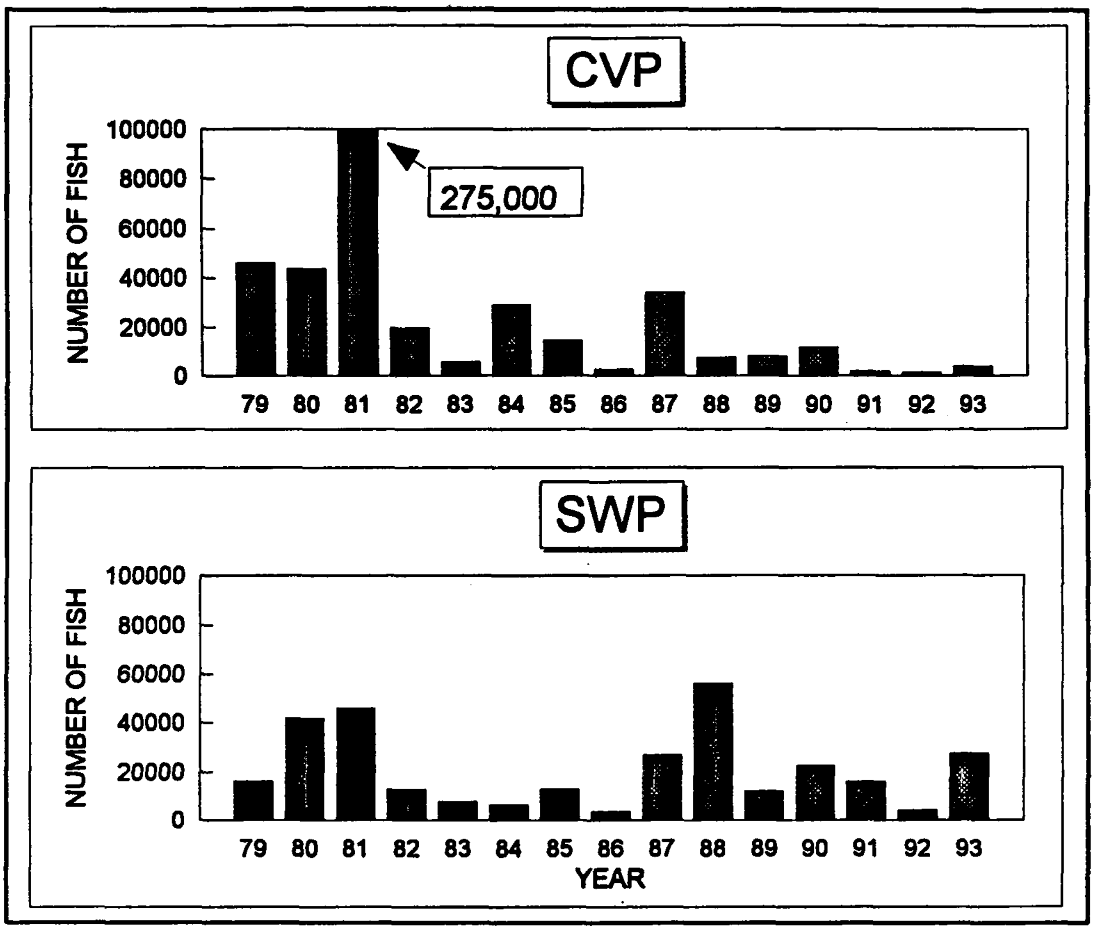


Figure 25
ANNUAL SALVAGE ESTIMATES FOR DELTA SMELT AT THE CVP AND SWP FISH FACILITIES
Data before 1979 are not included because of identification problems described in the text.

Chapter 5

FACTORS THAT MAY INFLUENCE DELTA SMELT ABUNDANCE AND DISTRIBUTION

The Bay/Delta and much of its watershed had been substantially modified before construction of the first CVP facilities in the 1940s — by mining; by dredging and fill, which resulted in loss of about 90% of wetlands and riparian habitat in the watershed; by over-exploitation of fisheries, resulting in extinction of several species; and by introduction of several exotic species. The impacts of the CVP and SWP, therefore, occurred in a heavily altered ecosystem.

In this complex and highly altered ecosystem, a number of factors may adversely affect delta smelt abundance and distribution. Although many of these factors are interrelated, they are discussed individually in this chapter.

It is apparent that the two projects have had a significant impact on native aquatic resources, partly because of their direct impact on the hydrology of the central and southern Delta. Adult delta smelt are lost to predation and entrainment at the pumps; salvage operations have only limited success in reducing these losses. Early life stages appear to be particularly vulnerable to pumping because they drift into the zone of pump influence from throughout the Delta and because screens are not effective for these life stages. The extent of impact to early life history stages is not known because of difficulties in identifying delta smelt less than 30 mm long. Whether entrainment, as estimated by salvage, affects abundance remains to be demonstrated statistically.

There is evidence that outflow and the position of the entrapment zone have an influence on abundance and distribution of delta smelt — probably through transport of eggs and larvae to Suisun Bay, improvement of habitat in the estuary, and related changes in food abundance.

Other diversions, such as Contra Costa Canal, PG&E's power plants, and in-Delta agricultural diversions, result in take of delta smelt in numbers comparable to or greater than the estimated take at the CVP and SWP pumps. To the extent that CVP and SWP take affects abundance, these other diversions may also be considered to have an impact on delta smelt.

Predation and competition may affect delta smelt abundance, particularly that related to non-native species such as inland silverside, chameleon goby, and striped bass. Evidence suggests these and other species are either direct predators or compete with delta smelt for food or habitat.

Levels of phytoplankton have declined significantly over the period of delta smelt decline, and levels of primary food items (zooplankton) available to delta smelt have also changed. The impact of these changes has not been quantified. Concurrently, water transparency has increased, particularly in the spring in the southern, central, and northern Delta, where smelt could be subject to increased predation.

Contaminants may have a significant impact on delta smelt abundance and distribution. Levels of contamination determined to be lethal to juvenile Chinook salmon and striped bass have been found in some agricultural drainage; delta smelt are likely to be adversely affected by these high levels of contamination.

Factors such as outflow and position of the 2-ppt isohaline explain (statistically) only about 25% of the annual variation in abundance indices for delta smelt, and stock-recruitment relationships also explain a relatively small amount of the observed variation. Therefore, it is probable that those factors listed above have a significant role in delta smelt abundance and distribution. In particular, factors that co-vary with year type, such as nutrient levels, water transparency, and concentration of toxins should be examined closely in developing management plans for protection and recovery of delta smelt.

Delta Outflow and the Entrapment Zone

Delta outflow is the amount of fresh water that flows past Chipps Island into Suisun Bay. Because it is not yet possible to measure directly, an index of Delta outflow is calculated using the inflow to the Delta; State Water Project, Central Valley Project, and Contra Costa Canal exports from the Delta; and estimated depletions of channel water within the Delta. Total Delta outflow levels are shown in Figure 26.

Outflow (and diversions) may affect the speed and direction of fish movement in and through the Delta. A reduction in transport time may adversely affect delta smelt, which spawn upstream and depend on currents to distribute their larvae throughout the nursery area. There is evidence that freshwater outflow may also influence the abundance and distribution of many other species. Outflow acts as a hydraulic barrier to reduce movement of salt upstream from the ocean. It also determines the location of the entrapment zone. These factors are discussed below, beginning with a discussion of the influence of hydrology on outflow.

Effect of Hydrology on Outflow

Delta outflow is influenced by both human activities and natural occurrences. Human influences include Delta diversions, upstream reservoir regulation of water throughout the Central Valley, and upstream diversions and return flows. The major natural factors are Central Valley precipitation patterns, including both rainfall and snowpack, and corresponding runoff.

The Sacramento River Index is a measure of unimpaired runoff for the Sacramento Valley. Figure 27 shows the Sacramento River Index for 1967-1992 and the long-term average for 1905-1992. The figure reflects the variability of Central Valley hydrology over the last 26 years. Figure 28 shows that recent years have deviated significantly from the long-term mean. The late 1960s and early 1970s were somewhat wetter than normal, followed by a sharp decline during the 1976/1977 drought. The 1980s and early 1990s show a high deviation from the long-term average, with exceptionally wet years (1982-1984) and extreme drought (1987-1992).

Hydrologic variability is an uncontrollable part of any natural or regulated ecosystem. The 1980s and

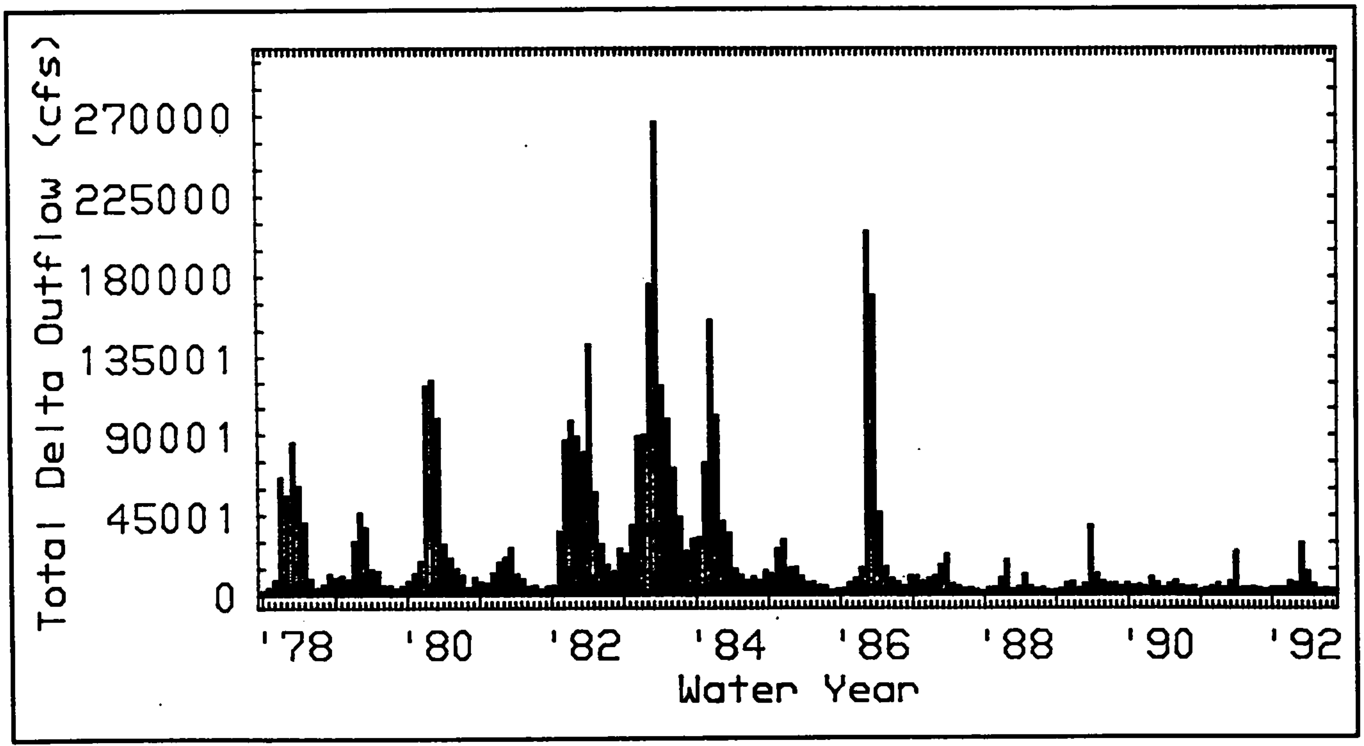


Figure 26
AVERAGE MONTHLY TOTAL DELTA OUTFLOW, WATER YEARS 1978 TO 1992
From the DAYFLOW Database

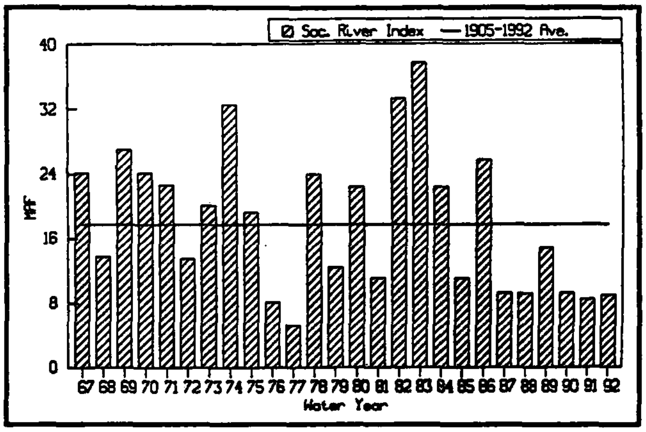


Figure 27
SACRAMENTO RIVER INDEX
UNIMPAIRED HYDROLOGY, 1967 TO 1992

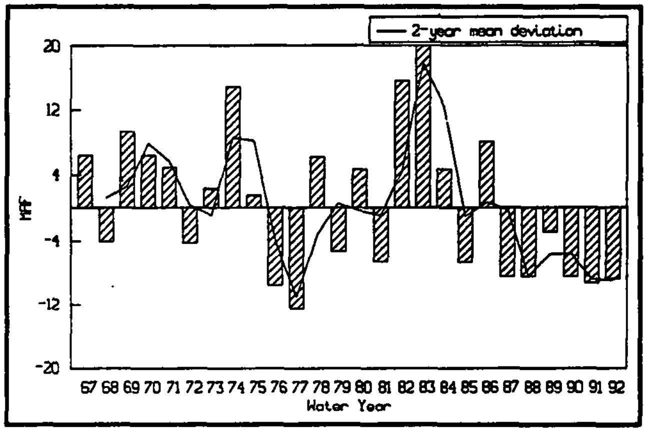


Figure 28
SACRAMENTO RIVER INDEX
DEVIATION FROM LONG-TERM AVERAGE, 1967 TO 1992

early 1990s contain one of the wettest and one of the driest periods recorded in the Central Valley. The uncontrollable aspect of Delta hydrology must be recognized as a factor that determines and affects outflow and, therefore, could affect the abundance and distribution of delta smelt.

It should also be noted that total outflow has two distinct components: regulated and unregulated runoff. Regulated runoff from reservoir releases is generally limited to about 20,000-25,000 cfs due to gate capacity and downstream channel capacity. The unregulated component is, therefore, responsible for outflows higher than about 25,000 cfs.

Delta Outflow

Decreases in outflow during drought years have been reported to affect the abundance of a number of biological resources of the estuary (Armor 1992). Moyle and Herbold (1989) suggest that delta smelt benefit from moderately high flows, which place the primary nursery area in Suisun Bay. However, Stevens and Miller (1983) and Moyle *et al* (1992) did not find any statistical relationship between delta smelt abundance indices and outflow. This indicates that if outflow does affect smelt abundance, the influence may be small relative to other factors in some or all years.

Delta outflow does appear to have a strong impact on geographical distribution. Stevens *et al* (1990) showed that significantly more delta smelt were found west of the Delta when outflows were high. As shown in Figure 29, the tow-net index for the first and second tow-net surveys of each year (survey=1, survey=2 on the figure) in the Suisun Bay

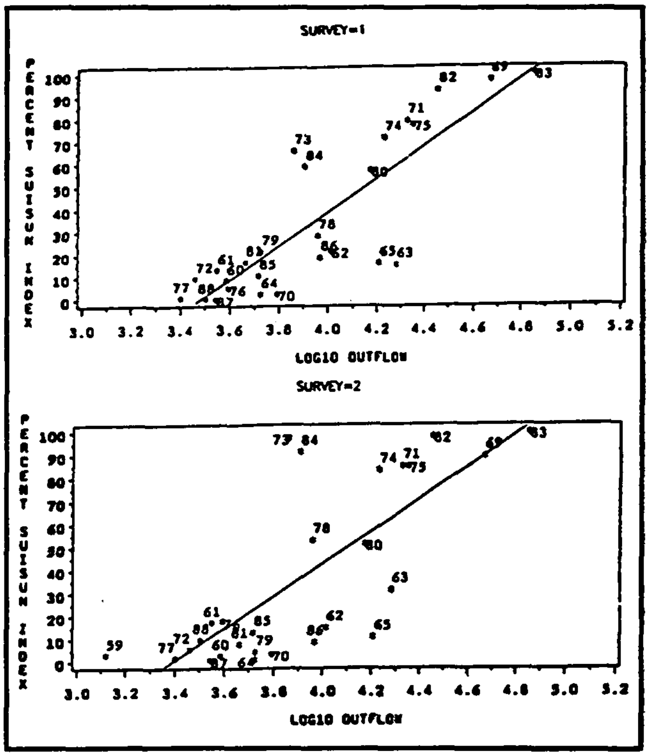


Figure 29
RELATIONSHIP BETWEEN THE PORTION OF DELTA SMELT POPULATION WEST OF THE DELTA AND
LOG DELTA OUTFLOW DURING THE SURVEY MONTH FOR SUMMER TOW-NET SURVEY, 1959 TO 1988
For arcsine transformed percentages, $r^2 = 0.74$ for survey 1 and $r^2 = 0.55$ for survey 2.
Source: Sweetnam and Stevens 1993.

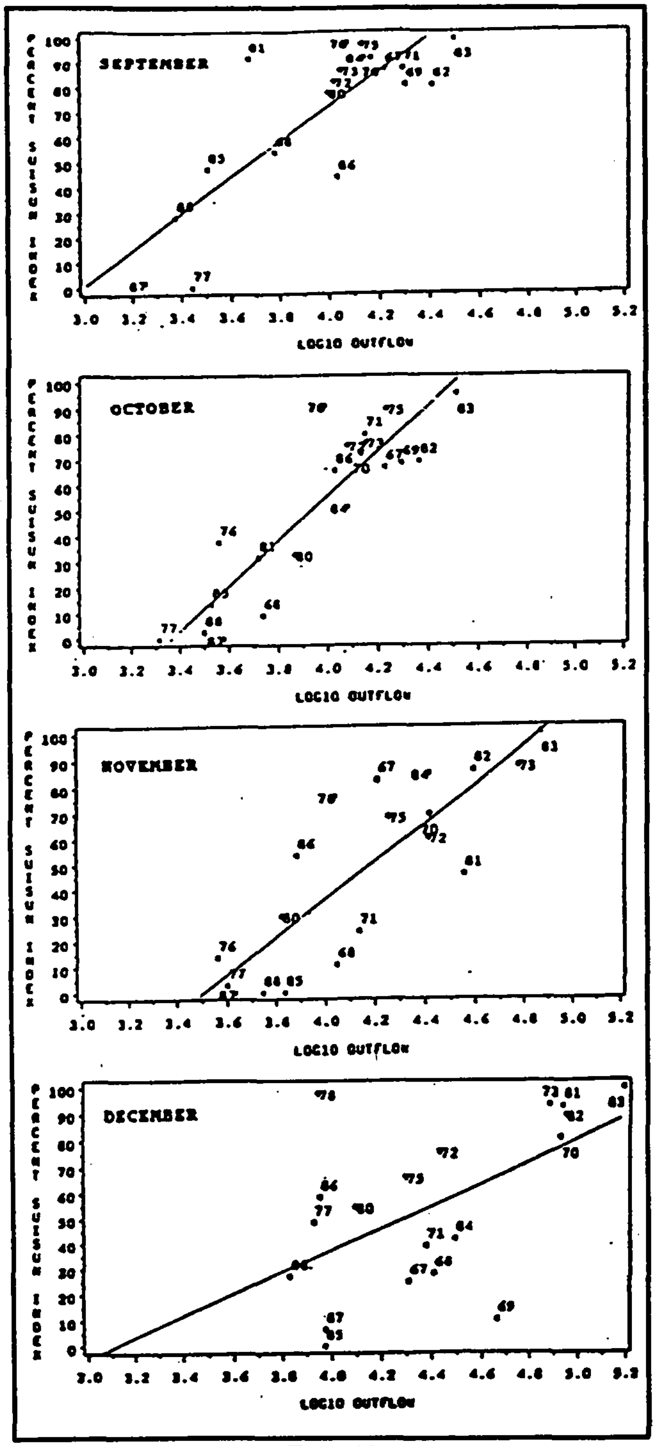


Figure 30
RELATIONSHIP BETWEEN THE PORTION OF DELTA SMELT POPULATION WEST OF THE DELTA AND LOG DELTA OUTFLOW DURING THE SURVEY MONTH FOR FALL MIDWATER TRAWL SURVEY, 1967 TO 1988
For arcsine transformed percentages, $r^2 = 0.84$ for September, 0.76 for October, 0.71 for November, and 0.34 for December.
Source: Sweetnam and Stevens 1993.

region increases directly with outflow. A similar trend is evident for the fall midwater trawl survey for September through December (Figure 30).

Entrapment Zone

The entrapment zone is a transient region of the estuary where fresh water and salt water interact to concentrate the level of suspended particulate matter. It is formed as fresh water flows downstream over the more dense, landward-flowing salt water, creating a circulation pattern that concentrates particles such as sediment and plankton. An operational definition of either 2 µS/cm surface specific conductance or 2 ppt isohaline position (X2) is frequently used as an index of entrapment zone position, even though it is not strictly equivalent to the entrapment zone (Arthur and Ball 1978, Kimmerer 1992a).

Location of the entrapment zone is regulated by the interaction of tides, Delta outflow, and the complex bathymetry of the estuary, as well as mixing by wind in shallow waters (Peterson *et al* 1975, Arthur and Ball 1978). The entrapment zone has generally been located between Honker Bay and Sherman Island, but in extreme water years it has ranged from below Suisun Bay (wet years) to above Rio Vista (critical years).

The entrapment zone provides habitat for species that reside in or nearby it. It may also serve as a food supply region for consumer species such as fish. The entrapment zone has been found to contain elevated concentrations of juvenile striped bass and some species of phytoplankton and zooplankton (Arthur and Ball 1980). Dauvin and Dodson (1990) provide evidence that rainbow smelt larvae feeding rates are higher in a similar region in the St. Lawrence estuary. It is not known if delta smelt feeding is also enhanced in this region. However, annual measures of several estuarine resources seem to be related to the position of the entrapment zone in the estuary. Jassby (1993) found statistically significant relationships between entrapment zone position and the abundance of phytoplankton and phytoplankton-derived carbon; survival of larval striped bass; and abundance of mollusks, mysids, Crangon shrimp, longfin smelt, juvenile striped bass, and starry flounder. Mechanisms for these relationships are not well understood.

Analysis of the salinity preferences using midwater trawl data indicate that delta smelt distribution peaks upstream of the entrapment zone (Obrebski 1993). It should be noted, however, that the distribution of delta smelt is fairly broad, particularly in years when abundance levels are high (DWR/USBR 1993). Evidence from the 1993 year class also demonstrates that salt field position does not necessarily regulate delta smelt distribution in all years. In late 1993 and early 1994, delta smelt were found in Suisun Bay region despite the fact that X2 was located far upstream. Samples collected in this area demonstrated that high levels of the copepod *Eurytemora* were present, suggesting that food availability may also influence smelt distribution.

Although these results show that delta smelt is not an entrapment zone specialist, there is some evidence that their abundance may be correlated with X2. Initial studies by Obrebski (1993) found that X2 position was weakly correlated with the fall midwater trawl index. However, there was evidence of autocorrelation problems with the analysis, confounding interpretation of results (DWR/USBR 1993). Autocorrelation occurs when errors in the variables being analyzed are not independent and can result in erroneously high significance levels.[1] Furthermore, significant correlations may or may not represent cause-and-effect relationships.

The likely cause of autocorrelation in the dataset is stock-recruitment effects (discussed later in this chapter under "Spawning Stock Size and Year-Class Strength"). As evidence, Kimmerer (1992b) analyzed the same database and found that X2 was not significantly related to abundance when stock-recruitment effects were removed.

Herbold (1994) used a somewhat different approach to examine the relationship between abundance and saltfield position. Figure 31 shows the number of days X2 was in Suisun Bay during February-June versus midwater trawl abundance. The relationship was reported to be significant at the $p<0.05$ level ($r^2=0.246$), which explains relatively little of the variation in abundance of delta smelt. The relationship also remains significant at a similar level when log transformation is performed to normalize the midwater trawl data.

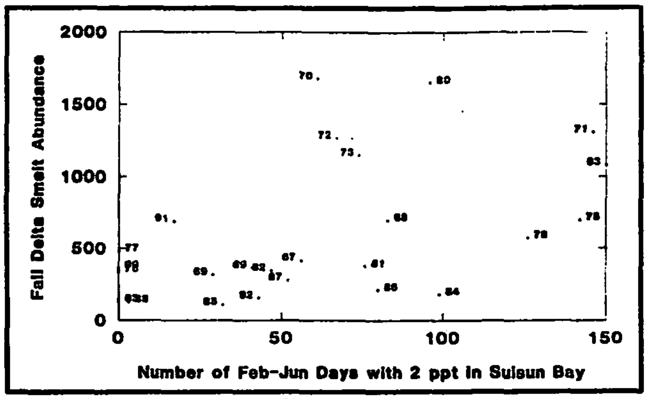


Figure 31
SPRING HABITAT EFFECTS ON DELTA SMELT RECRUITMENT

To identify the areas in Suisun Bay that contributed most to the overall relationship, Herbold (1994) calculated separate correlation coefficients for 5-km reaches of the historical range (San Pablo Bay to Rio Vista) of delta smelt. X2 was positively correlated with abundance between Carquinez and Chipps Island and negatively correlated for all other reaches (Figure 32). The reach from Roe Island to Middle Ground was the only reach for which the correlation was statistically significant ($p<0.01$). A similar analysis was performed to try to pinpoint the months of greatest sensitivity (Figure 33). Comparison of number of days when X2 was in Suisun Bay to subsequent midwater trawl abundance showed that the correlation coefficients peak in April, the only statistically significant month ($p<0.05$). Herbold (1994) noted that the analyses for individual reaches (Figure 32) and months (Figure 33) suffer from autocorrelations in time and space.

The relationship between the number of days X2 was located in Suisun Bay versus abundance was tested by Fox (1994) for autocorrelation problems similar to those described by Obrebski (1993). Four approaches were used: plots of the residuals versus time, calculation of a Durbin-Watson statistic, a Wald-Wolfowitz test on the residuals to determine if serial patterns were present, and a regression of the residuals versus a 1-year lag of the residuals. Autocorrelation was not detected in the Herbold (1994) analysis using any of the first three tests. The regression analysis indicated that if autocorrelation was present, it was very weak.

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[1] Similar autocorrelation problems may be present in other analyses in this report using abundance data.

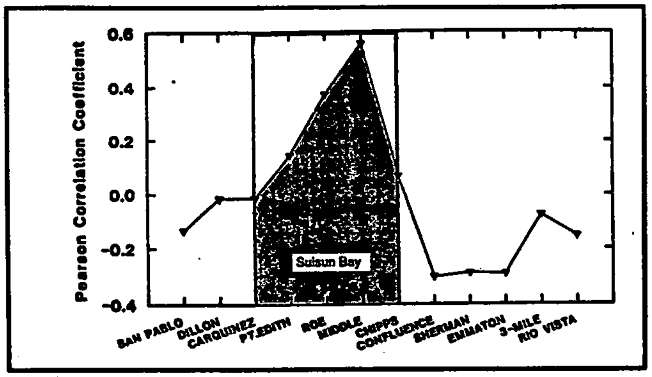

Figure 32
CORRELATIONS WITH 5-KM REACHES

Another concern is that the variance in abundance increases dramatically as X2 is located farther downstream. When this occurs, the ordinary least-squares estimation technique violates regression rules, requiring amended statistical procedures (Fox 1994). This usually involves use of weighted least squares, with weights inversely proportional to the variance (Draper and Smith 1981).

An alternative approach to at least avoid autocorrelation problems is to use grouped comparisons such as ANOVA methods. Jones and Stokes (1994) tested this technique by grouping log-transformed midwater trawl abundance data according to frequency of location of February-June X2: years with X2 frequently downstream of Suisun Bay (San Pablo Bay to Carquinez Strait), years with X2 most frequently in Suisun Bay, and years with X2 most frequently upstream of Suisun Bay. Abundance was significantly higher ($p<0.05$) when X2 was frequently in Suisun Bay than upstream or downstream. A similar analysis using log-transformed summer tow-net indices showed that abundance was significantly higher when X2 was frequently located in Suisun Bay versus areas upstream ($p<0.01$), but no differences were found between Suisun Bay and areas downstream.

A "response" analysis has also been conducted by Buell (1994b) to explore the possible relationship between delta smelt midwater trawl abundance indices and location of X2. This analysis displays the sequential "response" of the index as average February-June location of X2 changes from year to year as a line graph. If the lines connecting sequential years in the response diagram form a detectable pattern, a consistent response to the independent variable is indicated. Although Buell found consistent patterns using this analysis for other species, none emerges for delta smelt (Figure 34). The high variability in abundance when X2 is between Honker Bay and Suisun Bay is apparent, however.

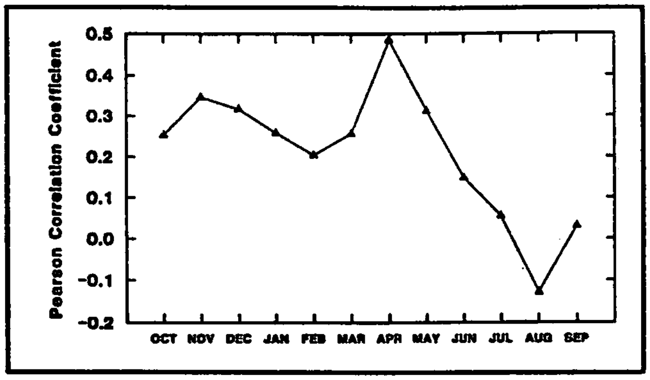

Figure 33
CORRELATIONS IN EACH MONTH

To summarize, regression relationships between X2 and delta smelt abundance are confounded by nonhomogenous variance and perhaps to some degree by autocorrelation in the data. However, simple grouped comparisons using ANOVA methods suggest that increased residence of X2 in Suisun Bay may contribute to significantly higher abundance. It must be emphasized, however, that the response of delta smelt in this region of the estuary is highly variable and the predictive ability of the relationships developed to date is limited. This suggests that location of X2 may be a "necessary but not sufficient condition" for a high abundance index, but that other factors determine whether or not that opportunity is realized. A causal mechanism for the influence of outflow on delta smelt needs to be established before management efforts are implemented.

Reverse Flow

The magnitude and direction of flow through Delta channels are determined by inflows, channel capacities, agricultural diversions, SWP and CVP pumping, and especially tides. Twice a day, high tides push Delta water upstream. The intensity of tides varies within months and seasons. Although tidal flow is most pronounced in the western Delta, it is also significant in the interior Delta. For example, flow over a tidal cycle during the summer can be hundreds of thousands of cubic feet per second in the western Delta, tens of thousands in the

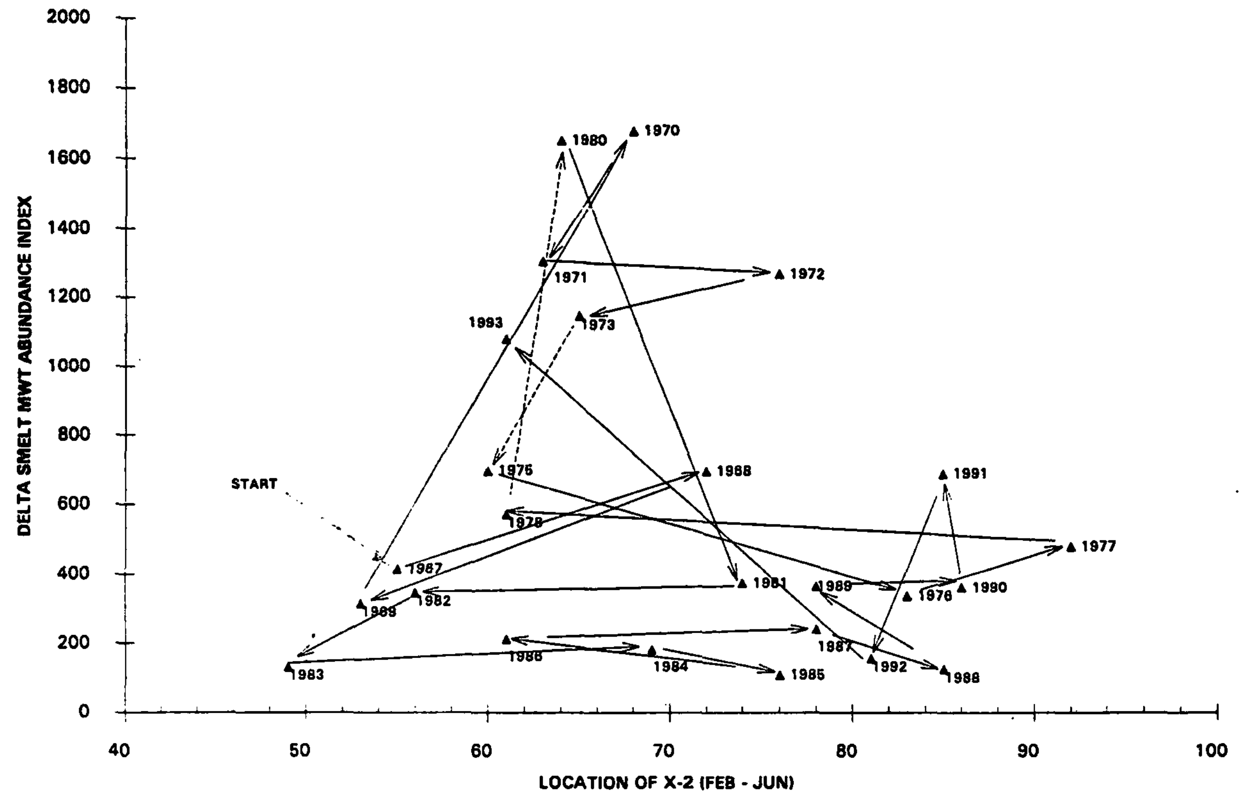

Figure 34
DELTA SMELT MIDWATER TRAWL ABUNDANCE INDEX VERSUS X2 LOCATION, 1967 TO 1993
The arrows show the direction of change. If a pattern is present, the response lines should form a trend, such as a line or curve.
Location of X2 is shown as kilometers from the Golden Gate.

central Delta, and thousands in the eastern Delta (Figure 35). If the tidal effects on flow are removed, a net flow will remain that will affect the direction and distance a water molecule, plankton, and possibly even small fish may move in the channel over an extended period if they remain suspended in the water column.

The interaction between water diversions and inflows can also affect the direction of flow in Delta channels. When inflow from upstream tributaries is insufficient to meet exports and agricultural diversions, the pumps and siphons pull water from downstream areas. This can intensify upstream tidal flow in some channels, and also cause net upstream or "reverse" flows where they would not otherwise occur. Net reverse flows are most common and greatest in the southern and western Delta during summer and fall, when nearly all the CVP and SWP exports are drawn across the Delta from the Sacramento River (Figure 35). However, reverse flow can occur any time southern Delta diversions are higher than San Joaquin inflow.

Because flow in the western Delta is usually dominated by tidal flow, net flow is difficult to measure directly. As a consequence, nearly all analyses of the effect of net reverse flow on fishery resources have used a calculated value called QWEST as an index of net reverse flow in the lower San Joaquin River. QWEST is reported in the DWR DAYFLOW database, and is the sum of flows from the San Joaquin River, the eastside streams, and the Sacramento River through Georgiana Slough and the Delta Cross Channel, minus CVP and SWP exports from the southern Delta and 65% of net channel depletions in the Delta. Average monthly QWEST values for 1978 to 1992 are shown in Figure 36.

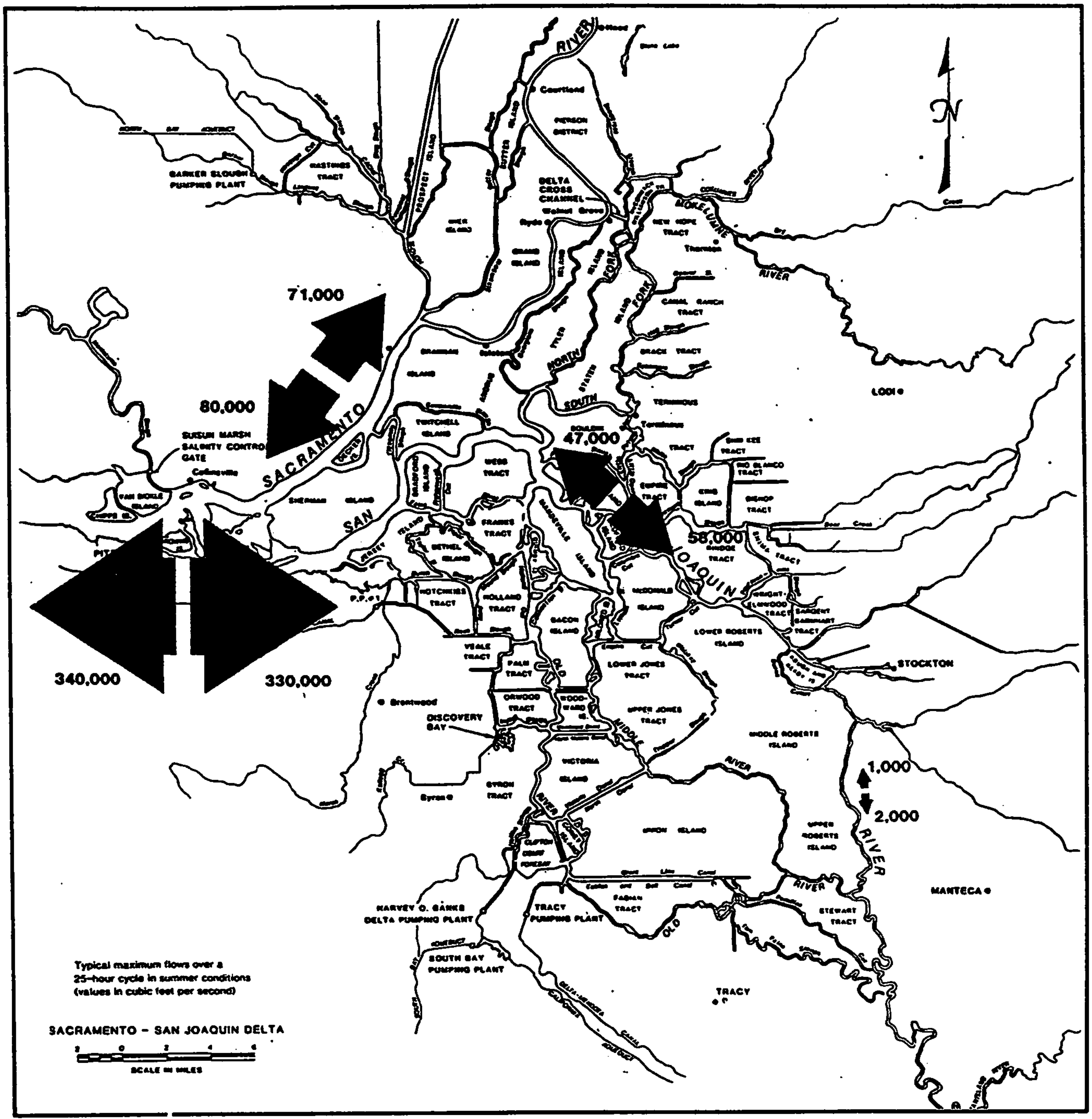

Figure 35
TIDAL FLOWS IN THE SACRAMENTO-SAN JOAQUIN DELTA

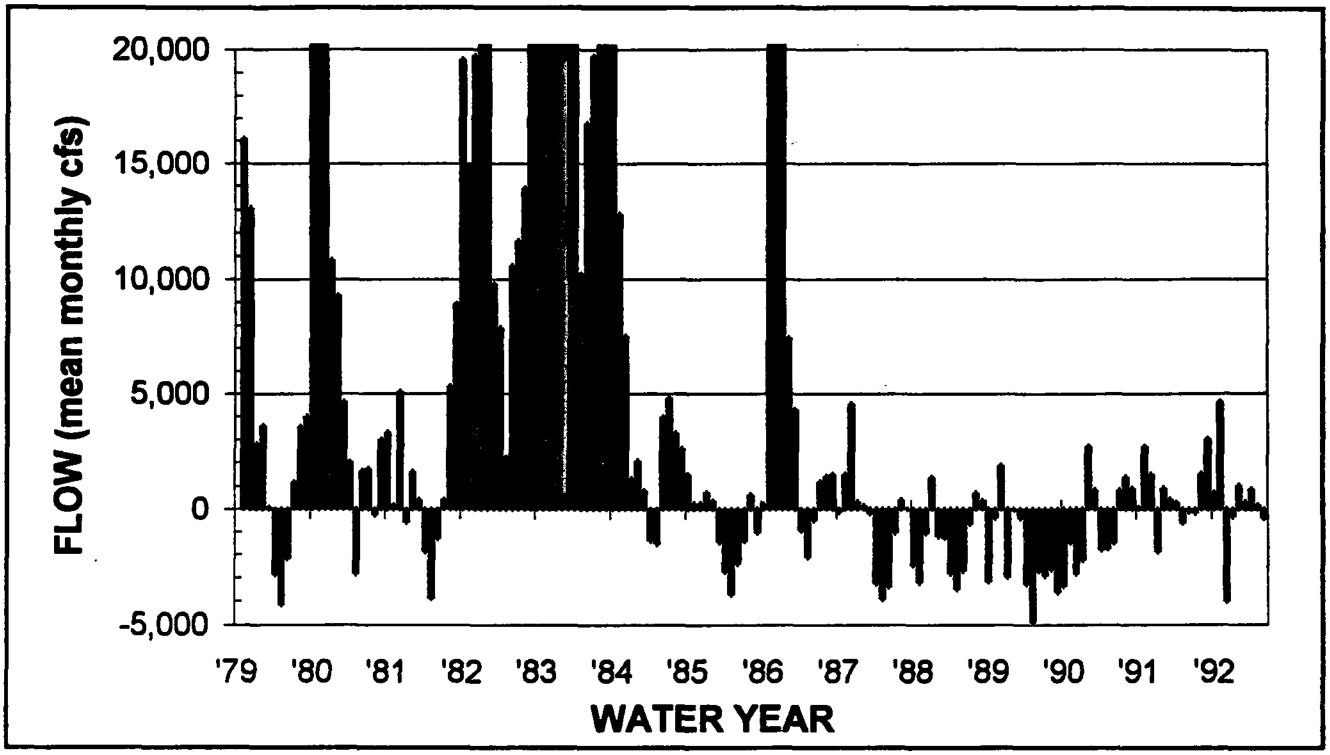

Figure 36
AVERAGE FLOW PAST JERSEY POINT (QWEST), WATER YEARS 1978 TO 1992
From the DAYFLOW Database

Effect of Reverse Flow on Delta Smelt Abundance

The effect of net reverse flow on movement of fish and their food supply has been a concern since construction of the CVP and SWP in the 1950s and 1960s.

There is some evidence that net reverse flow might be a factor for juvenile striped bass and salmon smolts. Wendt (1987) found a weak inverse relationship between QWEST and the number of young striped bass salvaged at Banks Pumping Plant in June and July. The Fish and Wildlife Service (1992) also reported a weak relationship between QWEST and survival of salmon smolts and suggested the relationship could be partly due to increased entrainment of smolts with reverse flow. However, validity of the latter relationship has been questioned because a narrow range of flows was analyzed and calculated flows did not take tidal effects into account (Brown and Greene 1992).

Several analyses of delta smelt data did not indicate any apparent relationship between QWEST and smelt abundance indices or entrainment at CVP or SWP facilities. The Department of Fish and Game used multiple regression analyses to examine reverse flow and several other factors that could affect delta smelt abundance (Stevens *et al* 1990). The number of days that QWEST was negative was used as the measure of reverse flow in the lower San Joaquin River. QWEST was analyzed individually and in combination with other environmental variables to identify potential effects on the summer tow-net index (March-June variables) and fall midwater trawl index (March-June, July-October variables). None of the analyses that included reverse flow as a variable explained a significant amount of variability in smelt abundance.

Moyle and Herbold (1989) indicated that low delta smelt abundance indices (fall midwater trawl data) were associated with the number of days of negative values of QWEST. However, their analysis found no statistical association between delta smelt abundance and the number of days of reverse flows. Nevertheless, they observed that years of high smelt abundance usually had positive flow in the lower San Joaquin River and years of low smelt abundance usually had a higher number of days of reverse flows. They concluded, therefore, that the frequency of reverse flow in the lower San Joaquin River was probably limiting smelt recruitment but that it was not a simple direct relationship. Furthermore, results of statistical analyses between reverse flows and smelt abundance are confounded by both the inability to measure reverse flows and autocorrelations with other environmental variables.

Moyle *et al* (1992) found that until 1984, water years[1] with 100 days of reverse flow were sporadic and rarely occurred during the delta smelt spawning season (February-May). From 1985 to 1989, reverse flows have characterized the lower San Joaquin River for more than 150 days of the year, and in every year except 1986, reverse flows have occurred for 15 to 85 days of the spawning season. An updated version of this analysis indicates that from 1990 to 1992 reverse flows continued during the delta smelt spawning season (Figure 37).

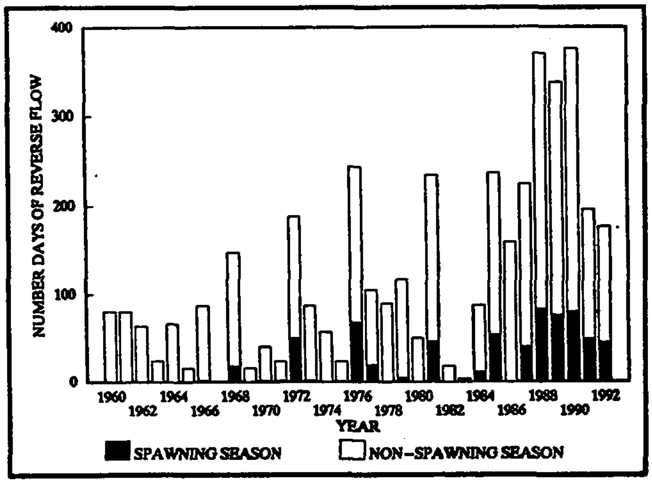

Figure 37
NUMBER OF DAYS OF REVERSE FLOW IN THE SAN JOAQUIN RIVER DURING WATER YEARS 1960 TO 1992
The black portion of each bar shows the number of days during the delta smelt spawning season (February-May).

Water Resources could not find a statistical relationship between the number of days of reverse flow and the delta smelt midwater trawl index (1967-1992) or tow-net index (1959-1993). Regression analysis did not show a significant association between the annual occurrence of reverse flow and the midwater trawl index (r^2=0.12; n=24) or the tow-net index (r^2=0.021; n=31). The association was also not significant between reverse flow during the major spawning period (February-May) and the midwater trawl index (r^2=0.12; n=24) or the tow-net index (r^2=0.037; n=32).

These relationships were also examined using Spearman's rank correlation test. No significant correlation was found between annual occurrence of reverse flow and the midwater trawl index (r=–0.29; n=24) or the tow-net index (r=–0.19; n=31). Also, no significant correlation was found between reverse flow during the February-May spawning season and the midwater trawl index (r=–0.31; n=24) or the tow-net index (r=–0.33; n=32).

Visual observation of the influence of water year type (critical, dry, below normal, above normal, wet) on delta smelt abundance indices suggests that index values may be lower in dryer years than in about half the wetter years (Figures 38 and 39). However, Spearman's rank correlation test showed no significant correlation between water year type and either the midwater trawl index (r=0.32; n=24) or the tow-net index (r=0.16; n=32). In addition, a comparison of indices grouped as dry or wet years found no significant difference between the midwater trawl index (Mann-Whitney U; p=0.12, n=12) or the tow-net index (Mann-Whitney U; p=0.47) of dryer years and those of wetter years.

QWEST and Fish Transport

QWEST is being used as a regulatory parameter to limit movement of winter-run Chinook salmon and delta smelt toward the CVP and SWP pumps[2]. Use of QWEST is partly driven by the perception that transport of small fish is largely dictated by QWEST.

Moyle *et al* (1992) propose that reverse flows draw young fish to the export pumps from spawning

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[1] A water year begins October 1 and ends the following September 30.

[2] Discussed in Chapter 2.

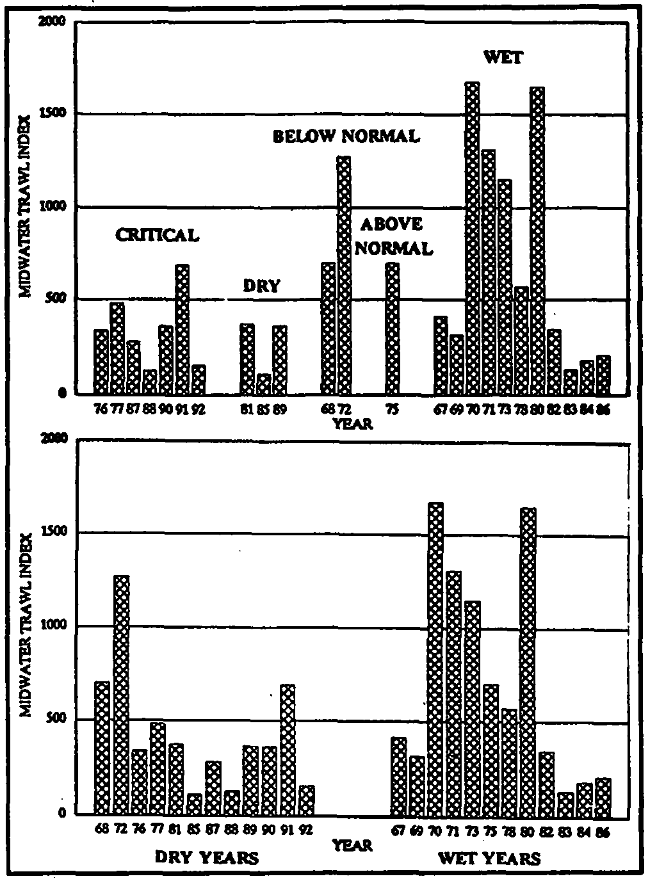

Figure 38
DELTA SMELT FALL MIDWATER TRAWL INDICES
GROUPED BY WATER YEAR TYPES

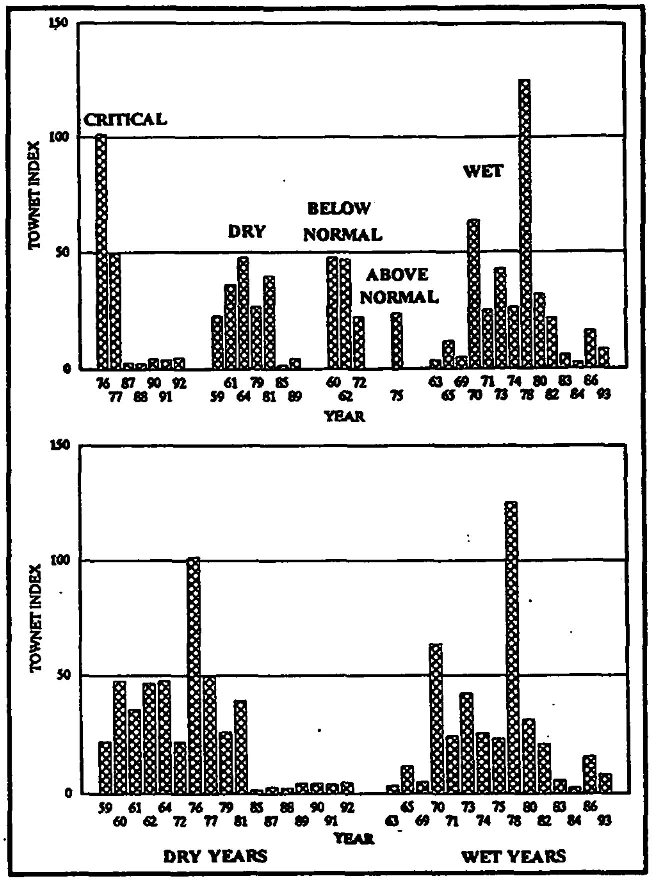

Figure 39
DELTA SMELT SUMMER TOW-NET INDICES
GROUPED BY WATER YEAR TYPES

and nursery areas in the central and western Delta. DWR egg and larval surveys suggest that at least some smelt larvae are transported into the southern Delta past stations on Old River and North Victoria Canal (Spaar 1993a).

Because of its possible importance, this issue was examined in further detail using simulation models. As will be shown, QWEST does not appear to be an appropriate parameter to control transport and entrainment of young fish in the Delta.

Water Resources recently examined the importance of reverse flow as a transport mechanism using the DWR Particle Tracking Model (Chung and Smith 1993). The model was developed to simulate how different flows are likely to affect the movement of neutrally buoyant particles at various locations in the Delta. The major processes simulated in the model under different flow conditions are advection, dispersion, and channel braiding.

The Particle Tracking Model used hydrology from the DWR statewide water simulation model, DWRSIM (Chapter 9), to develop general operations criteria. For this analysis, Decision 1485 standards and 1995 hydrology were used with three levels of QWEST: 1,865, 146, and –1,724 cfs. Delta outflow was held constant at 5,485 cfs throughout the simulation. Flow and velocity patterns were simulated using the DWR/RMA Delta Hydrodynamics Model (DWR 1992c). The fate of particles introduced at 19 locations was then examined using the Particle Tracking Model.

The results should be interpreted with caution, because delta smelt are not neutrally buoyant particles. Indeed, recent studies by Laprise and Dodson (1989) indicate that a related species, rainbow smelt (*Osmerus mordax*), do not behave like passive particles and show vertical movement in the water column due to active migration. Larval fish maintained their position in the estuary near the surface during flood tides and near the bottom during ebbs. Differences were also observed in the distribution of larvae of different ages. The biological and management implications of the behavior if found true for delta smelt are unclear. Nonetheless, the model provides an indication of the general processes likely to affect young fish. Results of a preliminary set of model simulations are summarized below. Additional studies are needed under a variety of conditions.

- High Sacramento River flows greatly affected average daily velocity in the northern Delta but had little effect on average velocity in the western Delta. As a result, the effect of high flows on the transport process diminishes rapidly as the flow approaches the western Delta.
- Particles in the interior of the Delta were entrained by CVP and SWP pumps and agricultural diversions despite high positive QWEST values. This suggests that QWEST is not a good indicator of entrainment losses in the interior delta. It is conceivable that the export pumps have a "zone of influence", and a large percentage of particles within it are likely to be entrained regardless of QWEST. Further model studies are being designed to characterize the likely zone of influence at different tributary inflows, export pumping, Delta Cross Channel gate operations, Clifton Court Forebay gate operations, and consumptive uses.
- Particles in areas west of Antioch were not greatly affected by negative QWEST (–1,724 cfs). This further shows that QWEST is not a good indicator of transport processes in the western Delta. However, additional studies are needed to examine the effects of different conditions.

Diversion and Entrainment

All life stages of delta smelt are vulnerable to entrainment in water diversions of the CVP, SWP, PG&E power generating plants, agricultural diversions, and industrial diversions near Suisun Bay and the Delta.

The discussion that follows addresses some of the variables that may explain entrainment. A better understanding of how entrainment of all life stages is influenced by operations, by outflow, and by other factors is essential to formulation of reasonable and prudent alternatives.

Conclusions about salvage of eggs, larvae, and juveniles are confounded by the difficulty in distinguishing between delta smelt, pond smelt, and longfin smelt until they reach a total length of greater than 30 mm (J. Wang, pers comm). The discussion of take of early life stages should, therefore, be viewed with caution. This is particularly a concern because take of juveniles is a major component of the salvage estimates for both the CVP and SWP, most take occurring from April through August and consisting of juveniles.

Central Valley Project

CVP facilities in the Delta include Tracy Pumping Plant, Contra Costa Canal, and the Delta Cross Channel. These facilities are described in Chapter 2, and their possible effects on delta smelt are reviewed below.

Tracy Pumping Plant

The most apparent effect of the CVP is entrainment of fish at Tracy Pumping Plant. Delta smelt are eaten by predatory fish in front of and within the Tracy Fish Facility. Others are lost as they pass through the screens and during handling and trucking in the salvage process. Losses of juvenile and adult delta smelt at the fish facility cannot be calculated with certainty, because there is no information for delta smelt pre-screening losses (predation rates) or on efficiency of the louver screens for delta smelt (Sweetnam and Stevens 1993). Estimates of annual delta smelt salvage and concerns related to the salvage data are presented in Chapter 4.

Several studies suggest survival of salvaged delta smelt is probably low due to the stress of handling and trucking. There was no survival of 2,590 delta smelt salvaged from June 22 to July 27, 1989, and held at the SWP Byron growout facility (Odenweller 1990). There was no indication of how long these smelt were held before they died. Initial field collections of brood stock to develop culture methods for delta smelt found most died within 48 hours using various netting techniques (Lindberg 1992). A modified purse seine technique was finally successful, with 88% survival in March 1992 and 10-47% survival in mid-April 1992.

Handling and transport mortality can be reduced by cooling and reducing the sloshing of water during transport (Mager 1993). Stress-related handling and trucking mortality can also be reduced by adding salt to transport water. A solution of 8 ppt reduces stress without causing problems for salt-intolerant species such as delta smelt (Mager and Cech, unpubl data). Until their response to stress is better understood and better handling methods are devised, losses can be expected to be high for smelt entering the CVP and SWP systems, and complete loss is a possibility.

Although exact levels of delta smelt losses are not known, salvage and larval data do indicate the timing and relative magnitude of project impacts. Evidence from Tracy Fish Facility and from larval surveys are summarized below.

Juveniles and Adults

Salvage data (monthly averages) indicate entrainment of juvenile and adult delta smelt is usually greatest in spring and summer, reflecting the late winter-spring spawning season and growth and mortality of young-of-the-year fish (Sweetnam and Stevens 1993) (Figure 40).

May through August appears to be a period of high salvage at the CVP, with a peak in May. Juveniles are usually collected from late February to August and adults from December through April (Figure 41). The near-ripe condition of adults collected from late December 1990 to April 1991 indicates they were salvaged during spawning migration (Wang 1991). In 1993, juvenile delta smelt were salvaged at the CVP in mid-May and again in late May through early July.

Between 1979 and 1994, salvage in spring and summer was lowest in 1983, 1986, and 1993 (all wet years) and 1991 and 1992 (both critical years). Annual salvage was highest in 1979, 1981, 1987, and 1994 (all drought years) and 1984 (wet year).

One factor that may influence the magnitude of entrainment among years of delta smelt is year-class strength. In years when delta smelt are more abundant in the system, entrainment losses could increase. One approach to examine this issue is to develop an index that incorporates year-class strength. To achieve this end, salvage data for each cohort were divided by the summer tow-net index. As will be described in detail for the SWP, two cohorts are present in the salvage data in late winter and spring. Year classes can be separated in salvage data using the assumption that during March through May, all individuals smaller than 50 mm are juveniles. As an example of how the salvage data were corrected for year-class strength, in June 1984 the summer tow-net index was 1.3 and 5,866 juvenile delta smelt were salvaged (1984 cohort), so the resulting index was 5,866/1.3 = 4,512.

In this discussion, the index is referred to as "entrainment index" rather than "salvage index" to avoid confusion with actual salvage numbers. The

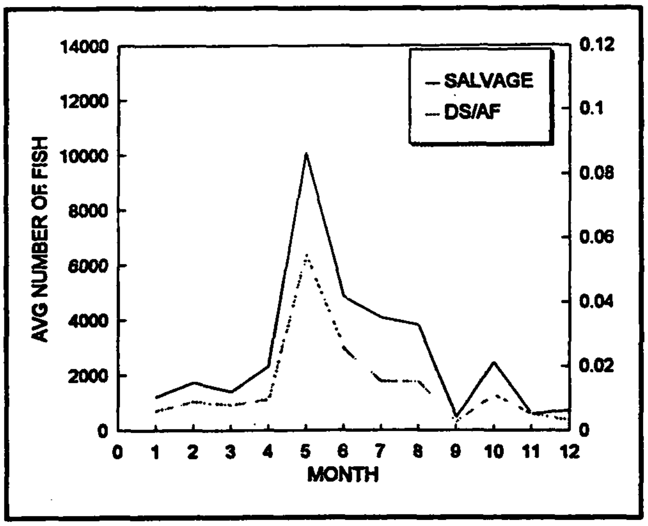

Figure 40
MONTHLY AVERAGE ESTIMATED DELTA SMELT SALVAGED AND SMELT SALVAGED PER ACRE-FOOT EXPORTED BY THE CVP TRACY PUMPING PLANT, 1979 TO 1993

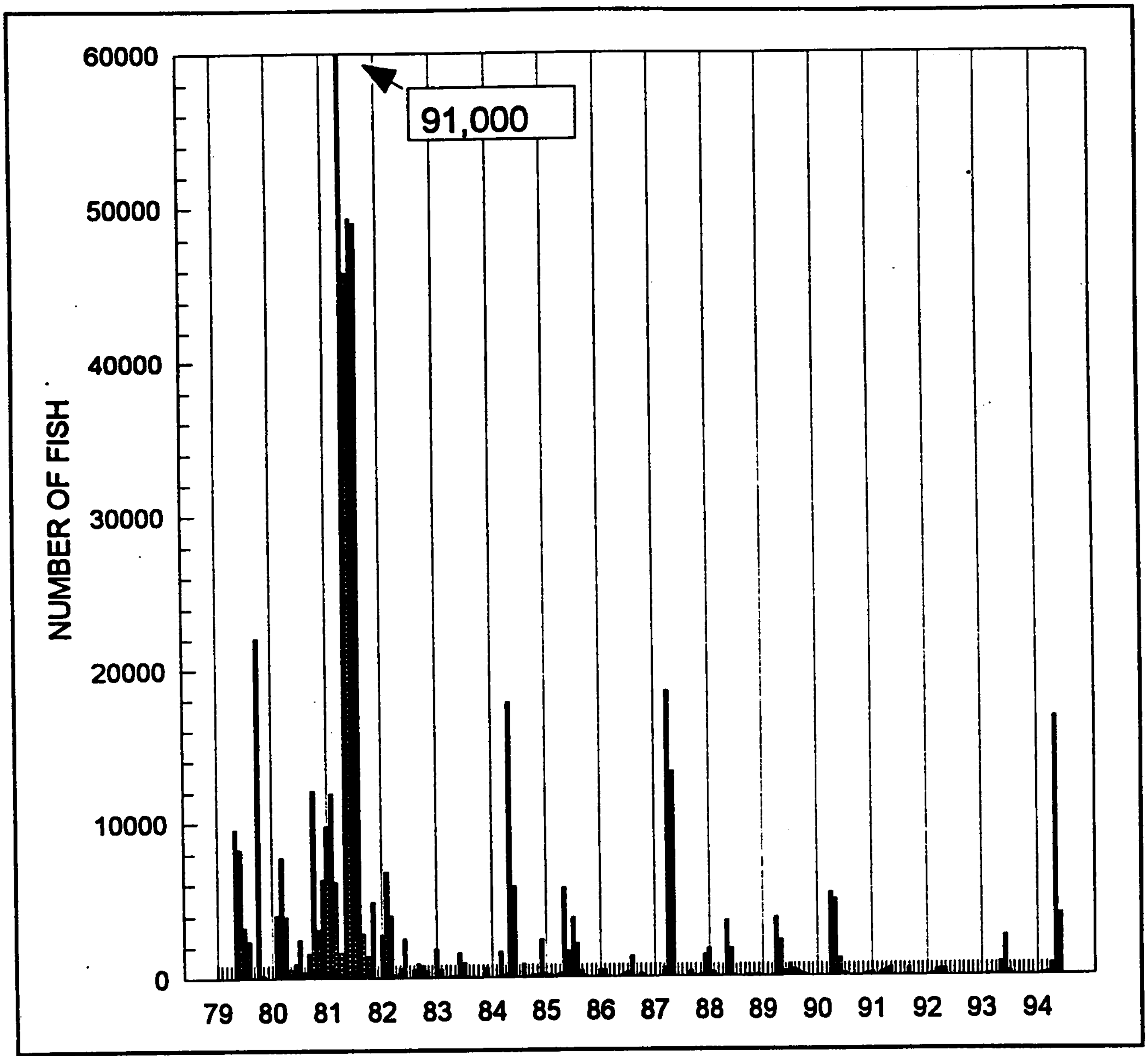

Figure 41
EXPANDED NUMBER OF DELTA SMELT SALVAGED MONTHLY AT TRACY FISH FACILITY, 1979 TO 1994

concept is similar to the loss rate index Fish and Game developed for striped bass (Kohlhorst *et al* 1993). However, the loss rate index is based on calculated losses of striped bass, and the entrainment index for delta smelt uses salvage as an index of losses. By incorporating year-class strength, both indices provide a relative measure of when impacts are likely to be greatest at the population level. For example, losses are likely to be more detrimental to the population when elevated losses coincide with a weak year-class. A possible bias with these indices is that the summer tow-net index may not completely represent year-class strength because it may partly reflect some entrainment losses in the previous spring. The entrainment index also does not take into account seasonal changes in predation and screening efficiency, which could result in variation in salvage levels. Without this information, actual losses and entrainment levels cannot be determined.

Entrainment indices from 1980 through early 1994 are presented in Figure 42. Indices were low in most wet years (1980, 1982, 1983, 1986, 1993) and high in most drought years (1981, 1985, 1987-1990). This observation was tested statistically by summing the indices for the period of peak salvage (March-August), then grouping the annual indices into "dry" (below normal-critical) and "wet" (wet-above normal) years. A t-test using log-transformed data through 1993 confirmed that "wet" years had lower entrainment indices ($p<0.05$), but the differences were not significant using nonparametric methods (Mann-Whitney U-test, $p>0.05$).

The high index in 1984 is the major exception to the observation that entrainment is low in wet years. It appears that indices may have been elevated in 1984 as a result of unusual outflow patterns. Peak outflow (>50,000 cfs) occurred from November to January, followed by variable flow in February and March. Outflow dropped to much lower levels (<20,000 cfs) by April. By contrast, outflow was generally well above 20,000 cfs during April in all other wet years since 1980. Since spawning generally peaks during April and May, the year may have been functionally "dry" for delta smelt.

The low indices in 1991, 1992, and 1994, all critical years, are the major exception to higher entrainment in dry years. A possible explanation for 1991 and 1992 is that delta smelt may have spawned early and coincidentally with major flow events. In both years there were at least three outflow events greater than 25,000 cfs in February and March. These pulse flows may have been sufficient to transport young delta smelt beyond the "zone of influence" of the pumps. As discussed earlier in this chapter, a large number of delta smelt remain downstream in the Suisun Bay region despite high salinity in later, drier months. Although other dry years (1981, 1987, 1989) had comparable pulses in February and March, outflow may have been poorly synchronized with delta smelt spawning. The lower indices in 1994 may have been a result of operating the project according to the 1994 biological opinion. Reduced exports to comply with take limits likely played a major role. Also, the relative effects of entrainment may have moderated by the presence of a strong year class in the system. An alternative explanation for all three years is that entrainment may have occurred when smelt were too small to be effectively screened.

Larvae

Information on CVP entrainment of delta smelt larvae is available from the DWR Egg and Larval Entrainment Study for 1989 to 1993. Larval smelt entrainment was estimated beginning in 1989, when positive identification of all sizes of larval delta smelt became possible. Seven sites are sampled in the southern Delta (Sites 91-96, 98) and five sites were added in the central Delta in 1992 (Sites 930-934) (Figure 43).

In general, delta smelt larvae may be present in the southern Delta from late February through early June, but occurrence may vary within this period from year to year. There is apparently little spawning in this area. Fewer smelt are caught here and over a shorter seasonal distribution compared to areas of high abundance on the Sacramento and San Joaquin rivers. In 1992, no smelt larvae were caught at the southern Delta sites after April 12; at the central Delta sites, larvae were caught until June 7 (Spaar 1993a). Smelt larvae may have been present in the southern Delta during periods in April (18-26) and May (12-24) when bridge repairs rendered this area inaccessible to the survey boat. Sampling continued in both the southern and central Delta into July. The average catch per unit effort of delta smelt larvae at the central Delta sites exceeded the southern Delta catch every month (Figure 44).

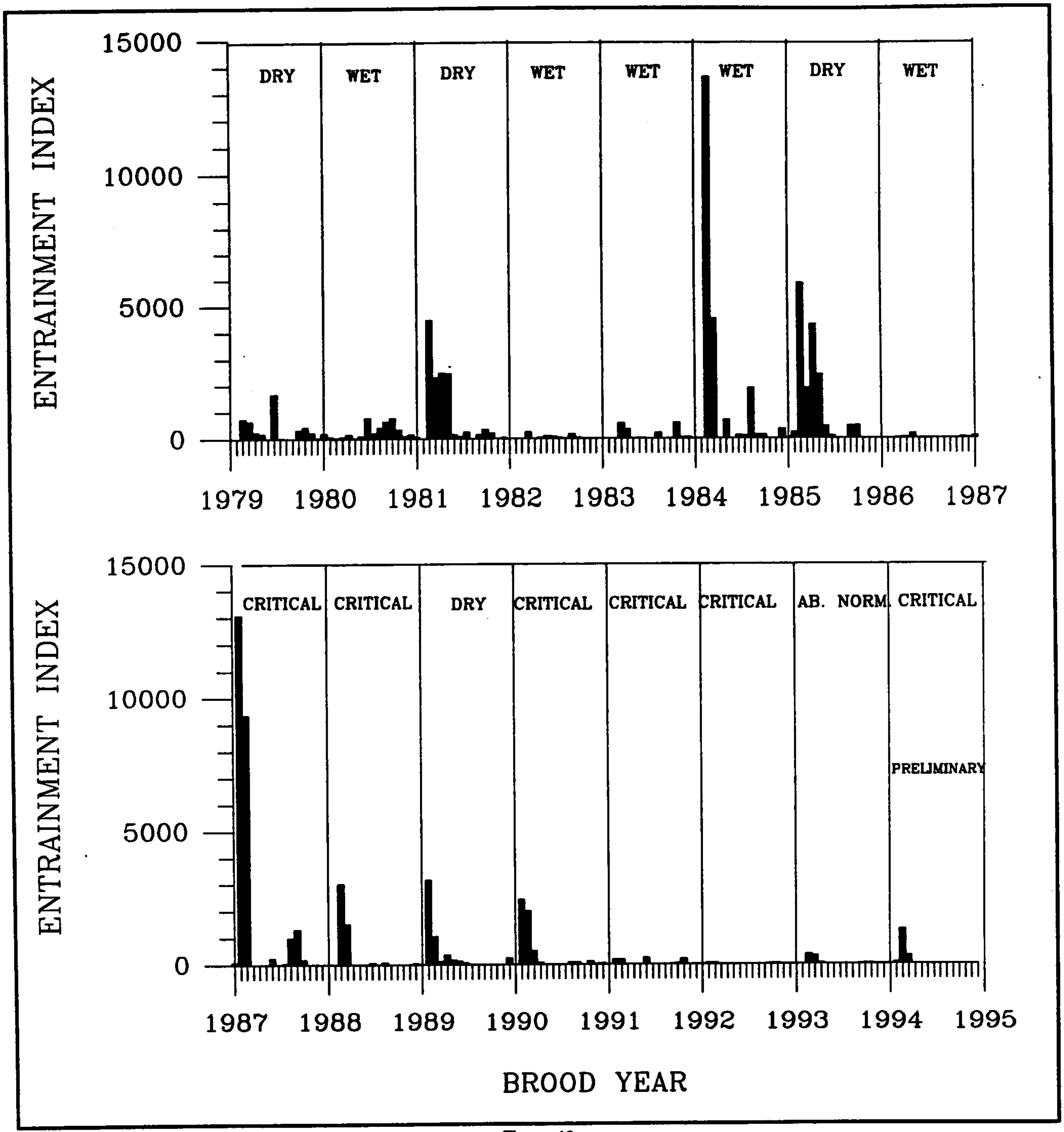

Figure 42

DELTA SMELT ENTRAINMENT INDICES AT TRACY FISH FACILITY FOR 1980-1994 BROOD YEARS

(Representing Salvage from March through May of the Following Year)

Water year types (from Decision 1485) represent the hydrology when the brood year was set.

Similarly, delta smelt larvae were collected near the SWP intake on March 27 and near the CVP intake on April 8, 1993. They were collected at other southern Delta sites (91, 95) between March 31 and April 6. No delta smelt were collected after April 8 in the southern Delta before or after the April 12 through May 20 sampling gap. In comparison, they were collected at central Delta sites (930-934) from March 2 through June 9.

Entrainment estimates for delta smelt larvae (less than 21-mm long) for the CVP and SWP indicate the projects entrain about the same magnitude of larvae (Figure 45, Table 2). The SWP entrained about one-third more than the CVP during 1989 to 1993. This is probably because the SWP intake is closer to the central Delta and because the CVP takes more San Joaquin water from upstream through Old River. Reverse flows in Old and Middle rivers may transport larvae to the southern Delta, but larvae are less abundant in the southern Delta than in the San Joaquin River and central Delta.

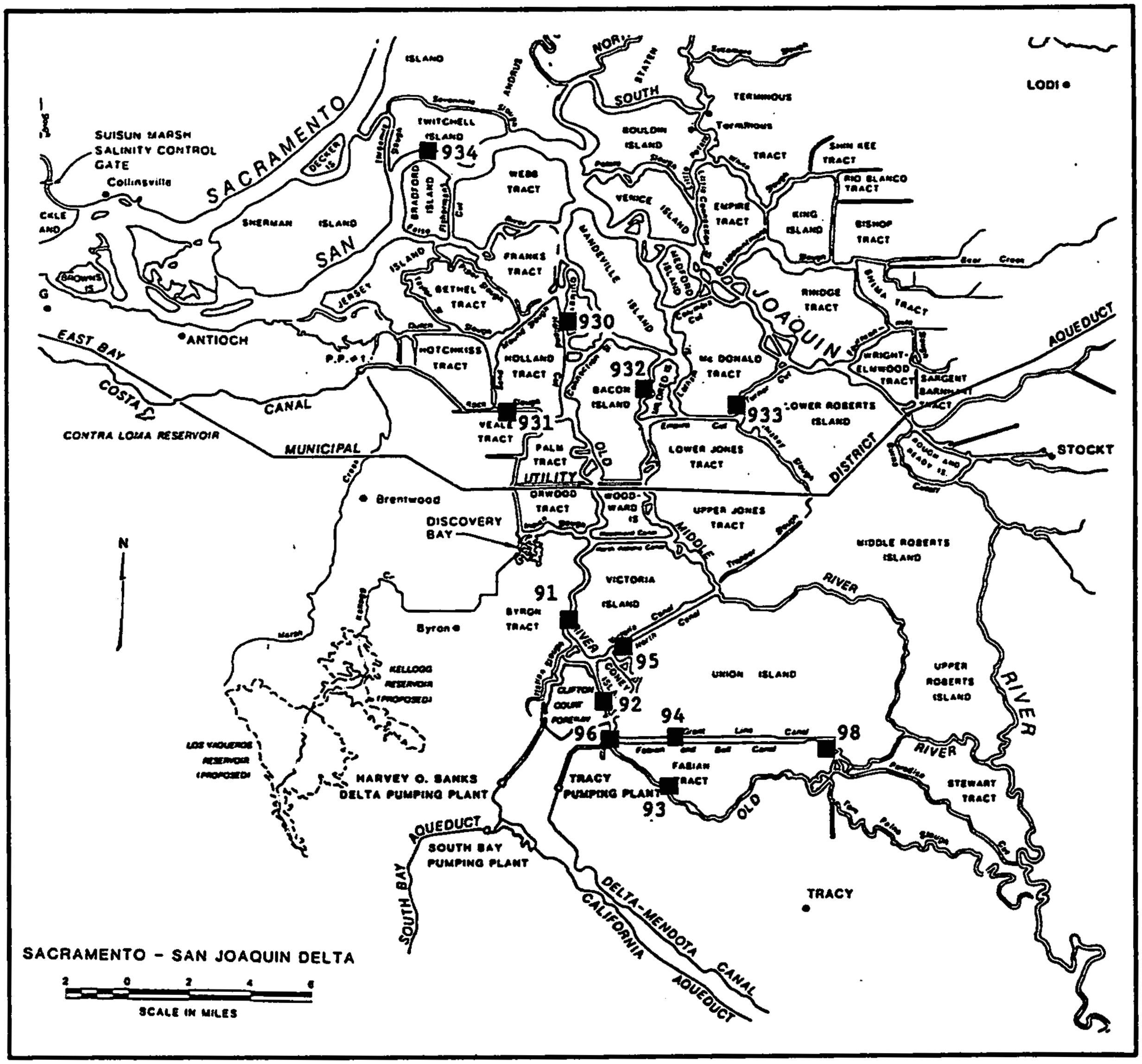

Figure 43

DELTA EGG AND LARVAL ENTRAINMENT STUDY SITES IN THE SOUTHERN DELTA AND AGRICULTURAL DIVERSION STUDY EGG AND LARVAL SITES IN THE CENTRAL DELTA

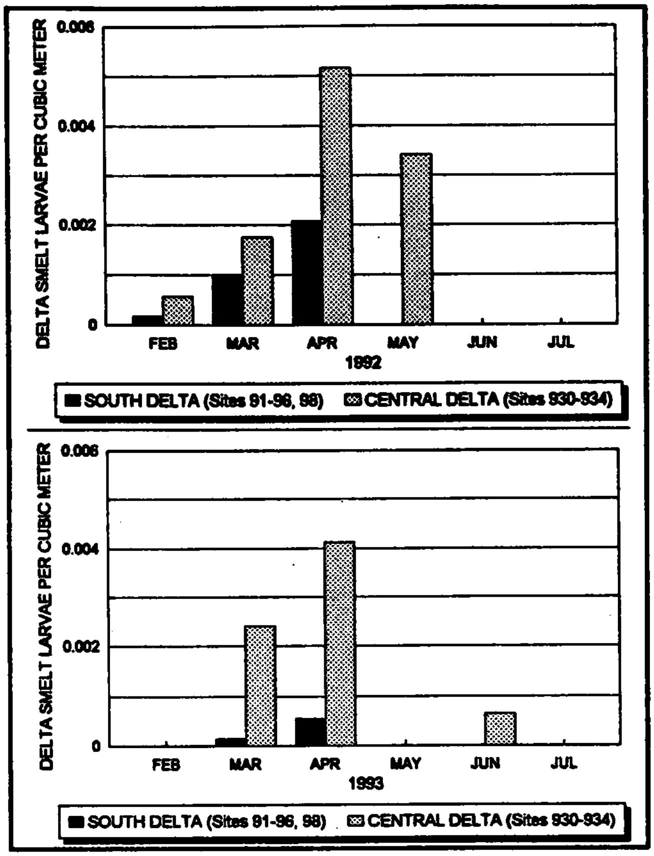

Figure 44
AVERAGE MONTHLY CATCH DENSITIES PER TOW OF DELTA SMELT LARVAE AT SOUTHERN AND CENTRAL DELTA EGG AND LARVAL SAMPLING SITES, 1992 AND 1993
(In Larvae per Cubic Meter)
For Sites 932-934, sampling began on April 6, 1992.

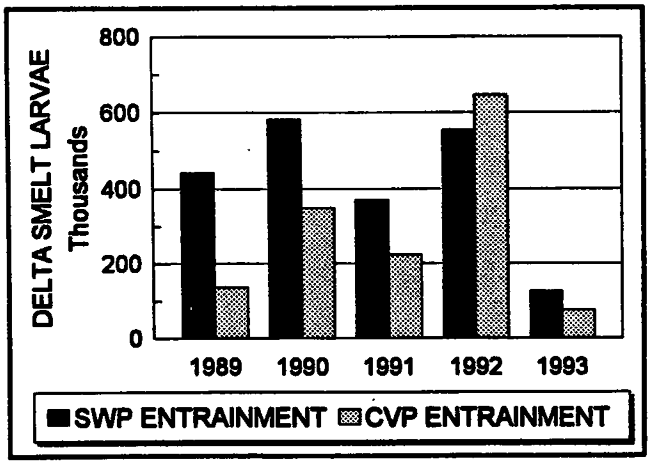

Figure 45
ESTIMATED ENTRAINMENT OF DELTA SMELT LARVAE AT THE STATE WATER PROJECT AND CENTRAL VALLEY PROJECT DELTA FACILITIES, 1989 TO 1993
1991 includes estimated entrainment for April 26 to May 26 as the mean 1989 and 1990 entrainment for the same period.
1992 — April 12-May 20 sampling gap.

Table 2
ESTIMATED ENTRAINMENT OF DELTA SMELT LARVAE, 1989 TO 1993
(In Thousands of Fish)

Year	SWP	CVP	Total
1989	443	136	579
1990	582	349	931
1991*	24	17	41
1992	554	645	1,199
1993	126	75	201
Total	1,729	1,222	2,951

* No sampling from April 16 to May 26, 1991, and April 12 to May 20, 1993, due to boat breakdown.

Contra Costa Canal

The Contra Costa Canal, owned by the Bureau of Reclamation and operated by Contra Costa Water District, is an unscreened intake at Rock Slough. The canal draws 50 to 250 cubic feet of water per second from Rock Slough. Contra Costa Canal and its operations are addressed in the September 9, 1993 biological opinion (FWS 1993a). Larval losses would be expected whether the intake were screened or not.

The Department of Fish and Game began the Contra Costa Canal intake entrainment study in January 1994. This year-round monitoring effort will be conducted every 2 days in February to May, every 4 days in June/July and December/January, and once a week in August/September. A sieve-net is used behind Pumping Plant 1 to monitor juveniles and adult fish. A plankton net is used for eggs and larvae. From January 28 to June 17, 1994, two delta smelt were collected in the sieve net during overnight sampling on March 23-24 and June 14-15. Loss estimates are not yet available for juveniles or adults.

DWR egg and larval monitoring, which began in Rock Slough in 1992, caught larval smelt on only three days between February 20 and July 15 (Spaar 1993a). Catch densities were:

March 3	0.0082 larvae/m^3
March 11	0.0051 larvae/m^3
April 8	0.0070 larvae/m^3

Data for the same period in 1993[1] indicate a total of six larval smelt were collected on five occasions. Catch densities were:

March 2	0.0038 larvae/m^3
March 19	0.0037 larvae/m^3
March 23	0.0047 larvae/m^3
March 31	0.0037 larvae/m^3
April 6	0.0068 larvae/m^3

Entrainment was estimated to be about 7,300 delta smelt larvae for 1992 and 13,000 for 1993. Entrainment was estimated using the same methodology as for the CVP and SWP intakes (Spaar 1988). A discussion of how larval entrainment is estimated is included in the North Bay Aqueduct portion of this section.

Monthly entrainment densities of delta smelt larvae per acre-foot at the Contra Costa Canal were estimated from densities measured in Rock Slough and compared with monthly entrainment at the SWP and CVP for 1992 and at the SWP, CVP, and North Bay Aqueduct for 1993 (Figure 46). The 1994 entrainment is not yet estimated. For 1992, delta smelt larvae were entrained in March at 7.91 larvae/acre-foot and in April at 8.68 larvae/acre-foot. These estimates may not be representative of actual entrainment because of the location of the sampling sites from the actual intakes and the tidal influences at these sites. Entrainment density was higher than at the SWP and CVP in March, but lower than at these sites in April. For 1993, delta smelt larvae were entrained in March at 4.89 larvae/acre-foot and in April at 6.36 larvae/acre-foot. No larval entrainment was estimated to have occurred in February or May-July, 1992 and 1993. However, no sampling occurred from April 12 to May 20, 1993, due to equipment failure. Entrainment density was very similar at Rock Slough, the North Bay Aqueduct, and the SWP in March but was higher at Rock Slough than at the other sites in April.

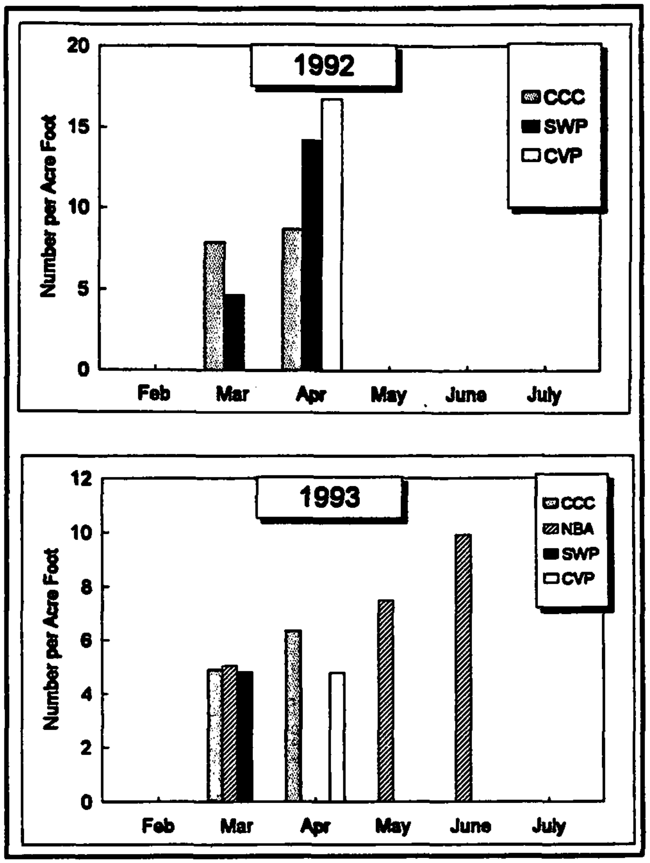

Figure 46
CALCULATED NUMBER OF DELTA SMELT ENTRAINED PER ACRE-FOOT FOR CONTRA COSTA CANAL (ROCK SLOUGH), NORTH BAY AQUEDUCT (BARKER SLOUGH), STATE WATER PROJECT, AND CENTRAL VALLEY PROJECT

Delta Cross Channel

The CVP Delta Cross Channel has two 60-foot gates at the Sacramento River to enhance transfer of water into the central Delta. Cross Channel operations could influence the upstream spawning migration of adult delta smelt or the downstream transport of larvae.

Although not documented, closure of the Delta Cross Channel could provide acceptable spawning habitat similar to a dead-end slough, where delta smelt have been observed to spawn, or closure could interfere with spawning success by delaying migration.

The Delta Cross Channel is thought to decrease survival of larvae by making fish more vulnerable to SWP/CVP diversions in the southern Delta (DFG 1993a). However, Wendt (1987) found no relationship between the number of bass salvaged at Skinner Fish Facility and the amount of flow

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[1] There was no sampling from April 12 to May 20 due to boat problems.

through the Cross Channel. A similar analysis has not been performed for delta smelt, but a number of transport modeling studies using tracers[1] suggest that closing the Cross Channel could reduce entrainment of larvae spawned in the Sacramento River (DWR 1993a). By contrast, fish spawned in the lower San Joaquin River system could be adversely affected because in the model closing the Cross Channel reduces the ability of flow pulses to transport tracers to downstream nursery areas (DWR 1993a). Given the conflicting results from these two systems and uncertainties about whether they apply to delta smelt larvae, the net effects are not known. It is possible, however, that impacts depend on the distribution of spawning. Wang (1991) found that the Sacramento River was not used as intensively as a spawning area as the San Joaquin River in 1989 and 1990. By contrast, Wang and Brown (1993) found that the lower and mid-Sacramento River was important habitat in 1991, indicating that spawning location may change annually or hatching success and larval mortality rates may change.

State Water Project

SWP facilities include Banks Pumping Plant, Clifton Court Forebay, North Bay Aqueduct, Suisun Marsh Salinity Control Structure, and South Delta Temporary Barriers. These facilities are described in Chapter 2. Their possible effects on delta smelt are reviewed below.

Banks Pumping Plant

The most apparent effect of the SWP is entrainment of fish at Banks Pumping Plant. Delta smelt are eaten by predatory fish as they cross Clifton Court Forebay. Others are lost as they pass through Skinner Fish Facility and during handling and trucking in the salvage process. Losses of juvenile and adult delta smelt at the fish facility cannot be calculated with certainty, because there is no information for delta smelt pre-screening losses (predation rates) or on efficiency of the louver screens for delta smelt (Sweetnam and Stevens 1993). Estimates of annual delta smelt salvage and concerns related to the salvage data are presented in Chapter 4. Survival of salvaged delta smelt is probably low due to the stress of handling and trucking.[2]

Although exact levels of delta smelt loss are not known, salvage and larval data do indicate the timing and relative magnitude of project impacts. Evidence from Skinner Fish Facility and from larval surveys are summarized below.

Juveniles and Adults

Entrainment of juvenile and adult delta smelt has usually been greatest during spring and summer, reflecting the late winter/spring spawning season and growth and mortality of young-of-the-year fish (Sweetnam and Stevens 1993) (Figures 47 and 48). Salvage of the pre-spawning adults was unusually high from December 1977 through February 1978, when exports increased after the drought.

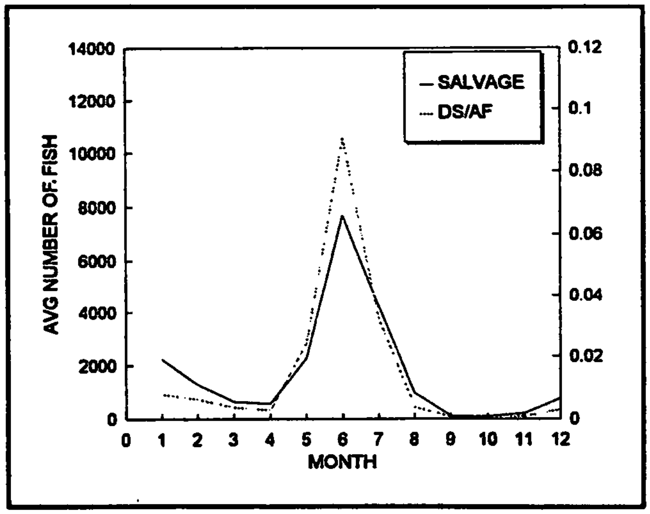

Figure 47
MONTHLY AVERAGE ESTIMATED DELTA SMELT SALVAGED AND DELTA SMELT SALVAGED PER ACRE-FOOT EXPORTED AT BANKS PUMPING PLANT, 1979 TO 1993

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[1] Smelt do not behave like tracers, but some of the same processes may apply.

[2] Handling and transport losses are discussed under "Central Valley Project", earlier in this chapter.

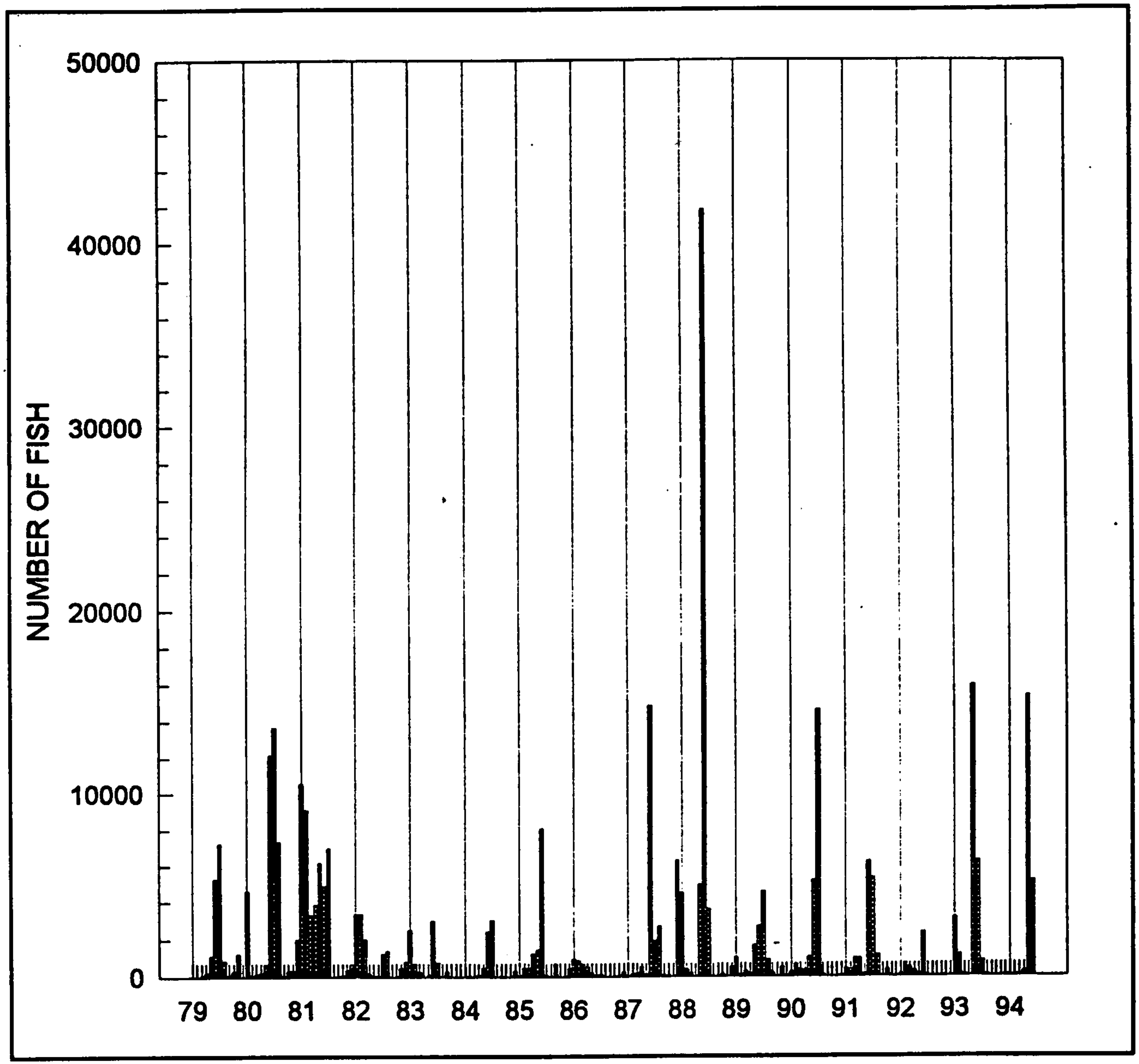


Figure 48

EXPANDED NUMBER OF DELTA SMELT SALVAGED MONTHLY AT SKINNER FISH FACILITY, 1979 TO JUNE 1994

Actual losses of juvenile and adult delta smelt salvaged at the SWP cannot be calculated at this time. Losses must be back-calculated from the number salvaged and estimated percentage lost due to trucking and handling, passing through the screen, and passing through Clifton Court Forebay. Experiments to determine forebay losses have been performed only for striped bass and salmon, and there are no estimates for other species, including delta smelt. Even bass and salmon loss estimates are not precise because experiments were not conducted over all seasons, hatchery fish were used rather than wild fish, and a relatively narrow size range of fish was examined (DWR 1992a). Forebay losses are believed to be lower in winter, when the predator populations have been lower (Kano 1990a) and cooler water temperatures probably reduce the metabolic and consumption rates of predators. In addition, screening efficiency estimates for Skinner Fish Facility are based on studies in the late 1960s and do not reflect subsequent design and operational improvements. How well the available information on loss factors applies to delta smelt is not known.

For this assessment, delta smelt salvage data (length and abundance) were examined to determine the effect of SWP operations on the delta smelt population and to determine what environmental parameters influence delta smelt salvage.

Daily length frequency of delta smelt salvaged between 1979 and 1991 (the period of most accurate data) indicates there are two distinct length groups: one composed of juveniles, primarily April-July, and a second composed of adults, primarily December-May (Figure 49). Based on life history information in Moyle *et al* (1993), delta smelt less than 50 mm salvaged in March through May were designated as juveniles (current year-class) and those 50 mm or greater were designated as adults (previous year-class). Delta smelt salvage, by year-class, plotted with Clifton Court Forebay inflow and Delta outflow indicates: many more juveniles are salvaged than adults; most juveniles are salvaged over a 2- to 4-month period; and this period varies between April through August. Before year-class 1982/1983, large numbers of both juvenile and adult delta smelt were salvaged. Since then, very few adults were salvaged except for year-class 1988/1989.

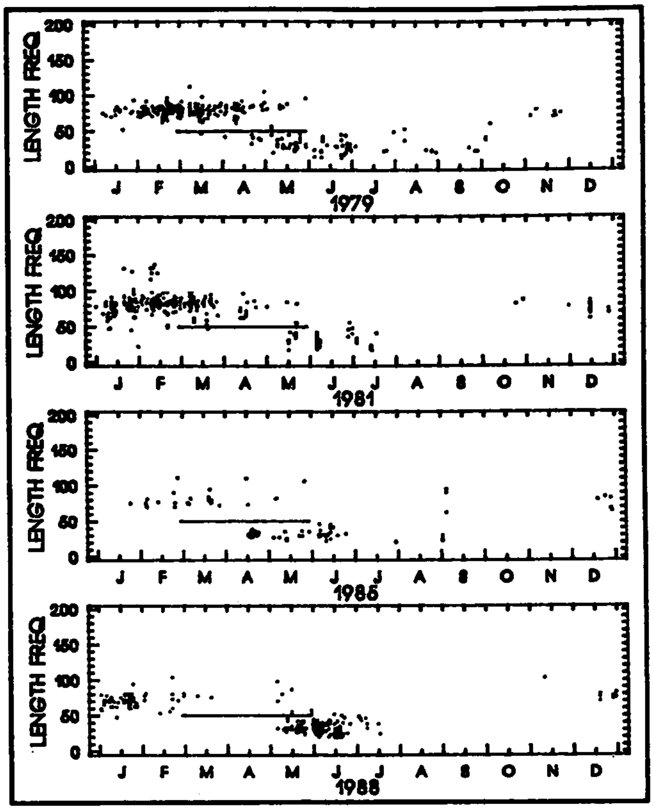


Figure 49
DAILY LENGTH FREQUENCY OF DELTA SMELT SALVAGED AT THE STATE WATER PROJECT IN SELECTED YEARS
Two year-classes of smelt are often present from late winter through spring.

The relationship between juvenile delta smelt salvage (summed for each year-class over the 2 to 4 months when most were salvaged) and Clifton Court Forebay inflow, Delta inflow, lower San Joaquin River flow, and Delta outflow (averaged over same 2- to 4-month periods) were investigated using regression analysis (Figure 50).

Two years, 1980 and 1983, produced the most variation in the regression equations. There is no apparent reason to exclude 1980 from the analysis, but the 1983 data are questionable because Delta outflow was so high that delta smelt were probably flushed out of the system and pumping was reduced dramatically in March through May. With the removal of 1983 data (Figure 51), juvenile delta smelt salvage appears to be significantly negatively related to Delta inflow ($p<0.01$, $r^2=0.56$, N=12), lower San Joaquin River flow ($p<0.01$, $r^2=0.63$, N=12), and Delta outflow ($p<0.01$, $r^2=0.69$, N=12). There was no significant relationship between juvenile salvage levels and Clifton Court Forebay inflow (Figures 50 and 51). These data

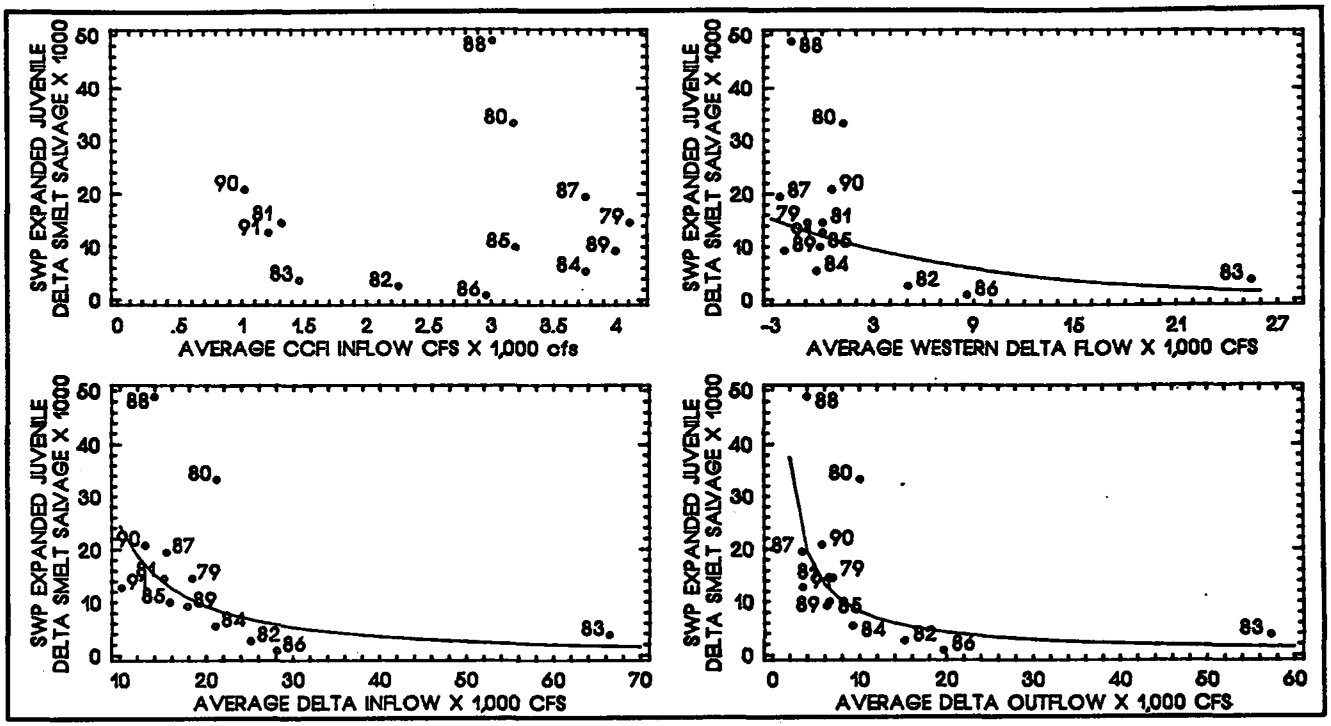


Figure 50

RELATIONSHIP BETWEEN JUVENILE DELTA SMELT SALVAGED AT SKINNER FISH FACILITY AND CLIFTON COURT FOREBAY INFLOW, WESTERN DELTA FLOW, DELTA INFLOW, AND DELTA OUTFLOW, 1979 TO 1991 (ALL YEARS)

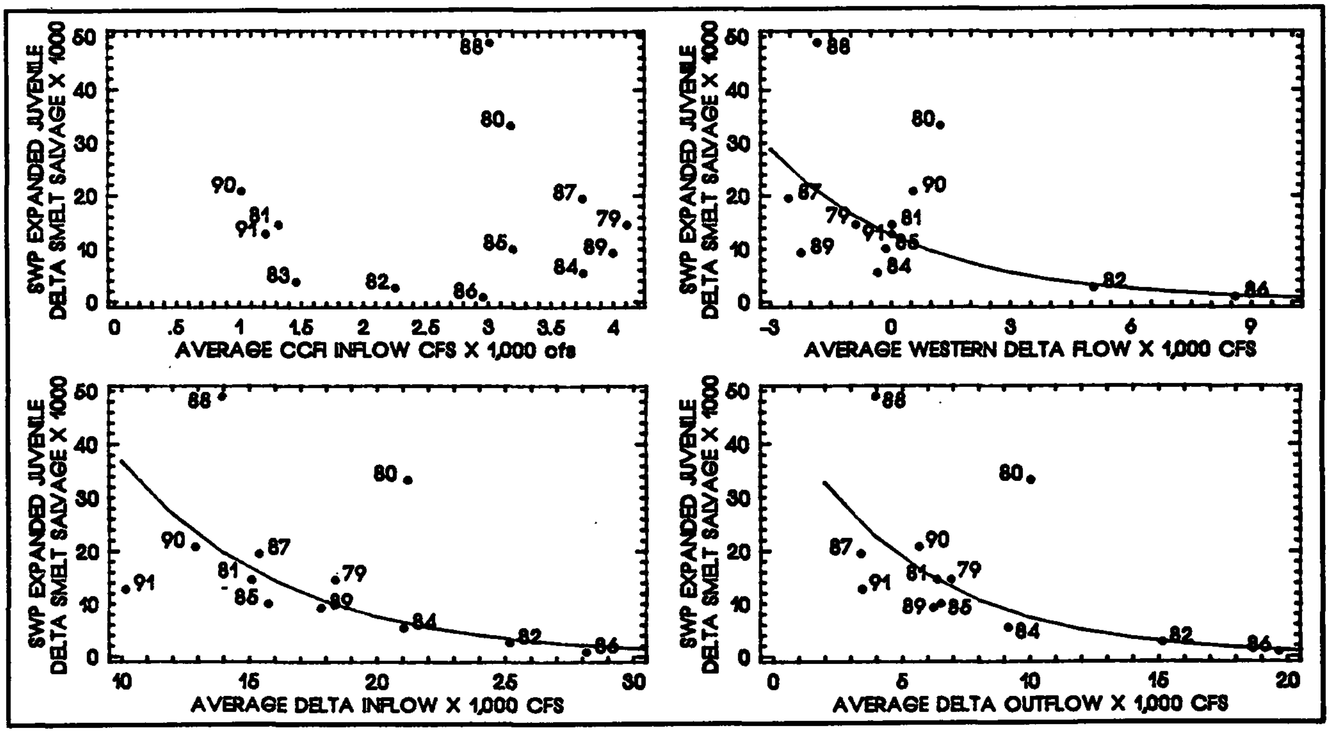


Figure 51

RELATIONSHIP BETWEEN JUVENILE DELTA SMELT SALVAGED AT SKINNER FISH FACILITY AND CLIFTON COURT FOREBAY INFLOW, WESTERN DELTA FLOW, DELTA INFLOW, AND DELTA OUTFLOW, 1979 TO 1991 (EXCEPT 1983)

Data points shown are for the 2-4 months during the April-August period when salvage was highest.

series have not yet been tested for autocorrelation problems, which may artificially elevate significance levels.

The SWP salvage/outflow relationships are consistent with the CVP salvage data (Figure 41), which frequently showed increased salvage in drought years during the same period. A possible explanation is that the distribution of delta smelt population shifts upstream during drier years (Stevens *et al* 1990), perhaps making them more vulnerable to entrainment. A higher risk of entrainment in the interior Delta is consistent with DWR Particle Tracking Model studies. While smelt may not behave like neutrally buoyant particles, the same process would tend to increase entrainment of smelt in drier years. The extent of the area affected by pumping is not known, but it could depend on tributary flows, exports, Delta Cross Channel gate operations, Clifton Court Forebay gate operations, and Delta consumptive uses.

If this hypothesis is accurate, one might also expect to find a relationship between Clifton Court Forebay inflow and salvage in drier years, when the population is closer to the export facilities. Figure 52 shows that this relationship did not improve when wetter years (1980, 1982, 1983, 1984, 1986) were removed. Similarly, if salvage levels depend on flow, it is reasonable to expect that there should be a correlation between the proportion of Delta inflow exported by the SWP and salvage. Yet Figure 53 suggests there is no such relationship (r^2=0.19, p>0.05). A possible explanation is that patchiness in the distribution of smelt spawning and larvae confounds the relationship between salvage levels and export rates. Daily or weekly variation in exports and outflow could, therefore, be important to salvage levels and obscure any relationship with Clifton Court inflow over longer periods (2-4 months in this analysis). Annual variation in year-class strength, described below, could also have a major impact on salvage levels.

Another concern is that the 1992 and 1993 data are inconsistent with the salvage/outflow relationships. Figure 54 shows that 1992 salvage levels were lower and 1993 levels were higher than expected based on trends in the previous years. The r^2 value for outflow drops to 0.20 for all years (p>0.05) and 0.14 if 1983 is excluded (p>0.05). The relationships for Delta inflow were also updated

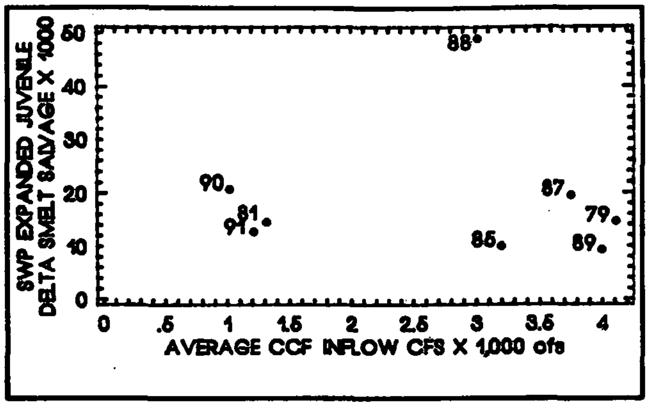


Figure 52
RELATIONSHIP BETWEEN JUVENILE DELTA SMELT SALVAGED AT SKINNER FISH FACILITY AND CLIFTON COURT FOREBAY INFLOW, 1979 TO 1991, AFTER REMOVING WET YEARS
Years Removed Are 1980, 1982, 1983, 1984, and 1986, Classified by Decision 1485 as "Wet".

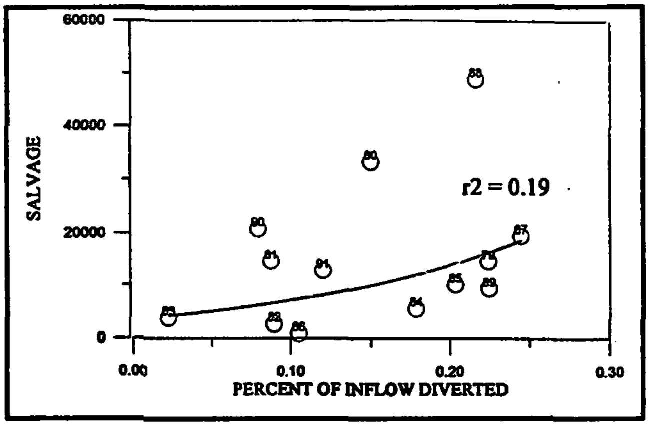


Figure 53
RELATIONSHIP BETWEEN EXPANDED SALVAGE OF JUVENILE DELTA SMELT AT SKINNER FISH FACILITY AND THE PERCENTAGE OF TOTAL DELTA INFLOW DIVERTED BY THE STATE WATER PROJECT, 1979-1993

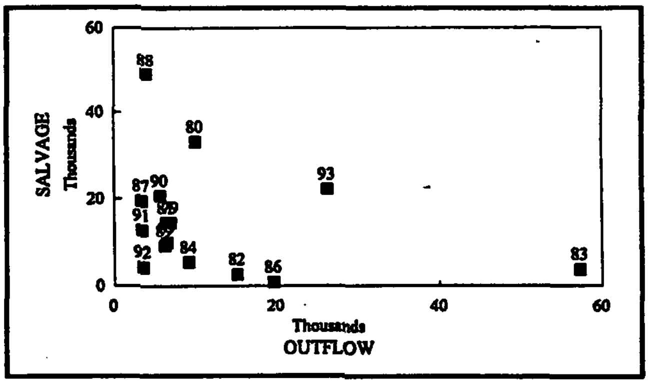


Figure 54
RELATIONSHIP BETWEEN EXPANDED SALVAGE OF JUVENILE DELTA SMELT AT SKINNER FISH FACILITY AND TOTAL DELTA OUTFLOW, 1979-1993

and found to be not statistically significant (r^2=0.13 for all data, r^2=0.09 excluding 1983).

The 1992 and 1993 results have not yet been sufficiently analyzed because they were not available until shortly before release of this document. Supplemental studies will likely be performed to examine the new data in further detail. However, if the original relationships through 1991 are not spurious, the recent data suggest that outflow effects may be obscured by other factors in some years or that conditions may have changed after 1992. The possible importance of other factors such as year-class strength and timing of Delta inflow are discussed below.

SWP salvage was also examined using entrainment indices as a means to correct for year-class strength and to examine population level impacts. An advantage of using entrainment indices is that they remove stock-recruitment effects that could cause autocorrelation in the salvage data series. Preliminary indices have also been calculated for early 1994 using the assumption that cohorts roughly correspond to salvage in April through June 1994. Final indices will be estimated as soon as size data are available.

Calculated entrainment indices are summarized in Figure 55. The indices are highest between May and July, representing salvage of young smelt. The smaller secondary peaks in December through February correspond to the adult smelt spawning migration. As for the CVP (Figure 42), indices were relatively low in most wet years (1980, 1982, 1983, 1986, 1993) and high in most drought years (1985, 1987-1990). This observation was tested statistically through 1993 by summing the indices for the period of peak salvage (March-August), then grouping the annual indices into "dry" (below normal-critical) and "wet" (wet-above normal) years. Differences were significant at the $p<0.05$ level using either a t-test or a Mann-Whitney U-test.

Note, however, that not all water years follow this pattern. Entrainment indices in 1984, a wet year, were higher than a number of dry years and all other wet years. Like Tracy Pumping Plant, a possible explanation is that 1984 was classified as "wet" because of heavy precipitation early in the year but was functionally "dry"for delta smelt spawners during a relatively low-outflow spring. Lower-than-expected indices for 1979 and 1981 may have resulted from exceptionally strong year classes that moderated relatively high salvage levels and associated loss. Tow-net indices in the previous year were relatively high, which is consistent with the hypothesis that a strong year class was produced from a large spawning stock.

The preliminary index for 1994 also appears lower than most other dry years. The low index may be a result of reduced pumping to meet 1994 biological opinion criteria. The index may also have been moderated by a strong year class, as indicated by a high midwater trawl index (adult spawners) in 1993.

In summary, SWP entrainment indices are reasonably consistent with SWP salvage data and with CVP entrainment indices. Also, SWP exports tend to take a higher fraction of the population when abundance is low and in a dry year. If the delta smelt tow-net index is relatively high, such as in 1979, 1981, and 1994, the impact of exports may be reduced in dry years. Results for 1980, 1982, 1983, and 1986 also suggest that population level impacts can be relatively small in wet years.

Although some of the factors regulating entrainment have been described, the question remains whether the CVP and SWP have a detectable effect on delta smelt abundance. Stevens *et al* (1990) analyzed water exports individually and in combination with other environmental variables for potential effects on the summer tow-net index (March-June variables) and fall midwater trawl index (March-June, July-October variables). None of the analyses explained a significant amount of variability in smelt indices.

One variable not tested by Stevens *et al* (1990) is the proportion of Delta inflow diverted by the SWP and CVP. Moyle *et al* (1992) observed that an increased proportion of diversion occurred during the period of declining delta smelt abundance. This hypothesis was tested statistically using regression analysis on abundance and hydrologic data through 1993. The average proportion of inflow diverted each year was calculated for the same months examined by Stevens *et al* (1990): March-June and July-October. The tow-net data

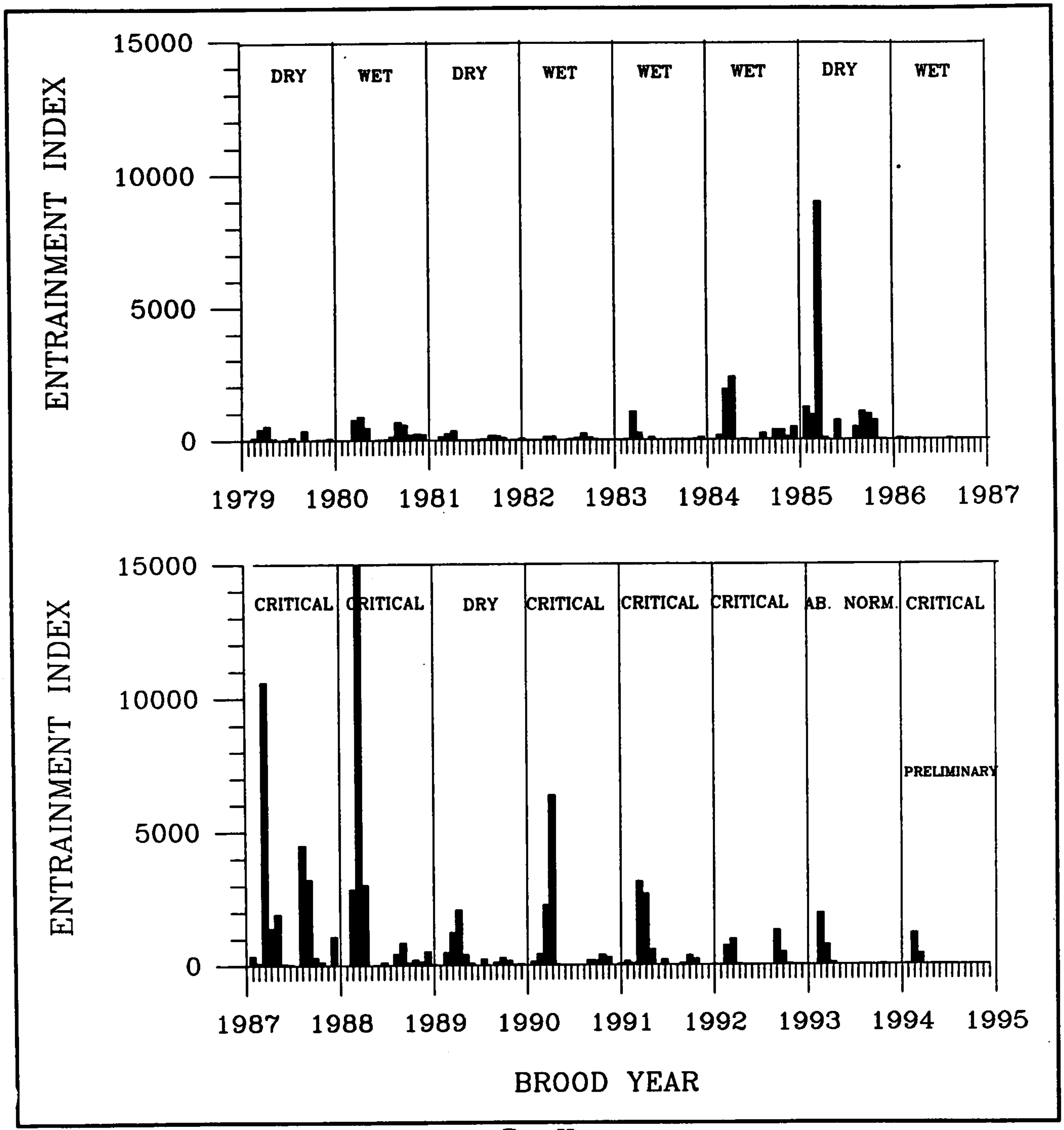


Figure 55
DELTA SMELT ENTRAINMENT INDICES AT SKINNER FISH FACILITY FOR 1979 TO 1994 BROOD YEARS, REPRESENTING SALVAGE FROM MARCH THROUGH MAY OF THE FOLLOWING YEAR
Water year types (from Decision 1485) represent the hydrology when the brood year was set.

were compared to March-June hydrology, and the midwater trawl indices were compared to hydrology for both periods. Abundance data were analyzed with and without log transformation. No relationship was found for any of the analyses; all values of r^2 were less than 0.09 ($p>0.05$).

The possible effect of project operations on abundance was examined further by comparing salvage levels with abundance indices.

Tow-net and midwater trawl abundance indices were log-transformed to help normalize the data. The effect of entrainment on abundance was examined by calculating the net change in the index between years. For example, the 1989 value (ΔTNS=0.019) was calculated as the difference between the 1989 index (log 2.3=0.361) and the previous year's index (log 2.2=0.342). This step was performed to remove stock recruitment effects, which have been found to cause autocorrelation problems in analyses of smelt data. There was no midwater trawl in 1979, so ΔMWT could not be calculated in 1979 or 1980.

The effect of project operations was assessed by examining the change in abundance indices versus combined salvage at the CVP and SWP fish facilities. Salvage data for 1979-1993 were separated into brood years using methods previously described. Juvenile salvage data were summed for March-June, the period leading to the measurement of the tow-net index. A slightly longer period (March-July) was used for comparisons with the midwater trawl indices because this survey is conducted later in the year. The effect of adult entrainment and associated losses on abundance indices in the following brood year was also studied by summing September-May salvage levels. All salvage totals were log-transformed before analysis.

Data were analyzed for all water year types and for dry years only. Based on previous analyses, dry year impacts were expected to be greater because the distribution of delta smelt shifts closer to the export facilities.

No relationship was found between salvage and ΔTNS for juveniles for all water year types (Figure 56) or dry years only (Figure 57). Similarly, there are no obvious trends for adults (Figures 58 and 59).

When all water year types are considered together, there does not appear to be a relationship between ΔMWT and juvenile salvage (Figure 60). This conclusion is consistent with Fox and Britton (1994), who found no relationship between delta smelt salvage and regional midwater trawl abundance indices (1979-1991) for regions of the Delta most likely to be influenced by the pumps: the lower Sacramento and San Joaquin rivers and the southern Delta. Although the analysis did not differentiate between adult and juveniles, the analysis is most comparable to juveniles, which numerically comprise most of the annual salvage.

However, Figure 61 indicates there may be a relationship in dry years. The major exception to the overall trend is 1992, which had the lowest salvage of all dry years. The relationship is not statistically significant ($p<0.05$) using regression or Spearman Rank methods unless 1992 is ignored ($p<0.05$), but there is no obvious reason to exclude this year from the database. As evidence that the trend may not be spurious, salvage data from additional dry years (1976, 1977) are included in Figure 61. Salvage data are less reliable for these years, but they follow the same trend. There were no trends in adult abundance for all water years (Figure 62) or dry years only (Figure 63).

To summarize, salvage data from the CVP and SWP show that dry year entrainment are generally greater than wet years. A shift in delta smelt distribution toward the export facilities is thought to be responsible for this trend. Based on analyses for the SWP, there appears to be a substantial increase in entrainment when outflow levels drop below about 10,000 cfs. However, there is evidence that year-class strength and the seasonal pattern of outflow may moderate or enhance the relative impacts to the delta smelt population.

Relationships between delta smelt salvage (and associated entrainment losses) and abundance indices or exports remain to be demonstrated statistically.

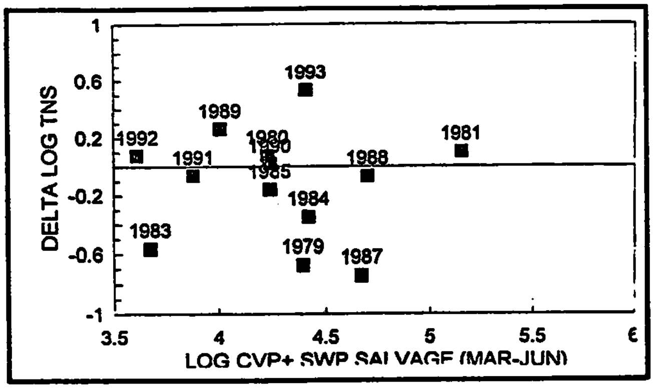


Figure 56
RELATIONSHIP BETWEEN SALVAGE AND CHANGE IN TOW-NET ABUNDANCE INDICES FOR JUVENILES, ALL YEARS

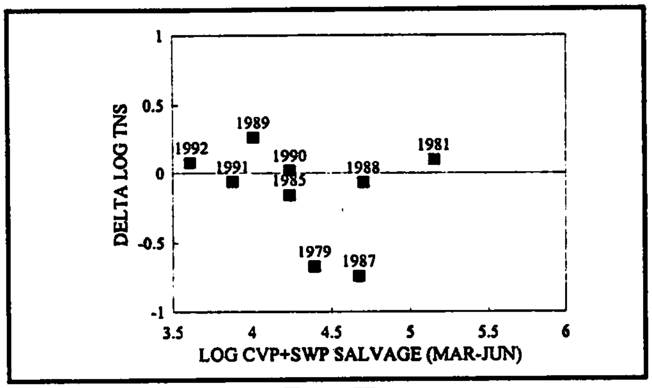


Figure 57
RELATIONSHIP BETWEEN SALVAGE AND CHANGE IN TOW-NET ABUNDANCE INDICES FOR JUVENILES, DRY YEARS

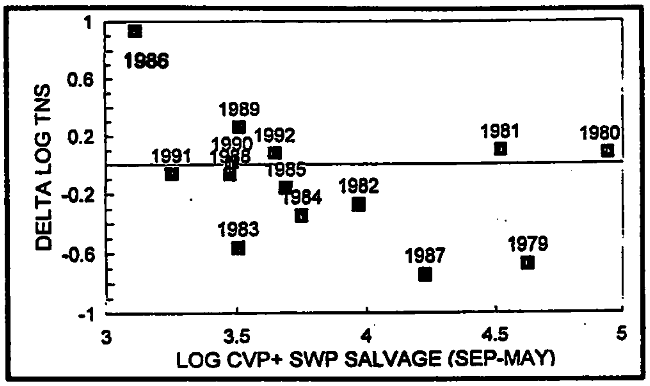


Figure 58
RELATIONSHIP BETWEEN SALVAGE AND CHANGE IN TOW-NET ABUNDANCE INDICES FOR ADULTS, ALL YEARS

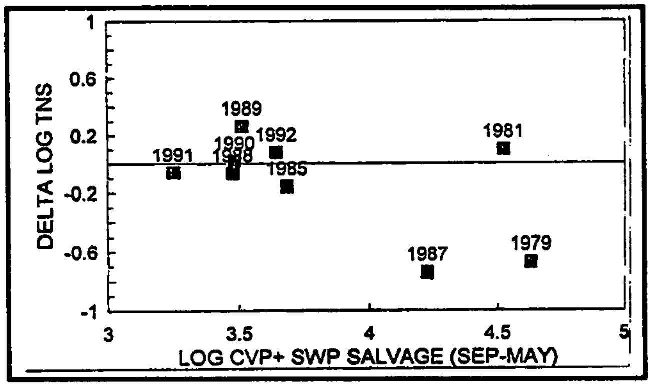


Figure 59
RELATIONSHIP BETWEEN ADULT SALVAGE AND CHANGE IN TOW-NET ABUNDANCE INDICES FOR THE FOLLOWING BROOD YEAR, DRY YEARS

Larvae

Information on entrainment of delta smelt larvae at the SWP is available from the DWR Egg and Larval Entrainment Study for 1989 to 1993 (Figure 45, Table 2). More information on larval delta smelt in the southern Delta near the SWP intake can be found in the discussion for the Central Valley Project.

Entrainment estimates for delta smelt larvae (less than 21 mm long) indicate that overall, the SWP may entrain slightly more larvae than the CVP. This is probably because the SWP intake is closer to the central Delta. Reverse flows in Old and Middle rivers may transport larvae to the southern Delta, but larvae are less abundant in the southern Delta than in the San Joaquin River and central Delta.

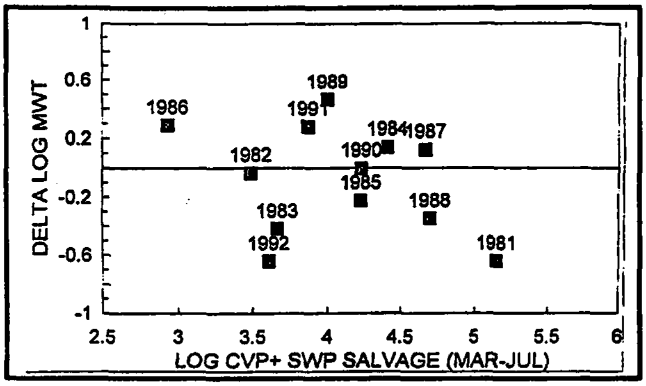


Figure 60
RELATIONSHIP BETWEEN JUVENILE SALVAGE AND CHANGE IN MIDWATER TRAWL ABUNDANCE INDICES, ALL YEARS

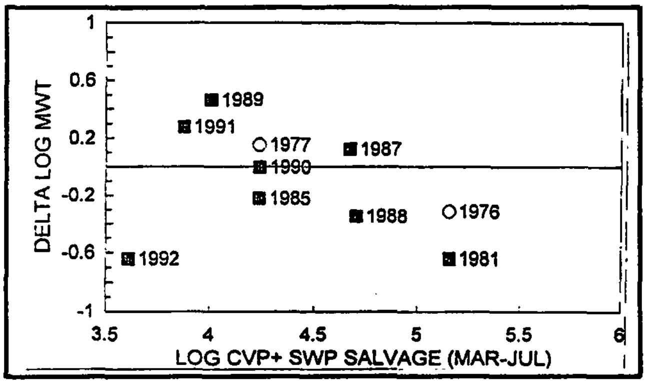


Figure 61
RELATIONSHIP BETWEEN JUVENILE SALVAGE AND CHANGE IN MIDWATER TRAWL ABUNDANCE INDICES, DRY YEARS

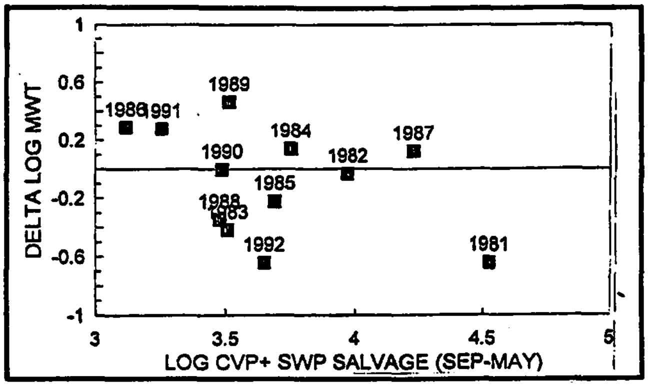


Figure 62
RELATIONSHIP BETWEEN ADULT SALVAGE AND CHANGE IN MIDWATER TRAWL ABUNDANCE INDICES, ALL YEARS

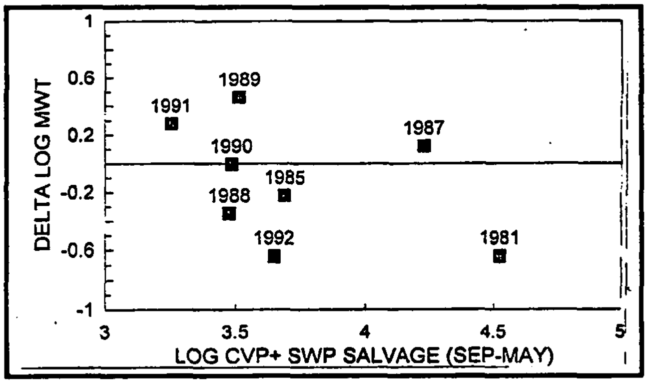


Figure 63
RELATIONSHIP BETWEEN ADULT SALVAGE AND CHANGE IN MIDWATER TRAWL ABUNDANCE INDICES IN THE FOLLOWING BROOD YEAR, DRY YEARS

North Bay Aqueduct

The North Bay Aqueduct has a screened intake at Barker Slough, which has historically drawn up to 90 cfs. Although the intake has a state-of-the-art fish screen, there are no facilities where juveniles and adults can be salvaged and counted. The effectiveness of the screen for juvenile and adult delta smelt is not known, but the screen was designed with a low approach velocity (0.5 fps) and to exclude fish 25 mm or larger. This approach velocity and the amount of water diverted are much lower than those at the Tracy and Skinner fish facilities. UC-Davis is currently doing research to define screening criteria for delta smelt.

Pickard *et al* (1980) evaluated screens of a similar design (0.5 fps approach velocity, excludes fish 25 mm and larger) at Roaring River Slough in Suisun Marsh. Entrainment data indicated significant reductions in losses of juvenile and adult delta smelt at screened versus unscreened culverts. Given the design similarities between the screens, it seems probable that performance may be similar. For larval and pre-juvenile smelt, however, losses would be expected since these life stages are primarily less than 25 mm. Larval delta smelt enter the pre-juvenile stage at about 16-20 mm TL, when the fin rays begin to complete development (J. Wang, pers comm). Pre-juveniles reach the juvenile stage at about 25 mm TL (±5 mm) and definitely by 30 mm TL, when the full complement of fin rays have developed.

Juveniles and Adults

From 1975 through 1979, DFG conducted a survey 3 times per year using an otter trawl and gill-net to monitor fish abundance in Lindsey Slough. Sample periods consisted of winter (February-March), summer (June-July), and fall (September-October). This survey fished a single site near the present DFG sampling site 718. Four delta smelt (1 juvenile, 3 adults) were collected from 24 otter trawls conducted over 12 sampling periods. All the adult smelt were captured in winter, presumably just prior to the spawning period.

From 1986 to present, DFG has been samplingin Barker Slough. During eight completed years of sampling (1986-1993), 29 delta smelt were collected. Of these, one was a juvenile-sized fish and the remaining were adults. Most of the adults (89%) captured in Barker Slough were taken in the winter survey, presumably just prior to spawning. Adults have been collected with greater frequency since the winter of 1989, the year following NBA start-up in June 1988.

Data from June 1988 through 1990 indicate juvenile and adult delta smelt are relatively low in abundance (1.22% of total catch) in comparison to the more abundant species of the sloughs, such as striped bass (21.76%), tule perch (17.6%), white catfish (12.22%), and threadfin shad (7.82%) (Kano 1990b). The smelt ranged from 59 to 116 mm FL. Relative abundance of delta smelt less than 100 mm long was greater during winter (February, 0.00215 smelt/cubic meter) than in summer (June, 0.00006 smelt/cubic meter) or fall (October, 0 smelt). Average size of these fish was 73.8 mm FL. One adult delta smelt (ripe female) was caught at the entrance to Barker Slough on March 15, 1991 (Bennett 1992). It appears that, at least in dry years, delta smelt are spawning in or near the Barker/Lindsey slough area.

Additional information on juvenile and adult delta smelt in the Cache Slough area is available from the fall midwater trawl survey and from recent purse seine sampling. The Cache/Lindsey/Barker slough area is not part of the summer tow-net survey. Midwater trawl results for stations in these sloughs indicate smelt are more abundant from October through December than in September, but they are not present in all years. DFG conducted purse seine sampling for juvenile delta smelt in June and July 1993, but results are not yet available (D. Sweetnam, pers comm). Some preliminary results are available for purse seine sampling in the Delta, including the Cache Slough area, on June 7-9, 1994 (Figure 64). Note that these numbers are only a rough estimate of catch rate as number caught per acre-foot sampled. The Cache Slough area had the highest catch rates (4.11-23.49 smelt/AF) in comparison to Montezuma Slough (0-1.37 smelt/AF) and the southern Delta (0-4.79 smelt/AF). Only Honker Bay had a higher catch rate (54.11 smelt/AF).

A purse seine was also used in March, April, and May 1992 in the Cache Slough area to collect delta smelt broodstock for development of fish culture methods for the species (Lindberg 1992). Adult smelt were collected throughout March, in mid-April, and again in early May. Additional purse seine sampling was conducted for adult delta smelt in a newly created "flooded island" area at the junction of Cache and Shag sloughs (Lindberg 1993). Adult smelt (both pre- and post-spawn) were caught in the island during surveys on March 13, April 9, April 27, and May 14, 1993. The highest density (average 3.6 smelt/haul) was just inside and south of the Cache Slough levee breach.

Larvae

Larval delta smelt have been monitored in Barker and Lindsey sloughs by DWR, DFG, and UC-Davis since 1986 (except 1992), but in 1986 and 1987 they were identified only to family. Sampling was conducted by DFG during April through July 1986 (7 visits) and 1987 (10 visits) at one station in Lindsey Slough and two in Barker Slough (Figure 65). Only one osmerid larvae was caught in 1986 (Barker Slough) and 6 larvae in 1987 (4 in Lindsey, 2 in Barker) (Table 3).

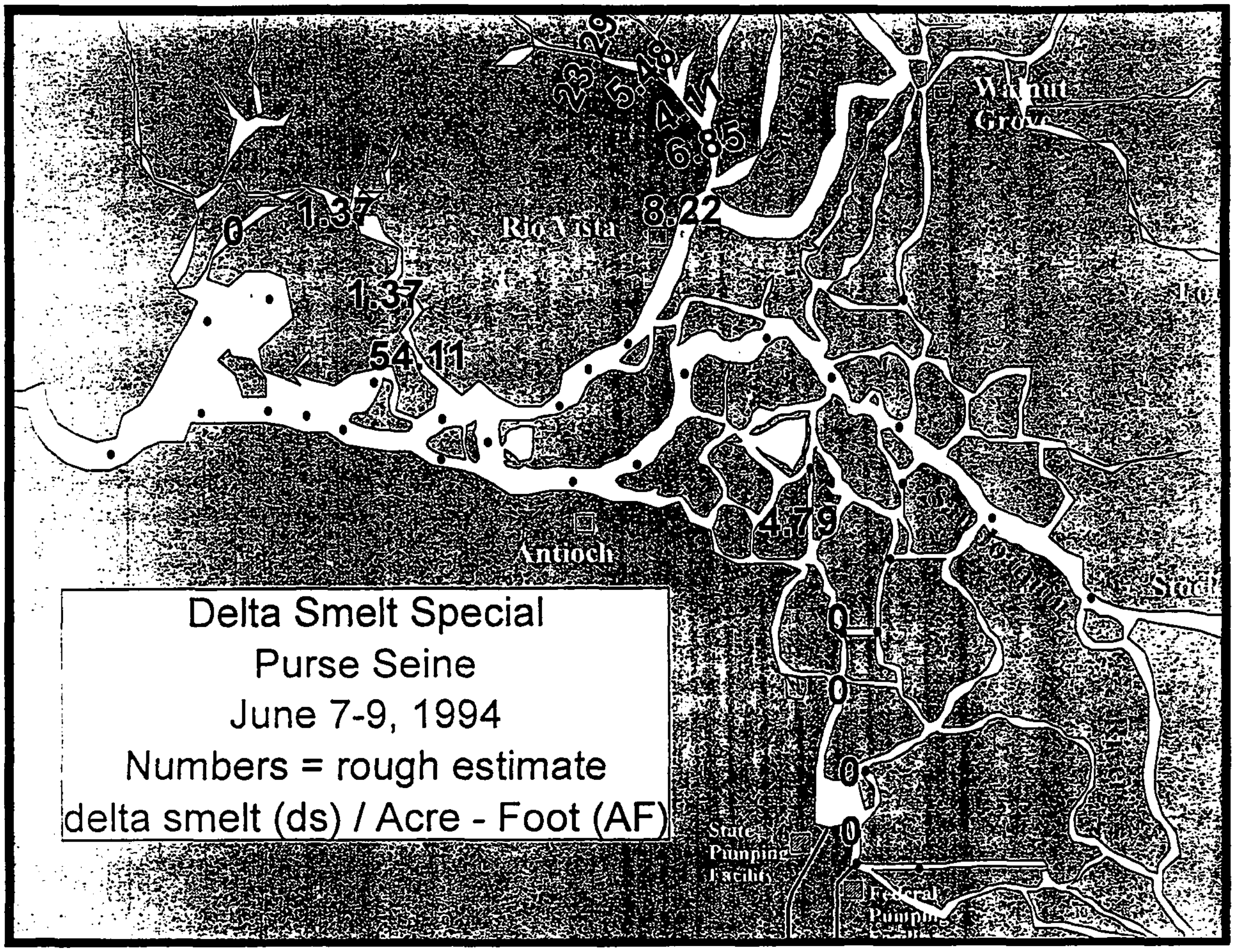


Figure 64
LOCATION OF DELTA SMELT SPECIAL PURSE SEINE SAMPLING, JUNE 7-9, 1994

From 1988 through 1990, sampling was conducted by UC-Davis weekly at 4 sites from late April through early July. In 1991 the sampling began in mid-March to include the delta smelt spawning season (Bennett 1993). No delta smelt were collected in Barker Slough during the 1988 to 1990 surveys (Table 3). No delta smelt were observed in Lindsey Slough in 1988, but they were collected in 1989 to 1991. Data for 1988 through 1991 indicate larvae are present near the Barker Slough intake from March to early May and in Lindsey Slough near Cache Slough from March to June (Bennett 1992).

No sampling was conducted in 1992. In February 1993, DWR resumed sampling in Barker and Lindsey sloughs. DFG assumed the survey in April 1993, eliminating Lindsey Slough site (719) and adding a replicate tow at Barker Slough site 721. The 1993 sampling was intensified to about every 2 days in response to the listing of the species and to restrictions on NBA pumping in the 1993 biological opinion for the protection of larval delta smelt. In 1993, most of the larval smelt were captured in Lindsey Slough despite unequal sampling effort (more in Barker Slough) between the sites (Table 3). Larvae were collected primarily from late March to late May (Figure 66). In 1994, every two day sampling by DFG indicates the abundances of larval delta smelt appear to be highest on record for the Lindsey/Barker Slough complex (Table 3). Larvae were collected primarily from late March to early May (Figure 67).

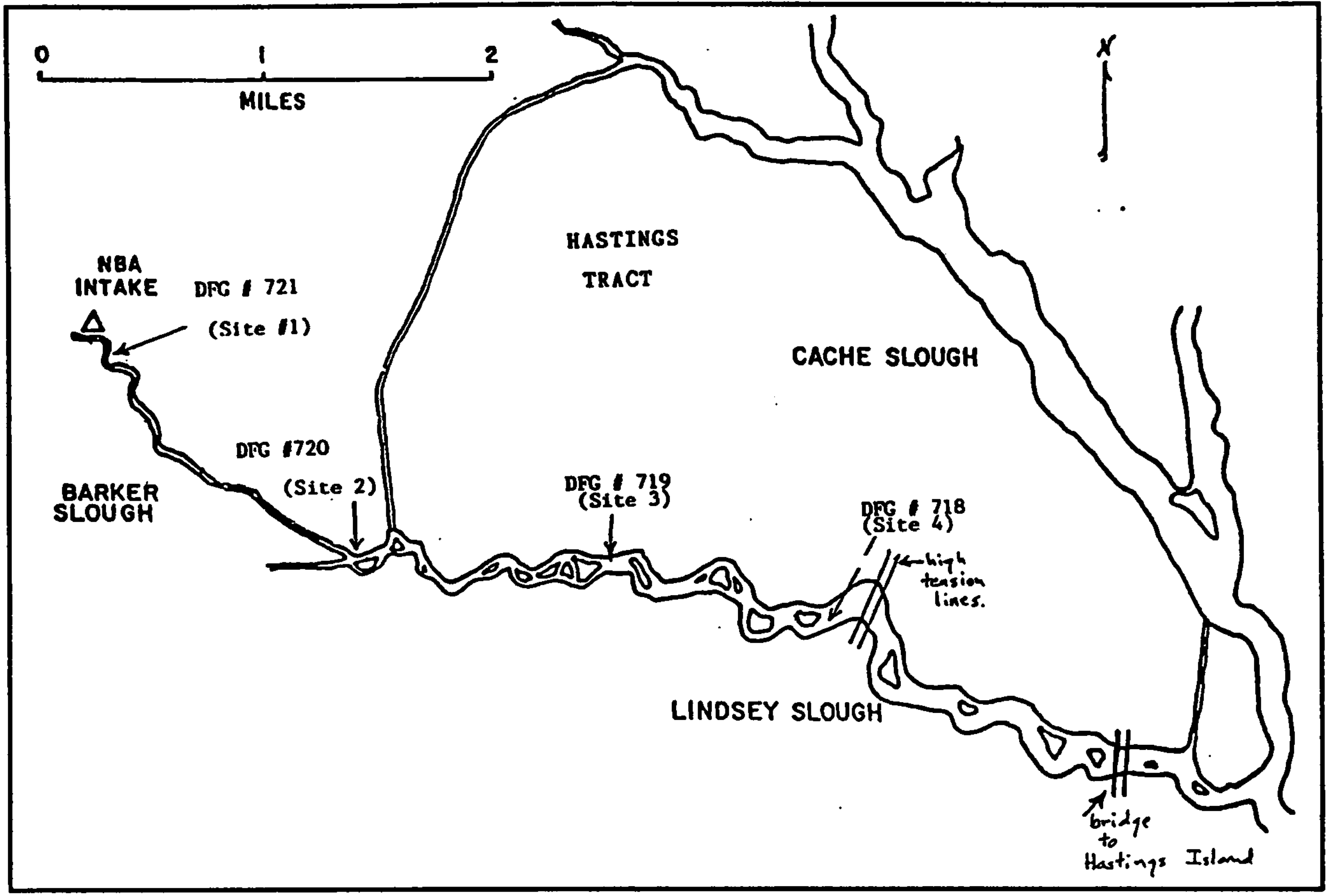


Figure 65
EGG AND LARVAL SAMPLING SITES FOR THE NORTH BAY AQUEDUCT

Table 3
LARVAL DELTA SMELT CATCH IN BARKER AND LINDSEY SLOUGHS NEAR THE NORTH BAY AQUEDUCT, 1986 TO 1993

Pre-Project Years are 1986 to 1988.
Smelt are Identified to Family Only in 1986 and 1987.
Sampling effort increased in 1993 and 1994.

	Lindsey Slough near Cache Slough		Barker Slough near NBA Intake	
Year	Site 718	Site 719	Site 720	Site 721
1986	0	NS	0	
1987	4	NS	0	2
1988	0	0	0	0
1989	5	5	0	0
1990	5	1	0	0
1991	9	2	3	3
1992	NS	NS	NS	NS
1993	20	0	3	7
1994*	213	NS	20	19
Total	256	8	26	32

NS No Sampling
* Through July 3

The 8 years of data on larval fish monitoring in Barker and Lindsey sloughs suggest that delta smelt larvae are captured more frequently and in greater numbers in Lindsey Slough. This may indicate more spawning occurs in Lindsey Slough than in Barker Slough or that larval smelt are being drawn into Lindsey Slough. The abundance and distribution (spatial and temporal) of larval smelt in this area is highly variable. Distribution is especially patchy in Barker Slough, where fewer young are collected. Replicate tow data support the notion of patchy distributions (Figure 66).

Information on the growth of delta smelt in this area is limited to partial records from 1994 monitoring (Figure 68). It can generally be seen that the smelt are growing throughout the spring and that this year they are approaching the juvenile size range (>20-30 mm TL) by mid-May. However, smaller larvae were present in mid- to late May, indicating a second or later period of spawning. Additional results indicate a few larval and prejuvenile smelt were caught in Lindsey Slough on

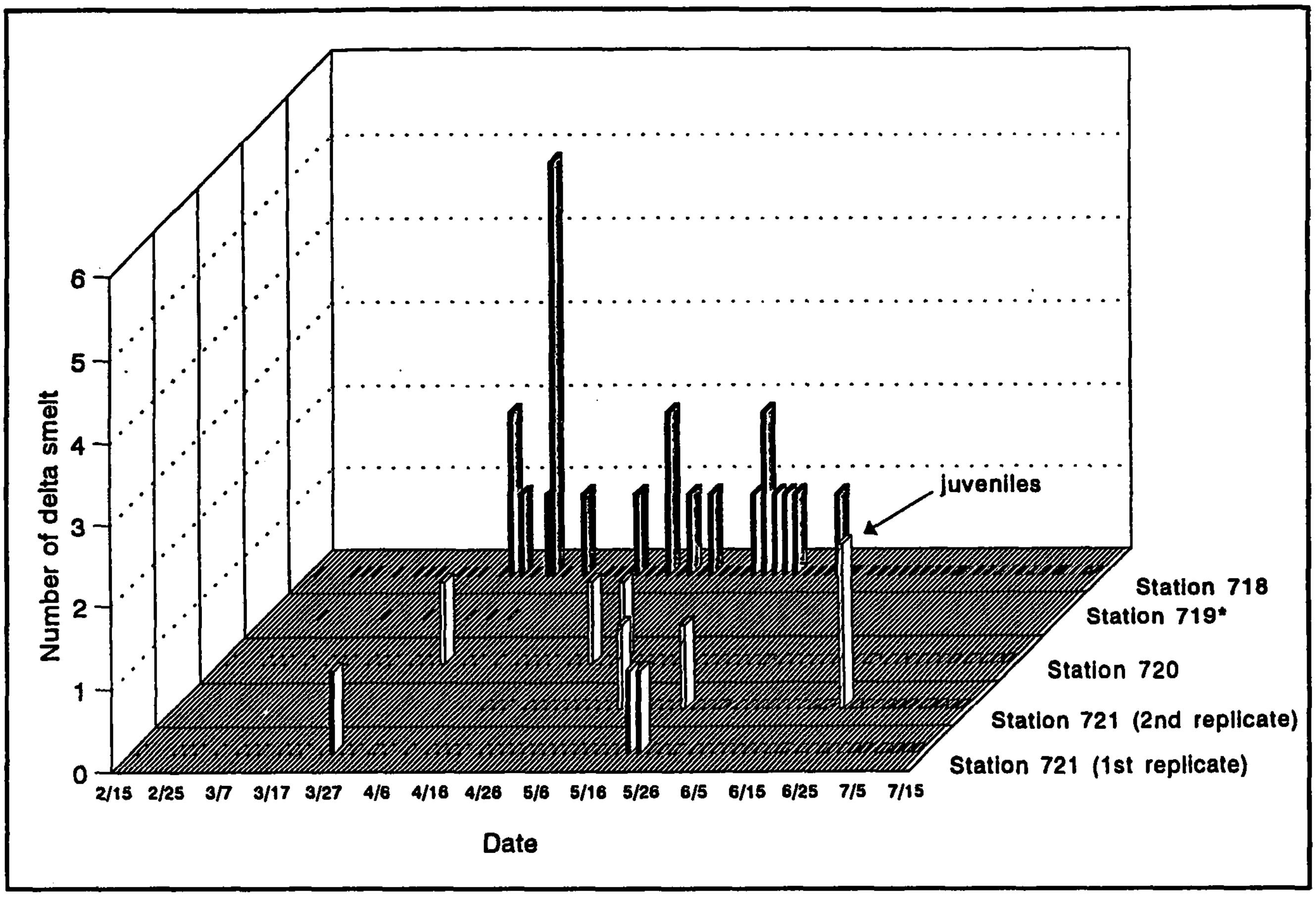


Figure 66
DELTA SMELT LARVAE AND JUVENILES CAPTURED IN LINDSEY AND BARKER SLOUGHS, 1993

May 28 (19 mm TL) and June 3 (17, 17, 20 mm TL), and juvenile smelt were caught on May 26 (29 mm TL) and June 19 (52 mm TL). One larvae (14 mm TL) was caught in Barker Slough near the intake on June 19.

Analysis of data prior to 1993 does not lead to any clear conclusions as to the effect of NBA operations on larval delta smelt. This sampling effort was sparse in comparison to the 1993 and 1994 efforts, which should be given more weight. The data for 1993 show only a slight increase over 1991 values (1992 was not sampled), even with 3 or 4 times the effort in prior years. In 1993, only 10 larval delta smelt were caught at the two sites nearest the NBA intake. The 1993 biological opinion placed a pumping restriction of 65 cfs on NBA operations from May through July. The 1993 data indicate that most of the larval smelt were found from late March to late May. Two juveniles (>20 mm) were found in late June 1993. Results for 1994 show a substantially greater number of larval delta smelt, which could reflect an apparent major increase in their numbers throughout the Delta. Larval smelt were found from early March to early June, with most from late March to early May. About five times more larvae were caught in Lindsey Slough compared to Barker Slough.

An analysis by Bennett (1993) used the BACI (Before-After/Control-Impact) design to test whether or not pumping was drawing striped bass larvae from the nearby Sacramento River to the facility, increasing larval density and entrainment. BACI analysis comparing the differences in larval density between the Sacramento River (control site) and Barker/ Lindsey Slough (potential impact site) during before (1986-1988) and after (1989-1991) pumping periods did not detect a pumping effect on mean larval density. The BACI design examined mean values, and results may have been influenced by highly variable spatio-temporal larval patterns. Therefore, Bennett concluded that it may not be appropriate for detecting the gradual

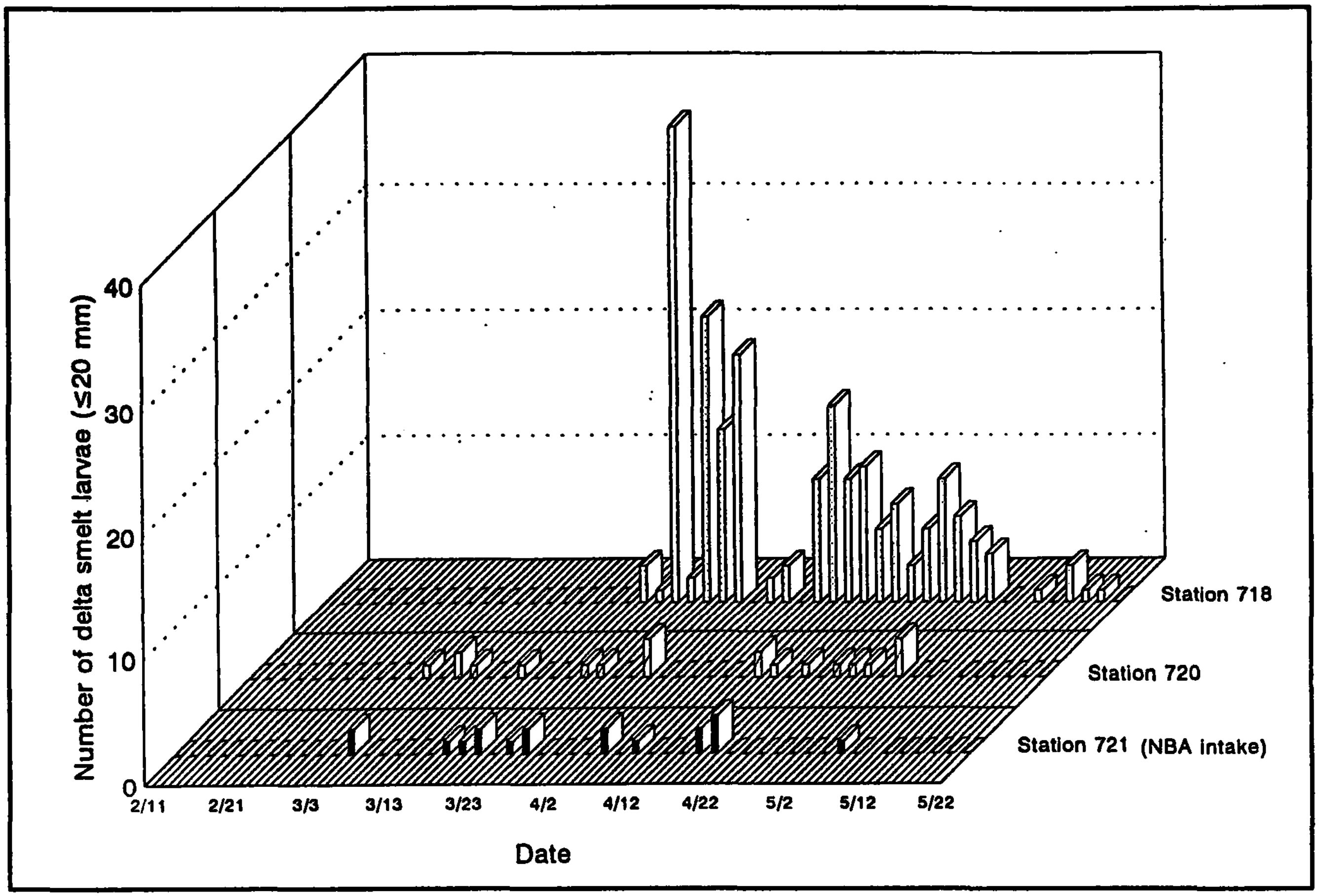


Figure 67
DELTA SMELT CAPTURED IN LINDSEY AND BARKER SLOUGHS, 1994

increase in peak densities and/or variability exhibited during the after-pumping period. Surveys before and after pumping operations began indicated densities in the intake slough increased gradually and became more variable after pumping began. Variation in larval density was significantly correlated with pumping rate on the day of sampling. Specific conductance during high pumping and larval density became more similar to that of the Sacramento River. Daily pumping rate over time (mean = 85 m^3/minute) was sufficient to replace the volume of Barker Slough daily, potentially entraining about 17,000 striped bass larvae per day. Overall, delta smelt larvae were 1-2 orders of magnitude less abundant than striped bass larvae and, thus, were estimated to be entrained at a rate of 170-1700 larvae per day.

Bennett's (1993) study also indicates abundance of striped bass larvae has increased significantly in Barker and Lindsey sloughs since project operations began. This could be due to water and larvae being drawn into the sloughs from the Sacramento River, where the striped bass densities are higher, or the area be used for spawning more in recent years because adults have been more concentrated in the lower Sacramento River. However, the abundance of delta smelt larvae did not appear to increase until 1994.

Some estimates have been made of entrainment of delta smelt larvae to the NBA based on pre-1993 sampling and the abundance of larval delta smelt in relation to larval striped bass in Barker Slough. Bennett (1992) concluded that delta smelt larvae are rare and have a patchy distribution (time and space) in Barker and Lindsey sloughs, making entrainment estimates uncertain. Bennett (1993) estimated that 170-1700 delta smelt larvae per day were entrained based on the relative abundance of smelt to striped bass (1-2 orders of magnitude lower) and an estimated potential entrainment of 17,000 striped bass larvae per day. Increased sampling frequency since 1993 has allowed a more

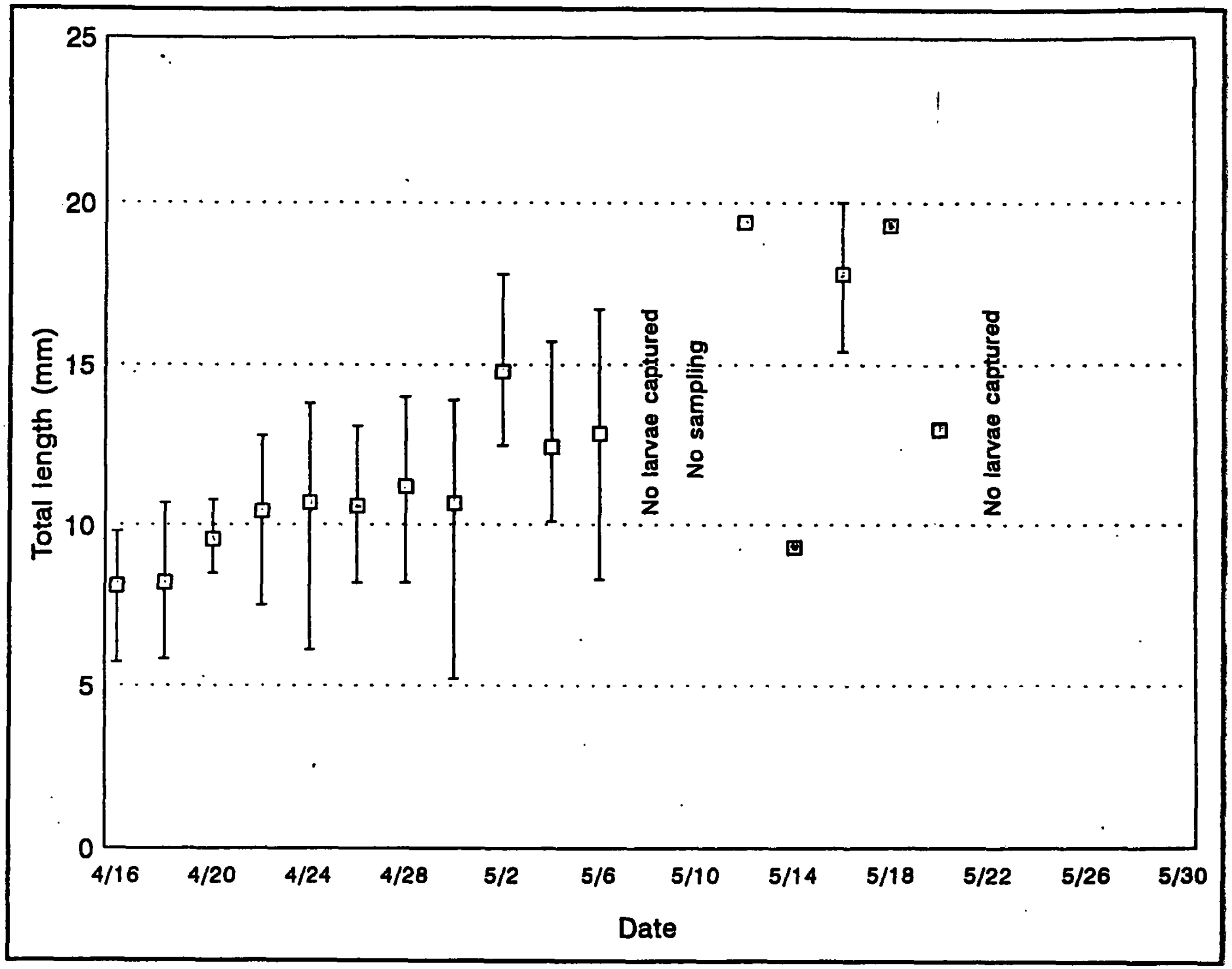


Figure 68
MEAN LENGTHS AND RANGES OF DELTA SMELT LARVAE COLLECTED IN LINDSEY AND BARKER SLOUGHS, 1994

refined, yet still rough, estimate of potential larval entrainment to the NBA.

DWR estimated larval smelt entrainment for 1993 using the same methodology as for the SWP and CVP intakes. The 1994 estimates are not yet available. The degree to which estimates represent actual conditions is not known. Entrainment for 1993 was estimated to be 8,289 larval delta smelt.

These estimates are based on the density of larvae at a particular sampling site and time. Due to the patchy nature of larval delta smelt distribution (temporally and spatially), density estimates may be highly variable, and entrainment estimates should be viewed with some caution. Small differences can result in highly variable density estimates even when replicate samples are used in their calculation. Density estimates are multiplied by the volume of water exported during a given period, usually daily export, to yield a daily estimate of entrainment. These entrainment estimates are based on two assumptions: all larvae at sites used to estimate entrainment are entrained at the project intake, and all water being diverted contains an equal density of larvae.

Both these assumptions are simplistic and may not be strictly accurate. Larvae present near the intake may not all be entrained. However, because of the probability of larvae being passively transported with moving water, this assumption may not be unreasonable. The second assumption assumes a directional and proportional relationship between loss and magnitude of pumping. This could result in an entrainment loss estimate of tens of thousands of larvae at a large diversion based on the density estimate from one larvae in a tow. This assumption may not be valid due to the highly variable distribution of delta smelt larvae in space and time. Vastly different entrainment estimates can be generated from replicate tows taken minutes apart at the same sample site. For species with highly variable distributions, more realistic estimates could result from a larger number of replicate samples. Another problem with present entrainment estimation methods concerns the sampling interval. On non-sampling days, the larval density from the last sampling day is usually applied. Losses may then be over or under estimated depending on what the actual abundance was during that non-sampling period.

Daily entrainment loss estimates of delta smelt to the NBA were also calculated by a consultant to the Solano County Water Agency using two methods. The first method used larval density based on the average of observed density at both Barker Slough sites (720, 721). The second used larval density only at the site nearest the NBA intake (721). Both methods calculated daily entrainment estimates that were then summed over the sampling season to yield a total entrainment estimate. Total entrainment losses for 1993 and 1994 (through May 24) are shown below:

	Sites 720, 721	Site Site 720	Number per Day*
1993	4,219	5,495	37
1994	22,489	17,618	157

*Based on Site 721 only.

Bennett's (1993) estimate of 170 to 1,700 larvae per day does not apply to days when no delta smelt larvae were present, and is, therefore, comparable to daily estimates in the 1993 and 1994 data only when larvae were collected. In other words, although daily entrainment estimates of the order of magnitude calculated by Bennett are occasionally valid when smelt larvae are found near the NBA intake, these estimated levels are reduced when no delta smelt larvae are captured.

Monthly entrainment of delta smelt larvae per acre-foot at the Barker Slough intake was compared with monthly entrainment at the SWP, CVP, and Contra Costa Canal intakes for 1993 (Figure 46). Estimates for 1994 are not yet available for all sites. At the North Bay Aqueduct, delta smelt larvae were entrained in March, May, and June only, at the following densities:

March	5.04 larvae/acre-foot
May	7.49 larvae/acre-foot
June	9.90 larvae/acre-foot

The North Bay Aqueduct had the most months of entrainment and highest entrainment densities when entrainment occurred at this site. No larval entrainment was estimated to have occurred in February, April, or July.

Suisun Marsh Salinity Control Gates

A monitoring program was implemented in 1988 to assess effects of the Suisun Marsh Salinity Control Gates on fish and other aquatic resources. This program includes existing sampling programs for *Neomysis* and zooplankton, egg and larval sampling, tow-net survey, juvenile salmon, and general fish population monitoring. A study of predators at the gates was added.

Monitoring results indicate minimal adverse impacts of the Montezuma Slough control gates on fish and other aquatic organisms (Spaar 1992). While abundance and distribution of fish species, including delta smelt, have changed in the marsh, the changes are probably due to factors causing the general fisheries decline and to the 1987-1992 drought more than to control gate operations.

Delta smelt populations have declined in the marsh since 1981 (Figure 19). Otter trawls caught 423 delta smelt between 1980 and 1983 and only 13 in 1984 to 1992 (Meng *et al* 1992). Of these 13 smelt, 12 were collected in 1988 to 1992, after control gate operations began. Gate operations have resulted in relatively low salinities in the eastern marsh (upstream of Cutoff Slough) compared to higher salinities in the small sloughs of the western marsh. The delta smelt catch has been low but consistent since 1988, when gate operations began. In contrast, no delta smelt were caught in 3 of the 4 years immediately before the project. It is difficult to determine whether gate operations are causing marsh conditions to be more favorable for smelt.

Project impacts that could negatively affect delta smelt appear to be the increased catch of predatory fish (striped bass and squawfish) at the structure since 1987. However, no delta smelt were identified in predator stomachs examined from 1987 to 1991.

Another concern in this area is entrainment of delta smelt into Roaring River Slough and other private diversions within the marsh. During the 1980-1982 evaluation of the Roaring River fish screen, delta smelt was the most abundant fish collected at the unscreened diversion and was collected through both diversion seasons (November to May and September to March) (Pickard *et al* 1982). A total of 5,841 smelt were collected: 3,731 in 1980/1981 (66 mm average fork length; range 30-100 mm FL) and 2,110 smelt in 1981/1982 (average FL 63 mm; range 41-107 mm FL). Catches were usually higher for all species in samples taken at night. In September 1981 to March 1982, only 8 smelt were entrained under screened conditions (average FL 60 mm; range 25-74 mm) compared to 2,110 under unscreened conditions (average FL 66 mm; range 30-100 mm FL), demonstrating that the screen was extremely effective in reducing entrainment.

South Delta Temporary Barriers Project

The South Delta Temporary Barriers Project is designed to improve water levels, circulation patterns, and water quality in the southern Delta and to reduce impacts of Tracy and Banks Pumping Plants on fish, particularly salmon. Potential concerns for delta smelt include barrier impoundment, attraction, redistribution, and predator concentration.

In 1993, analysis of April-to-September salvage levels suggested that delta smelt entrainment did not increase while the barriers were in place (DWR 1993b). Egg and larval data show the barriers had little or no effect on distribution and recruitment of delta smelt larvae, given the extremely small number of larvae in the area and the timing of larval occurrence relative to barrier placement and operation for 1993. Fish and Game collected no delta smelt in monthly hoop-netting and electrofishing surveys upstream and downstream of the barriers, and found no delta smelt in the guts of predators sampled.

In 1994, installation of the temporary barriers began April 18 and was completed by April 25. At the request of the Fish and Wildlife Service, the head of Old River barrier was removed on May 18 and the flapgates at the Old River near Tracy barrier were tied open.

Through April 12, no delta smelt were taken at the SWP. From April 23 to May 23, daily take was 10-300 at the SWP and 200-1,000 at the CVP. Between May 24 and May 31, the take was 900-4,400 at the SWP and 100-600 at the CVP.

The 14-day running average take of delta smelt allowed in the 1994 biological opinion for April-June is 755. The actual 14-day average take increased steadily beginning April 23, and the biological opinion take limit was exceeded on May 23. Delta smelt take continued to increase after removal of the head of Old River barrier. At this time, there is no apparent relationship between the take of delta smelt and installation of the temporary barriers in the southern Delta.

As an indication of potential impact of flow changes caused by the temporary barriers, delta smelt were monitored at three sites, using egg and larval nets. No smelt were detected in these samples, which were taken through May. However, the size of the smelt may have exceeded the efficiency of the nets, which would explain the lack of fish in the monitoring program while they were being taken at the SWP and CVP fish facilities.

However, transport modeling studies suggest that entrainment of neutrally buoyant particles could increase under certain conditions when the barriers are in place. In particular, simulated entrainment of a tracer mass was shown to increase from 14.2% under the base condition (no barriers) to 20.8% at the CVP under a 3-barrier configuration (Old River near Tracy, Middle River, and Old River at Head). It is unclear why this increase would occur, because tracer concentrations did not change appreciably at any other export source when the barriers were in place. However, the modeled particles may move differently than delta smelt larvae, so these results must be interpreted with caution (DWR 1993b).

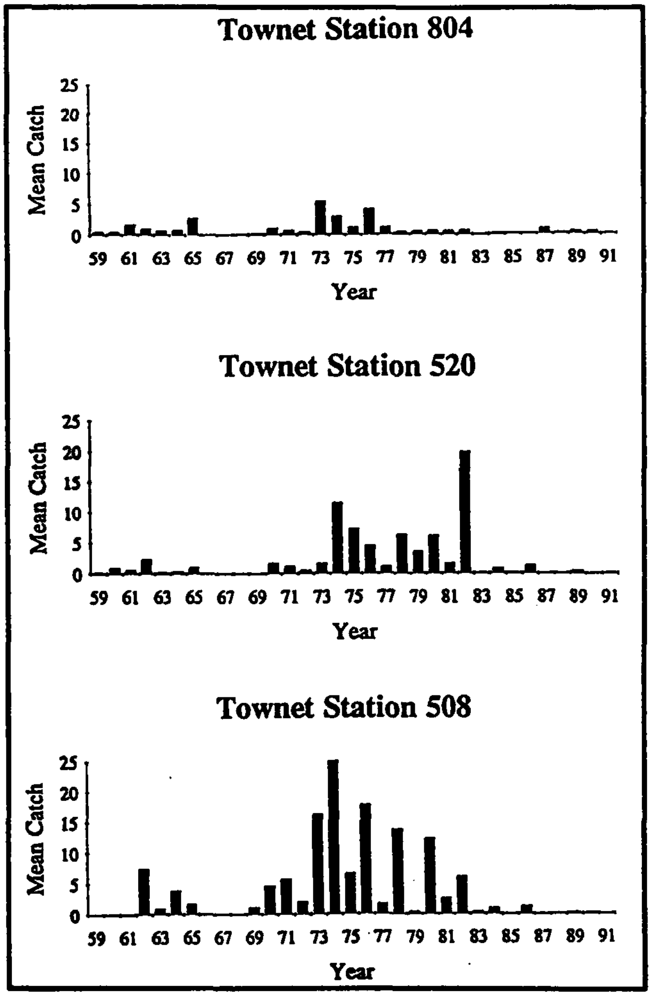
Pacific Gas & Electric Company

Pacific Gas and Electric Company operates two power generation facilities within the range of delta smelt: Contra Costa Power Plant and Pittsburg Power Plant. Contra Costa Power Plant is about 6 miles east of the confluence of the Sacramento and San Joaquin rivers. Pittsburg Power Plant is on the south shore of Suisun Bay, in the town of Pittsburg. Each power plant has seven generating units that rely on water diverted from the lower San Joaquin River and Suisun Bay for condenser cooling. Cooling water is diverted at a rate of up to about 1,500 cfs for the Contra Costa plant and 1,600 cfs for the Pittsburg plant, forming a thermal plume as it is discharged back into the estuary. Pumping rates are often significantly lower under normal operation. Intakes at all units at both power plants employ a screening system to remove debris, but the screens allow entrainment of fish smaller than about 38 mm and impingement of larger fish.

Information on occurrence and direct entrainment of delta smelt near the PG&E power plants is limited because of taxonomic problems with earlier studies. Young delta smelt and longfin smelt are difficult to differentiate, so much of the early data is at the family (Osmeridae) level only. The available information suggests that larval and juvenile smelt, including delta smelt and longfin smelt, were historically one of the most abundant fish taxa in the area. In 1978 and 1979, Osmeridae was the most common group collected in ichthyoplankton samples near Pittsburgh Power Plant and the third most abundant near Contra Costa Power Plant (Ecological Analysts 1981a, 1981b).

There is also some specific evidence that juvenile and adult delta smelt have persisted in the project areas. Surveys using a combination of gear types found that delta smelt comprised 1.8% of the catch of all species near Pittsburg Power Plant from August 1978 to July 1979 (Ecological Analysts 1981c) and 1.1% at discharge and reference sites from July 1991 to June 1992 (PG&E 1992a). Near Contra Costa Power Plant, delta smelt constituted only 0.1% of the catch in 1978 and 1979 (Ecological Analysts 1981d) but 0.7% in 1991 and 1992 (PG&E 1992a). However, results from the summer tow-net survey (Chapter 3) at stations closest to Pittsburgh Power Plant indicate abundance has declined since the peak levels in the mid-1970s. As shown in Figure 69, the mean catch of delta smelt declined in the 1980s at stations 520 and 508, located upstream and downstream of Pittsburg Power Plant. At station 804, near Contra Costa Power Plant, mean catch of delta smelt has been consistently low except in 1965 and 1973 to 1977.

PG&E has monitored extensively at both power plants. Early general monitoring was followed by studies emphasizing larval and juvenile striped bass. Entrainment estimates for smelt are available from 1978 and 1979 only, and larval data are limited because of difficulties in differentiating longfin smelt and delta smelt. PG&E (1981a, 1981b) reports that from April 1978 to August 1979, more than 50 million smelt larvae (Osmeridae) were entrained at Pittsburg Power Plant and an additional


Townet Station 804

Townet Station 520

Townet Station 508

Figure 69
MEAN CATCH PER TOW OF DELTA SMELT AT
SUMMER TOW-NET SURVEY STATIONS NEAR
PITTSBURG POWER PLANT AND CONTRA COSTA POWER PLANT
Station 804 is near Pittsburg Power Plant;
Stations 520 and 508 are near Contra Costa Power Plant

11,000 juvenile delta smelt impinged on the screens. Entrainment was similarly high at Contra Costa Power Plant for Osmeridae larvae (16 million) and juvenile delta smelt (6,400). An important consideration in evaluating these data is that larvae entrained in cooling systems are not necessarily lost. Survival rates of entrained striped bass and other species can be high, but the effects on delta smelt are not known. Smelt do not appear to tolerate stress, as indicated by low survival following trucking and handling during CVP and SWP salvage operations. In addition, temperatures from the cooling systems may be higher than those delta smelt can tolerate (Swanson, pers comm 1994).

Survey results from nearby summer tow-net sites suggest many of the larvae entrained in the 1978-1979 studies were delta smelt. Longfin smelt are rarely caught at station 804, near Contra Costa Power Plant, and were not observed in 1978 and 1979. This compares to low but detectable levels (mean catch/tow 0.5) of delta smelt. Delta smelt also outnumbered longfin smelt during 1978 and 1979 at station 520 (mean catch 5.0 delta smelt, 0.4 longfin smelt) just upstream of the Pittsburg plant and station 508 (mean catch/tow 7.1 delta smelt, 0.4 longfin smelt) just downstream of the Pittsburg plant. A limitation in interpreting these results is that the summer tow-net survey was conducted after the period of peak entrainment, so the species composition may not be strictly comparable.

Thermal effects may result in direct mortality, behavioral attraction, avoidance, blockage, or increased predation. This issue is discussed in a recent report by PG&E (1992b). The study found greater numbers of some fish species near thermal discharge sites, but no evidence for direct mortality of striped bass and no thermal blockage of migratory species, including Chinook salmon, striped bass, and American shad. Insufficient numbers of delta smelt were collected to draw any conclusions about how they are affected by the thermal discharges. Predation on juvenile Chinook salmon and larval striped bass suffering thermal stress may be higher in Contra Costa units 6 and 7 discharge canal, but the report concluded the effect is probably minimal. The overall effect of thermal discharges on delta smelt is not known, but sampling indicates there is no behavioral attraction.

Since the 1978-1979 studies were completed, PG&E has implemented a resource management program to reduce striped bass loss. During the period of peak striped bass entrainment (May to mid-July), power generation units are operated preferentially, using fish monitoring data. This program has reduced entrainment losses of larval and juvenile striped bass by more than 75% (PG&E 1992a). The revised operations may have incidental benefits to delta smelt by reducing entrainment, but they cannot be estimated because there is presently no monitoring requirement for this species.

Local Agricultural Diversions

Larval, juvenile, and adult delta smelt are vulnerable to entrainment into Delta agricultural diversions, a potential risk for the population. The risk to delta smelt populations from agricultural diversions is potentially significant for several reasons. First, the diversions are distributed throughout the range of delta smelt, placing the entire population at risk. Second, most of these diversions are unscreened, and there is no salvage of diverted fish. Third, the intakes are close to shore or to the edge of the main channel. If, as Moyle (1989) suggests, delta smelt prefer shallow-water habitat when it is available, they could be expected to concentrate in areas immediately adjacent to island levees, where flows would be lower and there would be some protection from predators. Fourth, an estimated monthly average of 2,000 to 5,000 cfs is diverted during the peak irrigation period (April-August) from about 1,850 diversions scattered throughout the Delta (Brown 1982). This is the same order of magnitude as is exported by the SWP and CVP in the southern Delta.

1992 Studies

In 1992, Water Resources initiated the Delta Agricultural Diversion Evaluation to assess the extent to which delta smelt and other species are lost to these diversions. Sampling was conducted from mid-April through October 1992 and began again in late April 1993. In general, 1992 results seem to show that some larval species (*eg*, threadfin shad, centrarchids, minnows, logperch) are more vulnerable to entrainment than others (*eg*, striped bass, chameleon goby, prickly sculpin) relative to their abundance in the adjacent Delta channel.

Larval fish also appeared to be more vulnerable than other life stages. Based on the initial analysis of data from the 1992 pilot study, entrainment appears to depend largely on the species in question, its life stage, seasonal abundance and distribution in the adjacent channel (including location in the water column), and operations of the diversion (seasonal timing; frequency and duration; flow and volume) (Spaar 1994). Many diversions do not operate continuously and divert water for only a few days to a few weeks at a time.

During 1992 sampling, no larval, juvenile, or adult delta smelt were collected from the four diversions sampled (Spaar 1994) (Figure 70). In this pilot year, however, sampling methods for juvenile and older fish were found to be inefficient. In addition, the Twitchell Island diversion off the San Joaquin River, an area of known delta smelt abundance, could not be sampled. Larval smelt were collected in April and May by egg and larval sampling in the Delta channels adjacent to the Twitchell Island, Bacon Island, and McDonald Island sites (Table 4).

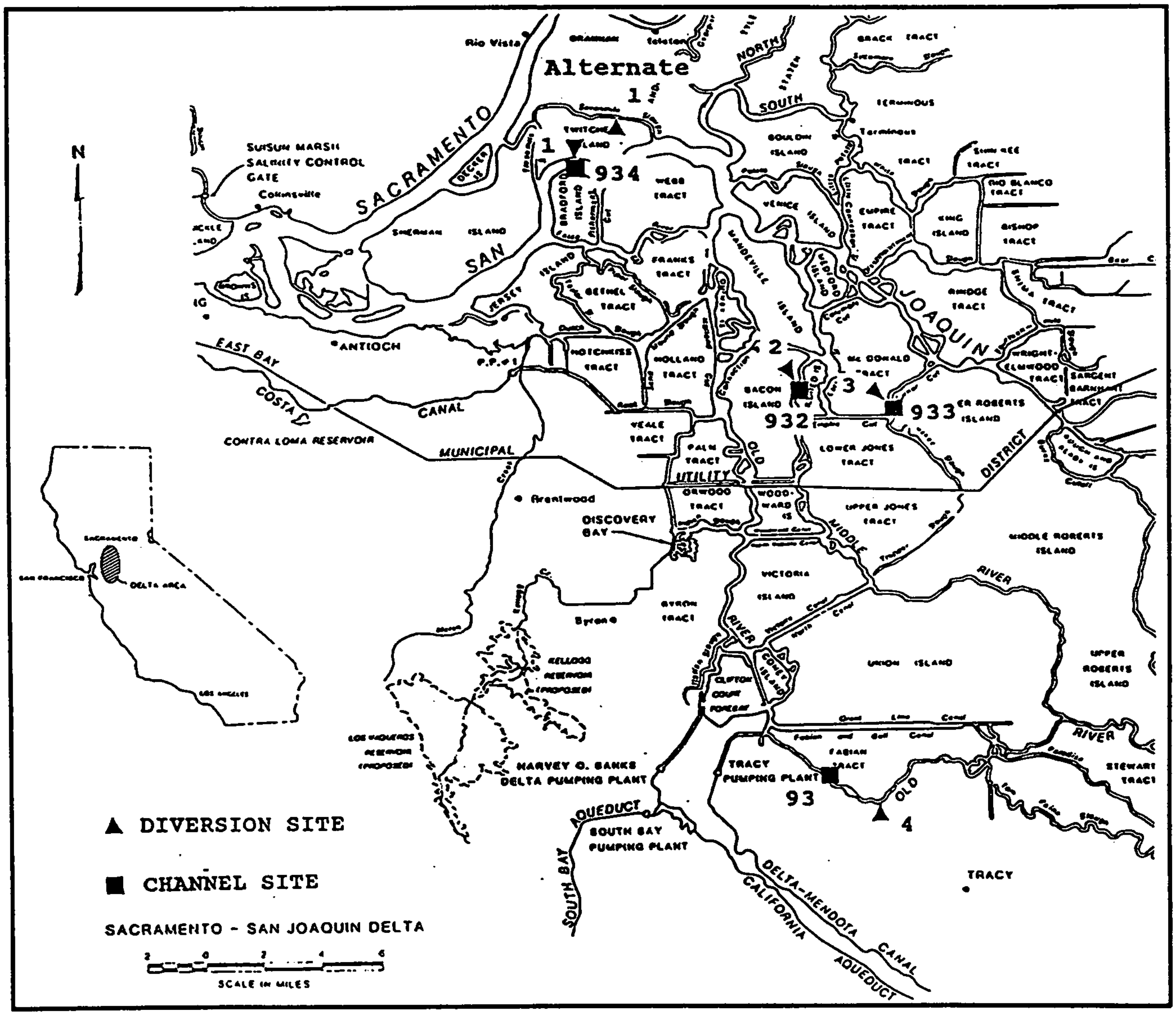


Figure 70

DIVERSIONS AND ADJACENT CHANNEL SITES SAMPLED FOR THE 1992 PILOT STUDY OF DELTA AGRICULTURAL DIVERSIONS

Site numbers refer to those on Table 4.

Table 4
TOTAL CATCH, BY SPECIES, OF LARVAL FISH COLLECTED DURING THE DELTA AGRICULTURAL DIVERSION EVALUATION, APRIL TO OCTOBER 1992
Number per 10,000 Acre-Feet

	Diversion Sites				Channel Sites			
Species	1 Twitchell Island*	2 Bacon Island	3 McDonald Island	4 Naglee-Burk	934 Twitchell Island*	932 Bacon Island	933 McDonald Island	93 Naglee-Burk
Chameleon goby	—	161.76	214.67	32.99	447.91	407.79	1650.76	282.37
Threadfin shad	9.14	99.41	337.01	82.04	50.01	48.28	123.11	49.98
Prickly sculpin	—	1.24	—	—	55.25	38.82	40.53	85.09
Striped bass	—	10.92	—	—	625.55	36.24	3.80	1.32
Centrarchids	9.61	18.13	1.36	7.33	0.86	1.08	1.51	1.70
Bigscale logperch	—	2.16	—	0.77	1.73	2.79	4.66	2.18
Inland silverside	46.21	—	—	—	—	—	—	0.80
American shad	—	3.59	—	—	—	—	—	—
Cyprinids	—	1.11	—	1.77	5.51	0.80	1.54	0.17
Delta smelt	—	—	—	—	2.74	0.80	0.39	—
Sacramento splittail	—	—	—	—	0.21	—	—	0.15
Sacramento sucker	—	—	—	4.67	—	0.41	—	—
Mosquitofish	—	—	0.41	—	—	—	—	0.06
Ictalurids	—	—	—	—	—	—	—	0.04
Yellowfin goby	—	—	—	—	1.13	—	—	—

*An alternative diversion site was sampled was on Sevenmile Slough. Channel site was on the San Joaquin River.

Larval smelt abundance in these catches was generally low, and catches were infrequent in comparison to most other larval species caught, such as chameleon goby, threadfin shad, and striped bass. No larval smelt were collected near the Naglee Burk site (93) in the southern Delta.

1993 Studies

At the time of the 1993 assessment, 1993 larval samples were still being processed in the laboratory. All samples have now been processed, and data are available for the entire diversion season, at all sites, and for all gear types. Sampling methodology and juvenile nets were modified in 1993 to increase sampling efficiency and reliability.

In sampling during 1993, no larval delta smelt were collected from the diversions using egg and larval methods (DWR unpublished data). Larval delta smelt were collected before and during the diversion season by egg and larval sampling in channels adjacent to the Twitchell and Bacon island sites (central Delta). In the San Joaquin River off Twitchell Island, fourteen Delta smelt larvae (5.0-7.0 mm TL) were collected between March 19 and April 10 and two (10.5 and 20 mm TL) were taken on June 7 and 17. In Middle River off the Bacon Island site, four larvae (5.5-7.4 mm TL) were collected on March 23, March 31, and June 9. Diversions at these sampling sites started later in 1993 than in 1992 due to heavy rainfall from fall 1992 through spring 1993, which delayed the onset of irrigation (late April at Bacon and late May at Naglee-Burk).

Preliminary 1993 data are also available from the juvenile net (1/8-inch mesh with live-box) (DWR unpublished data; Griffin 1993). Results indicate no delta smelt were caught at the Naglee-Burk and McMullin Tract sites (southern Delta) or at Twitchell or Bouldin islands (central Delta). However, five juvenile delta smelt were collected from the Bacon Island diversion site (central Delta):

Date/ Time	Total Length (mm)	Diversion Flow (cfs)	Juveniles per Acre-Foot Diverted
May 17			
1027	15.6	12.8	0.92
1135	14.8	12.5	0.89
May 20			
0600	23	14.5	0.76
2358	25.5	12.5	0.41
May 27			
1111	26	14.6	0.81

These data support results of the previous assessment (DWR/USBR 1993). In general, delta smelt are probably most vulnerable to entrainment from February through June, during their larval and early juvenile stages. Swimming ability is weakest in the larval stage for most fish species. The irrigation season runs generally from late March or early April through September (Brown 1982), but varies from year to year depending on the weather, crop, and other factors. Diversions are minimal during December through February. Winter irrigation is usually for wheat or other grains and, in a drought year, for permanent crops (orchards, vineyards). The agricultural diversions now being studied often do not begin operations until late April or May. Some diversions are often operated intermittently during the irrigation season. Four of the five sample sites monitored in 1993 divert intermittently, including all irrigation diversions for Bouldin Island. Potentially, the period of highest losses of delta smelt to agricultural diversions would be April through June, based on their life stages at this time and timing of the irrigation season.

Predation and Competition

Other factors that may control the abundance of delta smelt are predation and competition from native and introduced fish species and introduced invertebrates. The available evidence is reviewed below.

Given than neither outflow nor CVP/SWP exports explain a majority of the annual variance in delta smelt abundance indices, it is likely that other factors play a significant role in the apparent decline of the species in the last 15-20 years. It is not possible to calculate the relative contribution of predation and competition to this decline, but, as the following discussion indicates, there are numerous indications that it is significant. Further, predation and competition could affect delta smelt throughout its range.

Predation

Balanced relationships between predator and prey populations may be disturbed by perturbations in their environment. Fish stocks are continually subjected to predation of fluctuating intensity, with the surplus prey becoming the established population; predator/prey populations are usually in dynamic equilibrium (Bagenal 1978). When a newly introduced predator begins to consume a prey population that has been in equilibrium with its competitors and other predators, the initial effect is an increase in the mortality rate of the prey. If stocks are declining and fish are unaccountably disappearing, the decline may be due to new predators or some perturbation that has favored native or introduced predators.

Although the assemblage of native fishes in this estuary evolved together, some disturbance could favor native predators such as Sacramento squawfish, steelhead, and Sacramento perch. This seems unlikely, however, because none of these is presently abundant in the estuary (Stevens *et al* 1990).

One change in the estuarine environment that could have favored native or introduced predators was increased water transparency in many regions of the upper estuary over the last 20 years (see "Water Quality" later in this chapter). Increased water transparency could render delta smelt more susceptible to predation. This hypothesis is supported by recent studies by Ligon *et al* (in prep). Relatively small increases in turbidity at levels similar to those in Delta tributaries were shown to strongly inhibit largemouth bass predation. These results are consistent with studies using bluegill, another centrarchid. The extent to which these results apply to striped bass and other Delta predators is not known. However, recent decreases in turbidity levels in many parts of the estuary could have adversely affected delta smelt despite a reduction in the striped bass population since the late 1970s.

Correlation analyses suggest delta smelt abundance in several regions of the upper estuary declined significantly with increasing water transparency during various seasons and was most significant in winter and spring. However, this does not prove cause-and-effect; it only suggests a relationship between delta smelt abundance and water transparency. Water transparency may affect year class strength during the first half of each year; that is, increases in water transparency may adversely affect delta smelt during the period when year class strength is thought to be set. Comparisons between summer tow-net indices and fall midwater trawl indices suggest smelt year class strength is set before July (Stevens *et al* 1990).

Predation by introduced fish species is another possibility, although several of these species have also declined in abundance during the same period as delta smelt (Stevens *et al* 1990). Catfish and sunfish are predatory fish but were established in this estuary well before the decline of delta smelt. Striped bass has been the most abundant predator in the estuarine area inhabited by delta smelt (Stevens *et al* 1990) but has been present in the Delta for more than a hundred years. Previously, much larger populations of both striped bass and delta smelt coexisted (Sweetnam and Stevens 1993). Food habit studies in the 1960s, when both species were abundant, indicate that, although occasionally consumed, delta smelt were not a major prey item for striped bass. The planting of large numbers of juvenile striped bass near Rio Vista, an area where delta smelt have concentrated in recent years, may affect smelt to some degree through increased predation. This issue is now moot, because DFG discontinued stocking hatchery-produced striped bass in the estuary in 1992 due to concerns regarding predation on young winter-run salmon (Sweetnam and Stevens 1993).

The most likely predation factor in the delta smelt decline is that a recently introduced species may be responsible. Introduced species colonize rapidly under favorable conditions and may disrupt the structure of fish communities by competing with or preying on native fishes (Herbold and Moyle 1986). The species likely to have the greatest effect are the inland silverside (introduced in 1975) and the yellowfin and chameleon gobies (both introduced in the late 1950s). Chameleon gobies are not a likely suspect, since they have been abundant in the upper estuary and Delta only since the mid- to late 1980s. However, they may limit recovery of delta smelt populations.

Inland silverside, which could prey on delta smelt eggs and larvae, has been collected where delta smelt may be spawning (Moyle *et al* 1993), but its measured abundance has been highly variable (Sweetnam and Stevens 1993). Bennett and Moyle (1993) described research to be conducted at UC-Davis, to investigate competition and predation of inland silverside as co-factors with outflow as the cause of the dramatic declines in delta smelt abundance. They suspect such a situation between silverside and smelt in the estuary for several reasons:

- Silverside abundance increased dramatically in the early 1980s, concurrent with the smelt decline (Bennett and Moyle 1993) (Figure 71). Silverside co-occurs in high abundance with smelt eggs and larvae.

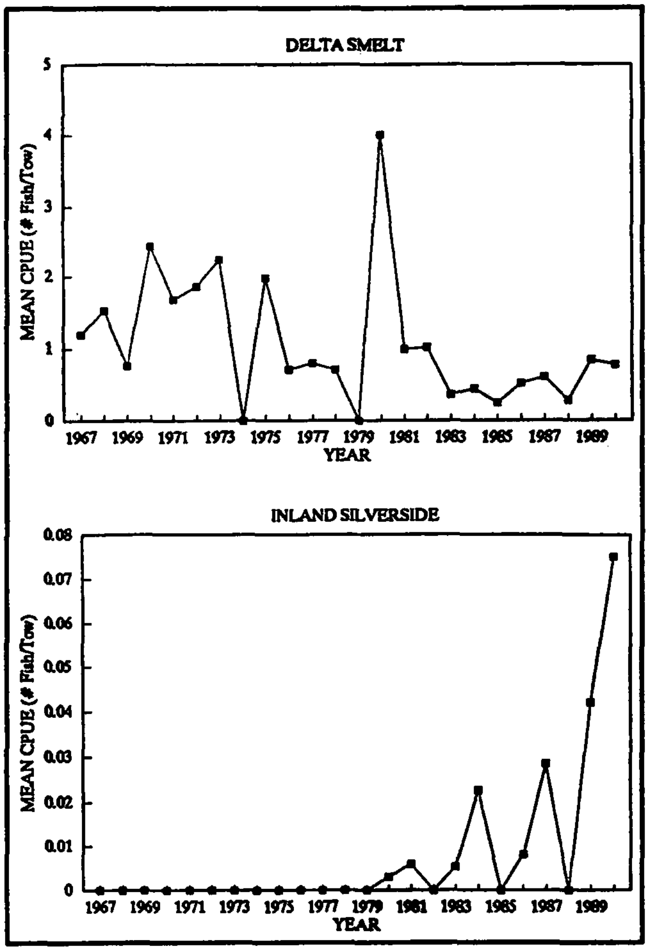


Figure 71
MEAN CATCH PER TOW OF
DELTA SMELT AND INLAND SILVERSIDE IN THE
FALL MIDWATER TRAWL SURVEY, 1967 TO 1990

- Recent predation experiments using large field enclosures in this estuary (Bennett *et al* 1993) indicate that inland silversides readily consume striped bass larvae (5-8 mm SL), producing higher daily mortality rates than those reported in similar experiments using larval fish prey and small fish predators (Pepin *et al* 1992; and Cowan and Houde 1993, cited by Bennett and Moyle 1993). Prey selection was also found to be size-based. Therefore, since smelt larvae are of similar size as those striped bass larvae used by Bennett *et al* (1993), they would also be consumed if encountered.
- Low outflow may exacerbate predation on larval smelt by concentrating the spawning smelt in areas of high silverside abundance in the Delta.
- A recent analysis of FWS beach seine data (B. Bennett, pers comm) appears to indicate that inland silverside abundance is negatively correlated with delta smelt abundance in both wet and dry years. That is, increased silverside abundance coincides with decreased delta smelt abundance. An exception to this occurred in 1993, when both silverside and delta smelt were abundant. In wet years, impacts to the delta smelt population may be lower because the probability is lower that the two species will co-occur due to a wider distribution of delta smelt.

Yellowfin and chameleon gobies could also prey on delta smelt eggs and young. Although generally not thought of as predators, gobies are small, bottom-dwelling carnivores of inshore areas that exhibit a lie-in-wait feeding behavior (McGinnis 1984). Yellowfin gobies are larger than the native marine gobies. Both species feed on invertebrates and small fish. In general, gobies are able to adapt to low salinities and to habitats not accessible to other fishes. In the Delta, chameleon goby appears to have a long spawning season, with larval stages collected from early April through mid-September (Spaar 1993). The young are zooplankton feeders until they reach 1-2 cm, at which time they assume their bottom-oriented piscivorous predatory role. Gobies also are known to consume fish eggs (Jude *et al* 1992).

Due to the bottom-dwelling, inshore nature of yellowfin and chameleon gobies, juveniles and adults are fairly successful in avoiding midwater tow-nets and trawl nets and generally appear to be low in abundance in these types of samples. However, goby larvae are susceptible to egg and larval nets, and juveniles and adults appear to be susceptible to otter trawls, which sample on the bottom. Results from egg and larval sampling in the southern Delta indicate that chameleon goby abundance increased tremendously, from comprising 2% (291 larvae, 0.95 larvae/tow) of the 1988 catch to its peak of 87% (137,455 larvae, 584.91 larvae/tow) of the 1991 catch (Spaar 1990; Spaar 1992). While abundance declined to 83,293 larvae (61% of total catch, 259.48 larvae/tow) in 1992, it is still the most abundant larval species caught at this study's central and southern Delta sites. Although sampling began in mid-February in 1991 and 1992, no chameleon goby were caught before April, as in other years. The tremendous numbers of larvae being produced alone would indicate this species could have a large impact on the estuarine ecosystem.

An ongoing, 14-year otter trawl survey in Suisun Marsh, done for Water Resources by UC-Davis, found that abundance of both yellowfin and chameleon goby has fluctuated dramatically in recent years, whereas other species have declined steadily (Meng *et al* 1993) (Figure 72). Recent work indicates that the chameleon goby appears to be a different species from the *Tridentiger trigonocephalus* that first invaded South Bay (Matern 1994). This species is not known outside of Asia, and its occurrence in Suisun Marsh is now being confirmed.

Figure 72
ABUNDANCE OF
CHAMELEON GOBY, YELLOWFIN GOBY, AND TOTAL FISH
IN SUISUN MARSH, 1979 TO 1992
Source: Meng *et al* 1993.

Native species, including delta smelt, were found more often in small, dead-end sloughs; introduced species (particularly chameleon goby) were found both in dead-end sloughs and the larger sloughs of the marsh. Yellowfin goby increased dramatically throughout the estuary from their first appearance in 1965 to their extreme abundance in 1967 (Britton *et al* 1970), and was the third most abundant fish caught in the marsh in 1980 through 1982. Its abundance in the marsh has fluctuated since that time (Figure 72), but it has remained one of the more abundant species (fourth in 1991 and third in 1992). Chameleon goby did not follow this pattern; it was first caught in the marsh in 1985 and by 1989 it was the most abundant fish caught. Recently, its numbers have declined, as might be expected for an introduced species. These changes in fish abundance in the marsh suggest introduced species, along with other environmental disturbances, have altered fish communities.

Competition

Effects of competition among species are difficult to determine. Introduced fish and invertebrate species may compete directly with delta smelt (adults and young) for food (phytoplankton and zooplankton) or may alter the species composition of the zooplankton community. The zooplankton food niche was originally divided between the native delta and longfin smelts (McGinnis 1984). Delta smelt occupies the fresher, upstream areas of the estuary, and longfin smelt occupies the more saline, lower reaches. The natural niche segregation between these species has been influenced by the introduction of exotic zooplankton feeders, which could compete with delta smelt for food resources. Although zooplankton food supply has improved in recent years (see next section, "Food Abundance"), this does not preclude the possibility that some form of competition, such as food depletion, could affect delta smelt.

Several introduced fish species could compete with delta smelt for food. Young striped bass, American shad, threadfin shad, inland silverside, chameleon goby, and wakasagi are all zooplankton feeders and probably compete with delta smelt for food. Striped bass has shown signs of population decline coinciding with or preceding the decline of delta smelt.

Inland silverside has been shown to be a successful colonizer and competitor with native or established species (Mense 1967; Li *et al* 1976; Bengston 1985). In Lake Texoma, Oklahoma, inland silverside completely replaced brook silverside in about 2 years after its introduction (Mense 1967). As adults, delta smelt and inland silverside are of similar size and have overlapping diet requirements, thus they may compete if shared food resources are limited (Bennett and Moyle 1993). In the Bay/Delta system, low food abundance and changing composition suggest food may be limiting for larvae as well as adults (Moyle *et al* 1992). Bennett and Moyle (1993) are investigating potential competition between inland silverside and delta smelt. Silversides form dense schools in shoal areas, whereas smelt are more abundant in river channels; this does suggest some degree of habitat segregation. However, they theorize that considerable overlap may occur between the species at prime feeding times. In Clear Lake, silversides are known to undertake diel inshore-offshore feeding migrations. Such behavior may produce locally depressed food resources for delta smelt at favored feeding sites and times, increasing the probability of resource competition.

Competition for food at the larval stage may also be increasing due to an unexplained population explosion of the chameleon goby in 1990 (Sweetnam and Stevens 1993). Wakasagi may also compete with delta smelt for food in the upper end of the delta smelt's range on the Sacramento River, but no research has been done on this.

The Asian clam, *Potamocorbula amurensis*, was first discovered in Suisun Bay in 1986. It may compete directly with delta smelt for food by consuming *Eurytemora affinis*[1] nauplii. *P. amurensis* has been implicated as the cause for the sharp decline of *E. affinis* in late 1988 (Kimmerer 1992a). It may also impact phytoplankton dynamics by decreasing phytoplankton biomass, thereby affecting higher trophic levels. However, *P. amurensis* occurs primarily downstream of Antioch, which has been the extreme lower range for delta smelt in recent years, so their overlap has probably been minimal. Overlap may

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[1] This copepod is a primary food of delta smelt.

increase in wetter years, such as 1993, unless distribution of the clam shifts downstream in such years. *P. amurensis* will likely be a continued problem for this region, as recent U.S. Geological Survey results show the clam was not significantly displaced downstream by high flows in 1993 (Jan Thompson, USGS, unpublished data). Despite such overlap in 1993, delta smelt abundance increased in response to higher flows, which transported many juveniles into Suisun Bay.

Food Abundance

Changes in the concentration of either phytoplankton or zooplankton could affect delta smelt abundance through food chain interactions. Exact food requirements of delta smelt are not known, but prey densities in the Bay/Delta appear low relative to other systems in the United States, creating the potential for food limitation (Miller 1991). Abundance of food for delta smelt is a function of three factors: total food abundance in the river/bay/delta ecosystem; competition for food; and changes in food organisms. These interrelated factors have the potential for cumulative effects.

Recent trends in concentration and composition of phytoplankton and zooplankton are described below in relation to delta smelt. It is important to note that food chain effects may be closely linked with entrapment zone position. Both phytoplankton and *E. affinis* have been shown to occur at peak abundances within the entrapment zone (Kimmerer 1992a). Although the abundance of each is also correlated to some degree with entrapment zone location, the mechanism for this association is unknown. The correlations may be due to underlying relationships with flow, strength of entrapment, or other factors that vary with entrapment zone position (Kimmerer 1992a; Jassby 1993). The possible importance of the entrapment zone is described at the beginning of this chapter.

Phytoplankton Trends

Phytoplankton levels were analyzed by removing the effects of specific conductance and season, which cause short-term and localized variation. "Anomalies" were calculated by subtracting pigment[1] measurements for each date and station from the mean pigment value for the specific conductance class (Table 5) and month. A positive anomaly indicates pigment levels were higher than would be expected for the respective month and specific conductance class. Use of anomalies is described in detail by Obrebski *et al* (1992).

Table 5

AVERAGE SPECIFIC CONDUCTANCE AND SALINITY IN SPECIFIC CONDUCTANCE CLASSES 1 TO 20

• Specific conductance values shown are referenced to a standard temperature, but change at different temperatures.

Class	Specific Conductance (µS/cm*)	Salinity (ppt)
1	126	0.071
2	150	0.084
3	167	0.094
4	187	0.105
5	210	0.118
6	240	0.135
7	284	0.159
8	355	0.199
9	473	0.265
10	674	0.378
11	979	0.550
12	1554	0.874
13	2511	1.417
14	3934	2.229
15	5817	3.313
16	8032	4.604
17	10583	6.112
18	13665	7.964
19	17444	10.284
20	24302	14.635

* µS/cm = microSiemens per centimeter

** ppt = parts per thousand

Over the last 20 years, a significant decline in phytoplankton biomass has been observed ($P<0.01$) in the region between Rio Vista on the Sacramento River and Martinez at the west end of Suisun Bay (Figure 73). Chlorophyll *a* concentrations declined sharply between 1972 and 1977, followed by increased levels between 1978 and 1982 and then another decline from 1983 through 1991. Mean annual chlorophyll *a* concentrations have been extremely low (<4 µg/L) since 1987. Seasonal and annual variation in phytoplankton is hypothesized to result from transport from outflow and interactions with benthic grazers (Alpine and Cloern 1992). Trends in phaeophytin *a* levels were similar to those for chlorophyll *a*. Ratios of chlorophyll *a* to phaeophytin

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[1] Pigment is an indicator of phytoplankton levels.

a hovered around zero during most years, although unexplained spikes in chlorophyll *a* occurred in 1979 and 1982. These results suggest the relationship between phytoplankton growth and mortality has been consistent in this region. However, this analysis does not reflect localized changes within regions of the Delta or shifts in species composition.

It appears that phytoplankton abundance may affect delta smelt directly, as well as through the

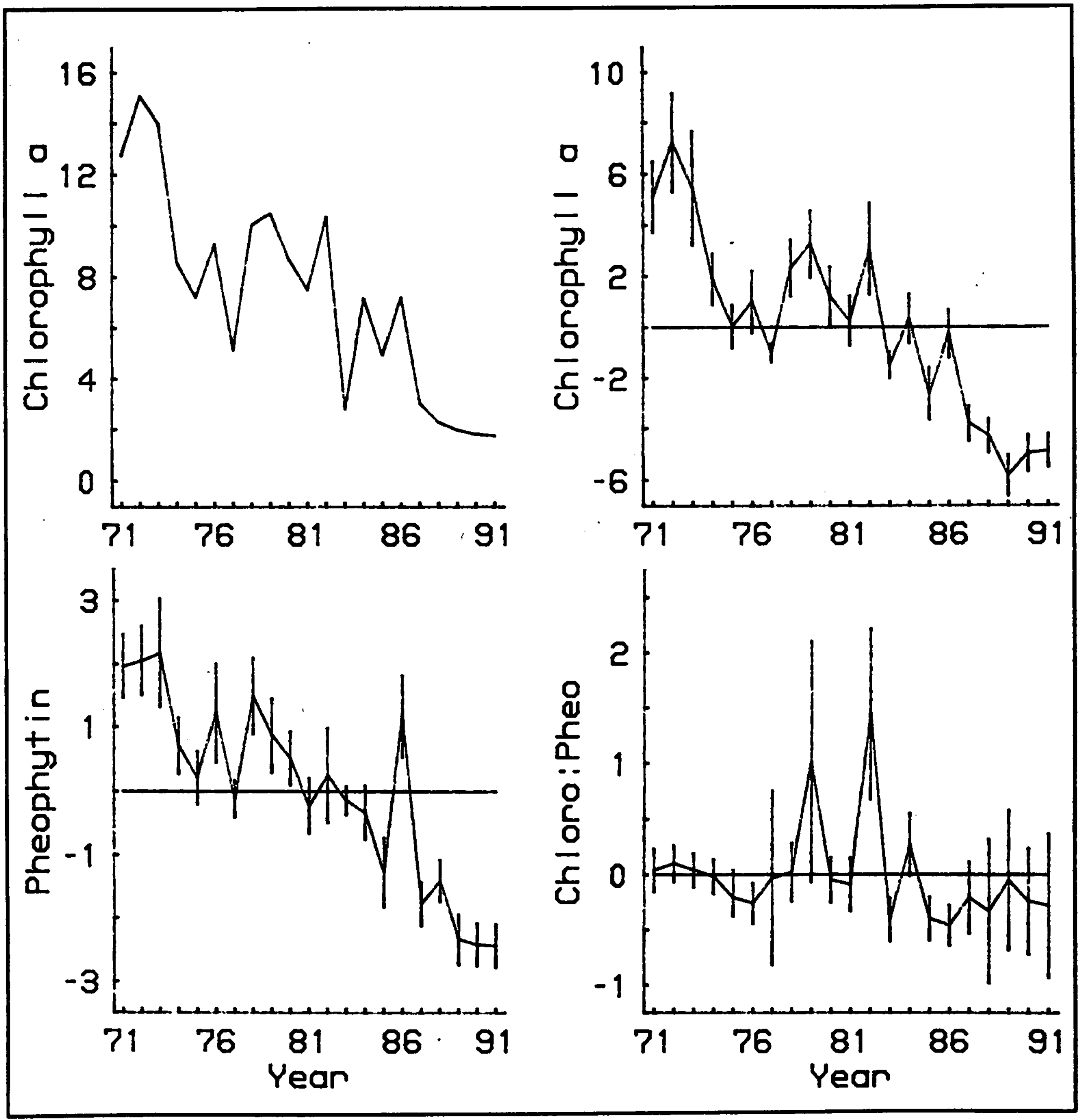


Figure 73
PIGMENT CONCENTRATIONS, RIO VISTA TO MARTINEZ, 1971 TO 1991
The upper left graph is mean annual concentration, in µg/L.
All other graphs are mean annual anomalies (described in text), with 95% confidence intervals.
Horizontal lines mark zero anomaly value.

zooplankton food chain. In laboratory culturing of delta smelt, Mager (1993) found that larvae first began feeding on day 4 (after hatch) on phytoplankton and on day 6 were feeding on rotifers. Prior to this, there has been no mention of phytoplankton as a food item for delta smelt in any reports or papers. The period of first feeding for larval fish is generally thought to be a critical time for larval survival.

Zooplankton Trends

Studies indicate copepods are the principal prey item of delta smelt, but species composition has shifted. Post-larval smelt collected in 1977 were found to feed almost exclusively on copepods (Moyle *et al* 1992). Gut analysis showed that the calanoid copepod, *Eurytemora affinis* was the dominant prey item (68% by volume), followed by *Cyclops* sp. (31%) and harpacticoid copepods (1%). Adult smelt were found to feed throughout the year on copepods and seasonally on cladocerans (*Daphnia* sp., *Bosmina longirostris*) (Moyle *et al* 1992). Opossum shrimp (*Neomysis mercedis*) was generally of secondary importance. By contrast, the main food item in 1988 samples was *Pseudodiaptomus forbesi*, an exotic species. *Sinocalanus doerii*, another exotic species, has also been found in gut samples, as have *Corophium* sp., Gammaridae, and Chironmidae (Moyle *et al* 1992).

Zooplankton data were examined using anomaly values, described in the foregoing section, to examine long-term trends. Trends for *E. affinis*, the most important prey item in the 1970s, show abundance of this copepod has declined significantly in the area between Rio Vista and Martinez during the last 18 years (Figure 74). The decline was gradual but continuous between 1972 and 1983, followed by a brief period of stable abundances, and ending in a major decline between 1987 and 1990.

The exotic clam *Potamocorbula amurensis* is thought to be at least partly responsible for the most recent decline of *E. affinis*. This clam was well established in Suisun Bay by 1987 and, with its efficient feeding habits, has managed to consume a significant portion of the phytoplankton biomass in Suisun Bay (Alpine and Cloern 1992) and possibly a significant number of juvenile *E. affinis* (Kimmerer 1992a).

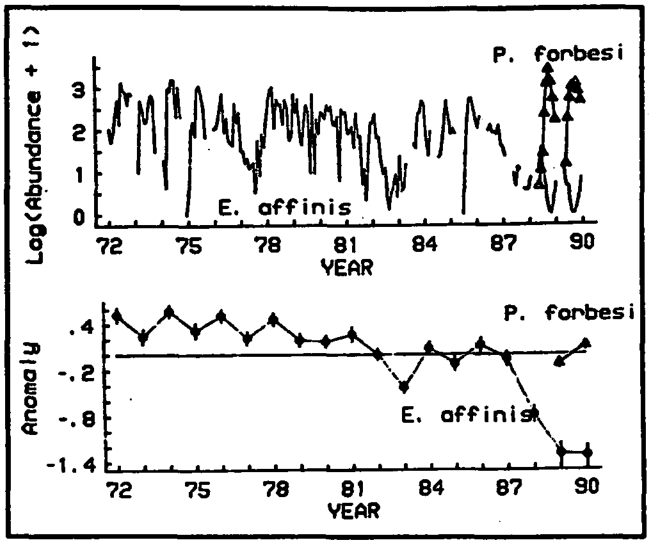


Figure 74
ZOOPLANKTON CONCENTRATIONS,
RIO VISTA TO MARTINEZ, 1972 TO 1990
Top graph is mean monthly log abundance of zooplankton from all sites sampled.
Bottom graph is mean annual anomalies (described in text),
with 95% confidence intervals.

The introduced zooplankton *Pseudodiaptomus forbesi* was discovered in this estuary in 1987 (Orsi and Walter 1991). By fall 1988, this copepod was found in high concentrations (>1000 m^{-3}) in many regions of the upper estuary. Diet studies of delta smelt completed in 1988 and 1991 show this organism is now the main food source of delta smelt. Abundances of *P. forbesi* in 1989 and 1990 were equal to those of *E. affinis* prior to its precipitous decline in the late 1980s (Figure 74). Thus, while abundance of *E. affinis* remains low, total food supply for delta smelt appears to have increased in recent years. Herbold *et al* (1992) made similar conclusions about delta smelt food availability. However, conclusions about the adequacy of delta smelt food supplies must be viewed with caution because many questions remain to be answered about the species' ability to utilize *P. forbesi* as a food source, in particular: whether delta smelt must expend more or less energy to capture and/or digest *P. forbesi* than *E. affinis*; and whether the new food source has equivalent nutritional value for delta smelt. In short, total biomass of available food may not be a sound measure of the species' ability to utilize a new food source.

Water Quality

Few water quality factors have the potential to affect the abundance and distribution of delta smelt over its entire range. Water temperature, water transparency, and specific conductance (salinity) are the water quality parameters that could most likely affect population levels, given the environmental changes within the estuary. Constituents such as pH and dissolved oxygen have not changed on a scale large enough to affect a mobile organism such as delta smelt, and chemicals such as silica, nitrate, and phosphate are not thought to directly affect delta smelt.

This section discusses the potential for water temperature, water transparency, and specific conductance to affect the delta smelt population. Data for many of the analyses were partitioned among various regions of the upper estuary (Figure 75) to permit a more detailed examination. Results should be interpreted with caution, however, because there is evidence of serial autocorrelation problems with the tow-net and midwater trawl data. This concern is discussed in the section "Entrapment Zone" earlier in this chapter.

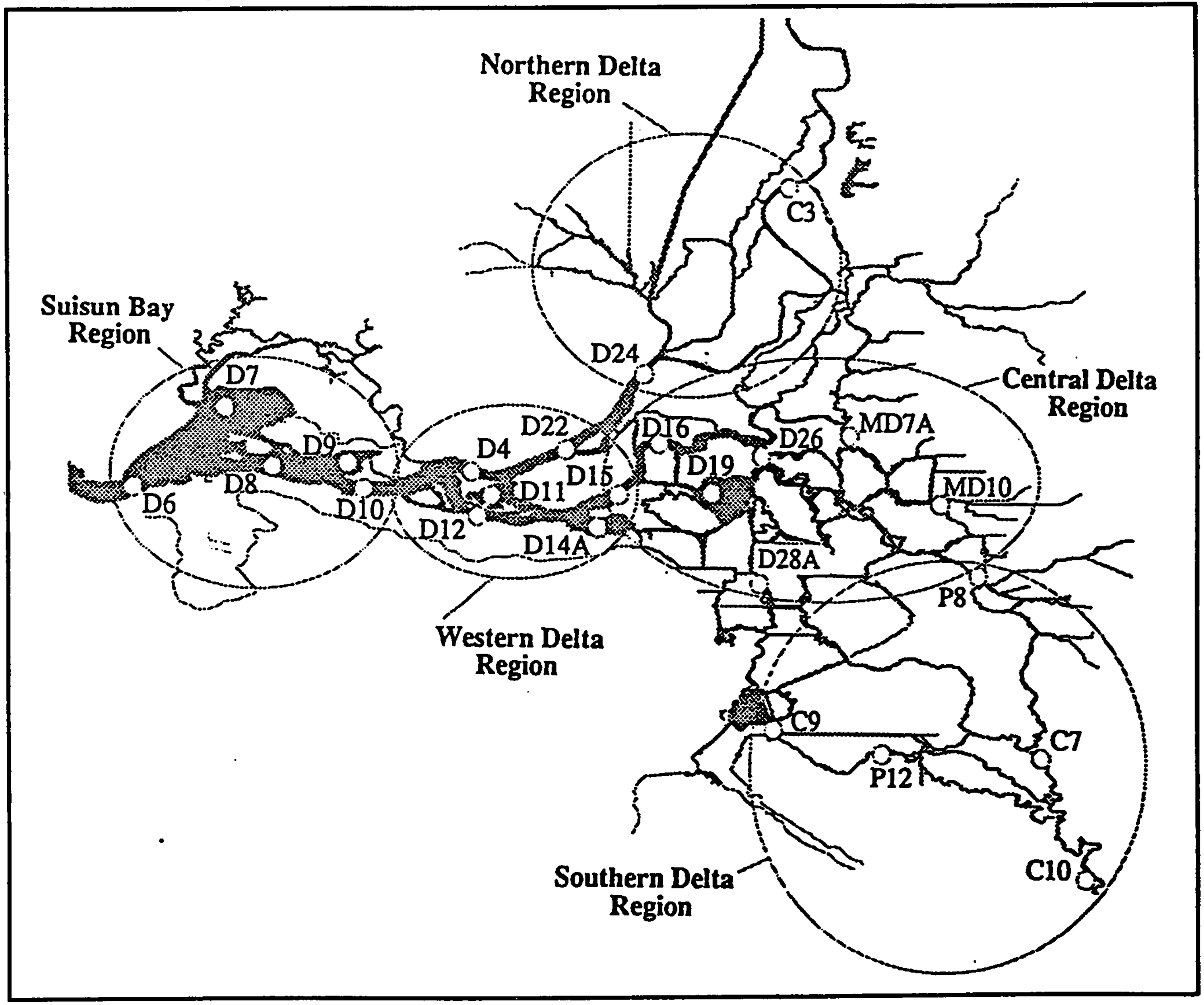


Figure 75

LOCATION OF CORE DATASET SITES AND REGIONS USED IN WATER QUALITY ANALYSES

For these analyses, Site D15 was considered part of the western Delta only.

Site C10 was not included in the Secchi disc depth analysis because this constituent was not measured at C10 after 1982.

Water Temperature

In this estuary, water temperature is regulated mainly by air temperature, but river inflow and tidal intrusions also influence estuarine water temperatures. Long-term trends in surface water temperature show a highly seasonal pattern that is consistent among years and regions (Figure 76). Water temperatures are lowest during winter and highest during summer.

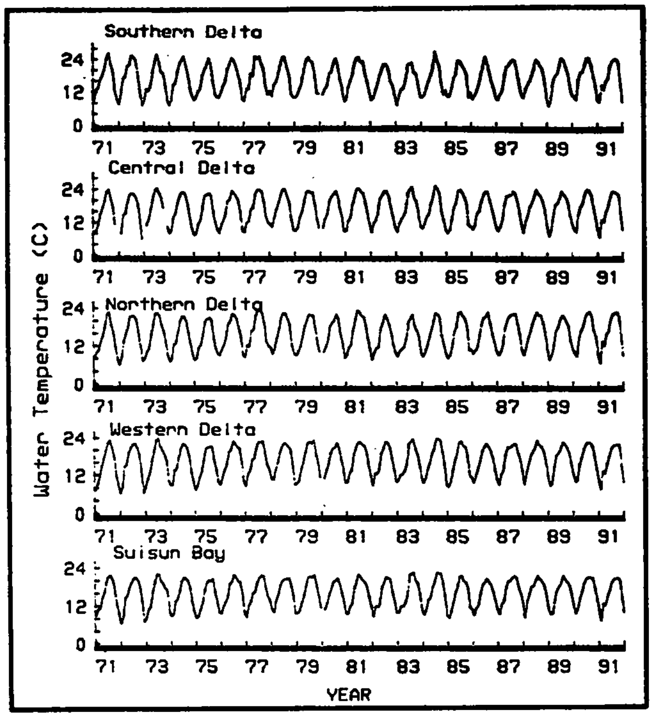


Figure 76

MEAN MONTHLY WATER TEMPERATURE FOR FIVE REGIONS IN THE UPPER ESTUARY, 1971 TO 1991

The predictable pattern of water temperature contributes directly to many of the seasonal changes noted throughout the estuary. Water temperature outside the optimal range for delta smelt could alter growth and mortality rates of this fish.

Water temperatures during delta smelt spawning reportedly range from 7 to 15°C (Wang 1986). However, water temperatures measured during high larval abundance (April-June) typically range from 15 to 23°C (DFG 1992). The ability of delta smelt to survive higher temperatures is supported by Moyle *et al* (1992), who found delta smelt in waters ranging from 6 to 23°C and averaging 15°C.

Long-term water temperature trends in the upper estuary show little or no pattern that could account for a decline in delta smelt abundance or a change in distribution. Lehman and Smith (1991) noted a slight increase in average monthly temperatures in the late 1970s, before most delta smelt abundance indices began to decline. Minor temperature changes could have caused a delayed response through the food chain or other mechanisms. However, Stevens *et al* (1990) found no relationship (by regression analysis) between water temperature and smelt abundance. During the last 20 years, water temperatures in all regions of the upper estuary have only occasionally been outside an assumed delta smelt tolerance range of 7-15°C between December and March and 15-23°C between April and June (Figure 76). Thus, the analyses suggest water temperature has not affected delta smelt abundance and distribution.

Water Transparency

Water transparency varies in direct proportion to concentration of suspended organic and inorganic particles. The major source of inorganic material is suspended sediments brought in with streamflows. This is a highly seasonal component that increases with runoff and flow. The two major forms of organic matter are particulate organic material and phytoplankton. This component is also seasonal; phytoplankton concentrations tend to be highest during spring through fall, and particulate organic material is probably highest during fall and winter.

Although any change in water transparency could affect delta smelt, increases in water clarity are probably of most concern. Increased water transparency may render delta smelt more susceptible to predation or decrease food availability, as many zooplankton are negatively phototactic.

Secchi disc depth readings show water transparency has varied greatly within and among years throughout the upper estuary but suggest an increasing trend in some regions (Figure 77).

Further analysis involving removal of the variation in Secchi disc depth due to season and salinity (anomaly calculations, described earlier) shows water transparency has increased significantly (slope of regression line >0; P<0.001) in all regions of the upper estuary except Suisun Bay (Figure 78).

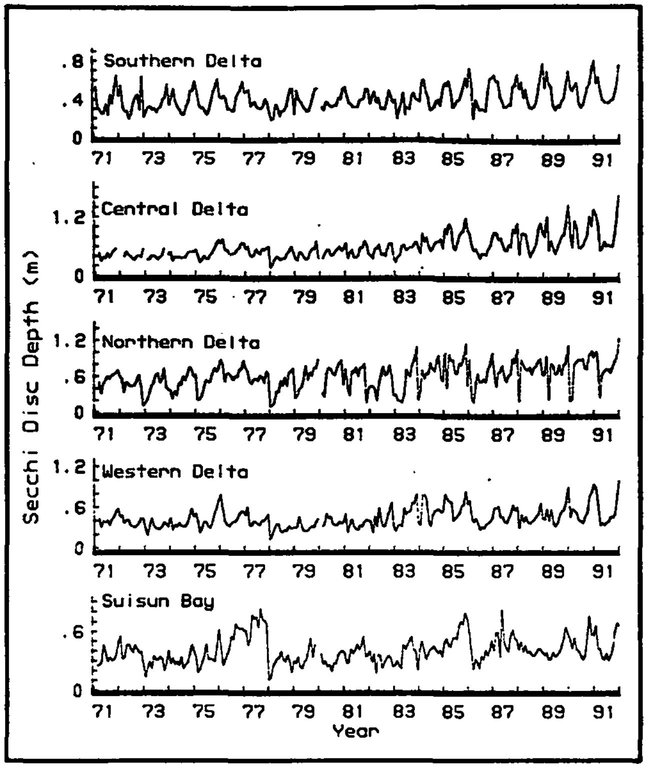


Figure 77
MEAN MONTHLY SECCHI DISC DEPTH
FOR FIVE REGIONS IN THE UPPER ESTUARY, 1971 TO 1991

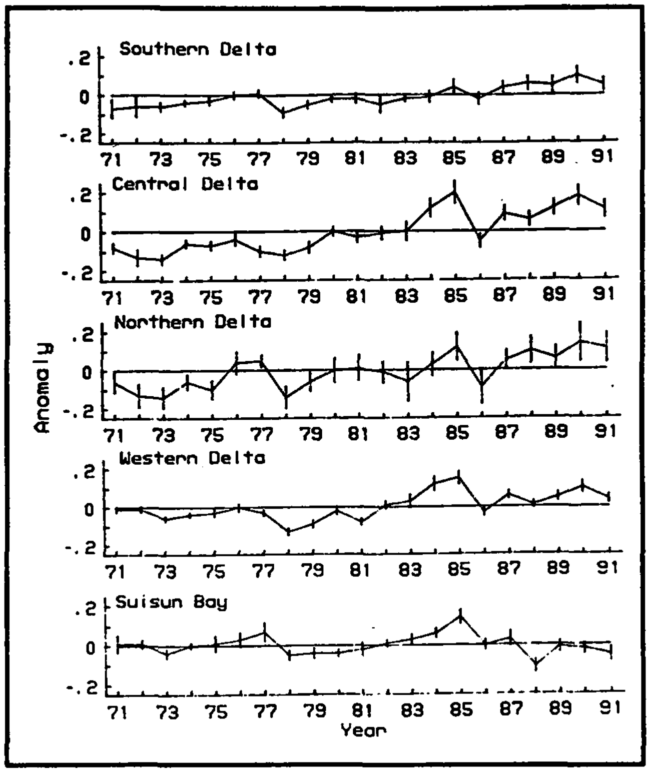


Figure 78
SECCHI DISC DEPTH ANOMALIES
FOR FIVE REGIONS IN THE UPPER ESTUARY, 1971 TO 1991
Values are annual mean anomalies, with 95% confidence intervals.

Stevens *et al* (1990) found a strong relationship between fall delta smelt abundance and July-October copepod abundance and water transparency. However, they considered this relationship tentative because the strong connection between summer tow-net indices and fall midwater trawl indices suggests smelt year-class strength is set before July.

Tests results for relationships involving various water quality and biological constituents can be misleading because most chemical and biological constituents vary with salinity. Delta smelt are no exception, having a definite abundance pattern over the salinity range common to the upper estuary (Figure 79). Thus, significant relationships between two constituents could occur because of covariation with salinity, when in fact there is little or no direct relationship between the two.

We have evaluated the relationship between water transparency and delta smelt abundance further with a somewhat different analytical approach from that used by Stevens *et al* (1990). First, the upper estuary was divided into five geographic regions (Figure 75). This increases the sensitivity of the analysis, because water transparency readings are not summed between regions that could be governed by different processes. Second, seasonal Secchi disc depth anomalies were calculated for each region. Anomalies were calculated to remove the effects of salinity from Secchi disc depth trends and, therefore, the covariation between water transparency and delta smelt abundance due to salinity. The anomalies were then correlated with an appropriate measure of abundance (tow-net index, midwater trawl index, or salvage), depending on the season and region, summarized in Table 6.

Results show delta smelt abundance is negatively correlated with water transparency. In addition, these correlations suggest delta smelt abundance in several regions declined significantly with increasing water transparency during various seasons. The relationship between delta smelt abundance

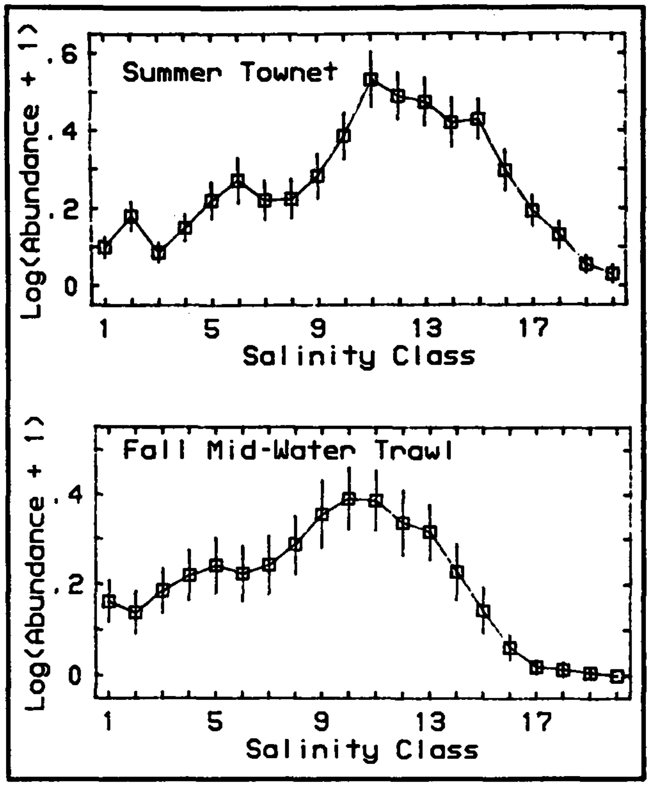


Figure 79

DELTA SMELT ABUNDANCE VERSUS SALINITY CLASS

All values are mean log base 10 abundance, with 95% confidence intervals.
Salinity classes are summarized in Table 6.

and water transparency was most often significant in tow-net analyses for winter and spring. This suggests water transparency has the greatest effect on year-class strength during the first half of each year; that is, increases in water transparency may adversely affect larval and juvenile smelt during the time when DFG believes year-class strength is set (Stevens *et al* 1990). If this relationship is not spurious, the effect may be related to increased vulnerability to predation. This issue is discussed in further detail later in this chapter.

These results suggest an inverse association between delta smelt abundance and water transparency, for which we may hypothesize at least two reasonable causal mechanisms, and they are consistent with the conclusion of Stevens *et al* (1990) that delta smelt year-class strength is set before July. However, they do not prove cause and effect. Moreover, autocorrelation problems could detract from reliability of the results. Studies designed specifically to test this relationship are needed before a definitive conclusion can be reached.

Table 6

RESULTS OF CORRELATION ANALYSES BETWEEN DELTA SMELT ABUNDANCE[1] AND MEAN SEASONAL ESTIMATES OF SECCHI DISC DEPTH AND SPECIFIC CONDUCTANCE FOR FIVE REGIONS IN THE UPPER ESTUARY

Constituent values are mean seasonal specific conductance and mean seasonal Secchi disc depth anomalies (variation due to specific conductance removed).
All results are for 1971 through 1991, except the salvage data, which are for 1976 through 1991.

Constituent	Correlation Coefficients			
	Winter	Spring	Summer	Fall
Southern Delta				
Secchi Disc Depth	-0.70***	-0.42*	-0.02	-0.45*
Specific Conductance	0.33	-0.02	0.17	0.04
Secchi Disc Depth[2]	-0.67**	0.13	0.05	-0.02
Specific Conductance[2]	-0.02	0.27	0.31	0.55**
Central Delta				
Secchi Disc Depth	-0.58**	-0.64***	-0.40*	-0.27
Specific Conductance	-0.10	0.08	-0.07	-0.25
Northern Delta				
Secchi Disc Depth	-0.30	-0.29	-0.36*	-0.39*
Specific Conductance	-0.05	0.11	-0.002	-0.14
Western Delta				
Secchi Disc Depth	-0.51**	-0.59**	-0.33	-0.09
Specific Conductance	-0.09	-0.12	0.10	-0.25
Suisun Bay				
Secchi Disc Depth	-0.46*	-0.16	-0.24	-0.07
Specific Conductance	-0.15	-0.003	-0.10	-0.19

* $P < 0.05$
** $P \leq 0.01$
*** $P < 0.005$

[1] The summer tow-net abundance index was used in winter and spring correlations. The midwater trawl abundance index was used in summer and fall correlations. Abundance of delta smelt salvaged at the SWP was *also correlated with the water quality constituents in the southern Delta region.*

[2] Constituent correlated with mean seasonal abundance of delta smelt salvaged at the SWP.

Specific Conductance

In this estuary, variations in specific conductance are driven primarily by the movement of salt water. The southern Delta region is a notable exception. Agricultural drainage water can comprise a substantial portion of the water volume in this area, thereby altering specific conductance independent of salt water movement. Specific conductance also varies with temperature, so values are usually referenced to a single temperature level. Numerous chemical and biological constituents are correlated with specific conductance, a measurement from which salinity can be determined (Millero 1984). Changes in specific conductance affect the ability of delta smelt to regulate their body fluids, and exposure to water outside its optimal salinity range are physiologically stressful.

Specific conductance directly affects distribution of delta smelt, which appears to have an optimal salinity range above or below which abundances decline (Figure 79). Tow-net and midwater trawl catches indicate delta smelt are most abundant between 800 and 7700 µS/cm (0.45-4.4 ppt). This is consistent with Moyle *et al* (1992), who found delta smelt in salinities from 0 to 14 ppt, with a mean value of 2 ppt.

Long-term trends show specific conductance has varied substantially within and among regions of the upper estuary over the last 20 years (Figure 80). In all regions, specific conductance was highest during drought periods (1976-1977 and 1987-1991) and lowest during wet periods (1975 and 1983). However, even with the large variation and lengthy droughts, specific conductance has not exceeded the upper end of the salinity range in which smelt are most abundant (7700 µS/cm) in three of five regions examined. In Suisun Bay, specific conductance has exceeded the salinity range for delta smelt almost every year between 1971 and 1991, and since 1983 specific conductance has remained above 7700 µS/cm for extended periods. In the western Delta, specific conductance has exceeded the salinity range for delta smelt only during five drought years (1976, 1977, 1987, 1988, 1990).

Because specific conductance has such a major influence on the estuarine environment, further analyses were conducted to explore the possibility of a relationship between salinity and delta smelt abundance and distribution. Mean seasonal specific conductance values were correlated with appropriate measures of delta smelt abundance on a regional basis, summarized in Table 6. Although one significant relationship was found, most results showed no significant relationship between seasonal specific conductance and delta smelt abundance. These results are consistent with the interpretation of long-term specific conductance data, which show substantial variation, primarily within the salinity range of delta smelt except in Suisun Bay.

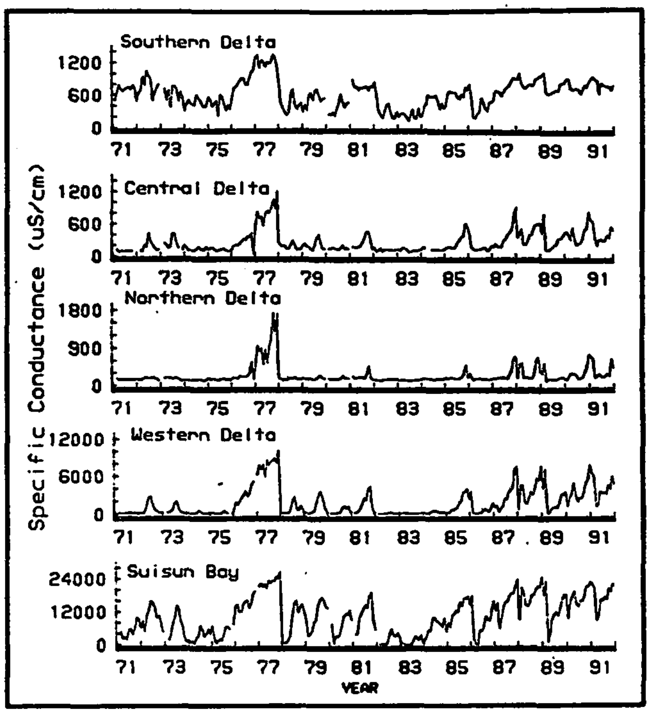


Figure 80
MEAN MONTHLY SPECIFIC CONDUCTANCE
FOR FIVE REGIONS IN THE UPPER ESTUARY, 1971 TO 1991

No long-term relationship between delta smelt abundance and specific conductance in Suisun Bay is evident, but the major decline in delta smelt and the most substantial increases in specific conductance did not occur until after 1983. Correlations between delta smelt abundance and mean seasonal specific conductance in Suisun Bay between 1984 and 1991 show a significant relationship only for spring ($r=-0.70$; $P<0.05$). This analysis suggests delta smelt may have been affected by the higher springtime (April-June) specific conductance levels in Suisun Bay after 1983.

Catches of delta smelt have also declined in Suisun Marsh. As with many other measures of delta smelt abundance, the turning point was 1983, after which only four delta smelt have been caught (Moyle *et al* 1992). Since 1983, monthly salinity values in the Suisun Marsh sampling region have exceeded the upper salinity range (4.4 ppt) where delta smelt are most abundant 36% of the time; between 1979 and 1982, monthly salinity values exceeded the upper range 20% of the time. Although these results suggest increased salinity levels could be limiting the distribution of delta smelt in Suisun Marsh, both salinity and smelt abundance have varied in this region (Figure 81). In fact, the increased variability in salinity may be limiting the occurrence of delta smelt in Suisun Marsh rather than the incidence of salinity values in excess of its salinity range. However, these results do suggest salinity levels and/or variability in Suisun Marsh may be adversely affecting delta smelt in this region.

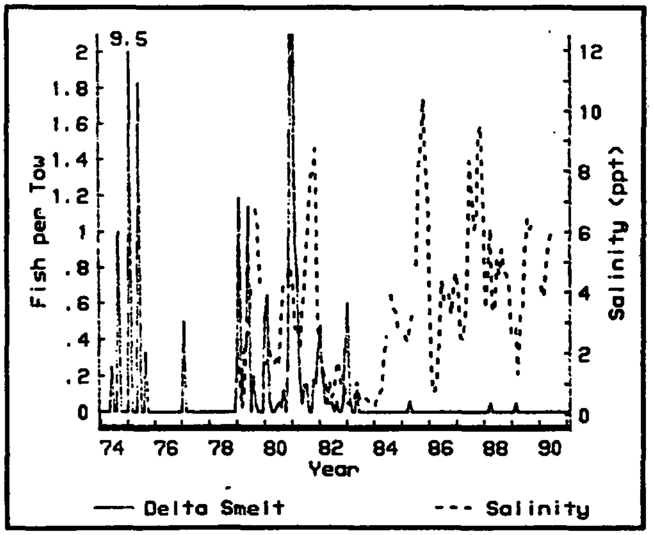


Figure 81
MEAN MONTHLY CATCH OF DELTA SMELT AND AVERAGE MONTHLY SALINITY IN SUISUN MARSH, 1974 TO 1990

Contaminants

Toxic contaminants have been identified as a factor that could affect delta smelt survival (FWS 1991). Possible pollutants include heavy metals, pesticides, herbicides, and polycyclic aromatic hydrocarbons. Although contaminants in the water column are probably the greatest threat to delta smelt, sediment interactions are also a concern. There is good evidence that pollutants in sediments may have significant effects on the biota of the benthic environment, even at low levels (Elder 1988).

Delta smelt eggs attach to rocks, gravel, or vegetation (Moyle 1976). Where these substrates contact sediments, interactions with contaminants are possible. Delta smelt larvae are generally pelagic rather than benthic (Moyle 1976), but they may also be at risk because significant numbers of larval and juvenile delta smelt have been observed near the bottom (Randy Baxter, DFG, unpublished data; Randy Mager, UC-Davis, unpublished data; also see "Agricultural Diversions" earlier in this chapter). Finally, there is evidence that disease occurs more frequently in fish larvae that contact toxic materials on the bottom in marine environments (Mearns, cited by Moyle and Cech 1988).

No toxicity studies have been conducted to verify the degree to which pollutants in water and sediments affect delta smelt. Available information is limited to monitoring of toxic compounds in the Delta and studies on other species. An epidemiological approach to evaluation of the influence of contaminants on delta smelt could, however, be developed by regressing abundance indices for each region of the Delta against monthly data from contaminant monitoring programs. Such statistical analysis could provide some indications, by inference, of the importance of contaminants to delta smelt survival, particularly for larval survival. Moreover, the Fish and Wildlife Service is studying levels of contaminants in several areas of the Delta where delta smelt are known to spawn, and these data should be available shortly (Schwartzbach, pers comm, 1994).

Monitoring of Contaminants

Concentrations of 9 trace metals and 39 chlorinated organic pesticides in the water column are measured biannually at 11 sites in the Delta and Suisun Bay. A report on Delta water quality during 1990 shows that the concentration of trace metals has decreased or remained the same since 1987, except for total iron concentration, which increased somewhat in 1990 (DWR 1992b). Between 1987 and 1990, organic pesticides were rarely found at concentrations above the minimum reporting limit. However, heavily localized or pulse events are rarely detected by the biannual survey. U.S. Geological Survey monitoring has found that volumes of agricultural water discharged into the Sacramento and San Joaquin rivers may persist as a toxic pulse through the Delta (Kuivila *et al* 1992, 1993; Meyers *et al* 1992). Compounds measured included molinate, carbofuran, thiobencarb, and diazinon, which were present at levels in excess of Environmental Protection Agency maximum criteria for aquatic life. Foe and Sheipline (1993) provide additional evidence that orchard and alfalfa pesticide runoff from the Central Valley often occurs at toxic levels.

San Francisco Regional Water Quality Control Board studies found cadmium, copper, chromium, nickel, lead, zinc, and mercury in sediments from Grizzly Bay and the Sacramento River within the range of delta smelt. These sediments have been found to be toxic to invertebrates in April, when larvae and young delta smelt occur in the system (Taberski *et al* 1992). Even if pollutants in the sediments do not directly affect delta smelt eggs or larvae, studies on heavy metal accumulation in waterfowl of San Francisco Bay (Ohlendorf *et al* 1986) and selenium accumulation in Suisun Bay (White *et al* 1989) demonstrate that impacts through the food chain are a threat.

Effects of Contaminants on Fish Species

No toxicity studies have been conducted on delta smelt, but there is evidence of problems for related species and other Delta fish. A 1978 study examined the effects of pollution on smelt populations (*Osmerus eperlanus*) in the lower River Elbe, Germany (Kohler and Holzel 1980). The river system was characterized by high levels of heavy metal pollution, pesticides, and polychlorinated biphenyls. In the study, smelt captured in the polluted Elbe showed severe liver problems compared to those from unpolluted areas in the North Sea.

Toxic substances have also been implicated in the mortality of striped bass at different life stages and may have played a role in their decline (Foe and Connor 1991). During the mid-1970s, increased applications of rice pesticides resulted in a sevenfold increase in toxic contamination in the Sacramento River flowing into the Delta. Bioassays showed that drain water entering the Sacramento River was toxic to striped bass larvae (Foe 1988, 1989). Foe (1989) also developed a correlation model, which showed that application rate of the rice pesticide methyl parathion accounted for a statistically significant portion of the variance in the young-of-the-year striped bass index.

The toxicity of agricultural discharges is supported by studies of the Colusa Basin Drain by UC-Davis (Bailey 1992). Drain water was found to be toxic to striped bass larvae for three consecutive seasons (1989 to 1991). The study also found a significant portion of the annual variation in striped bass recruitment from 1973 to 1988 could be accounted for by the level of rice pesticide used. Evidence also suggests that toxicity may have been reduced in 1991 and 1992 after a practice of holding irrigation water on fields throughout the growing season was implemented. However, striped bass did not increase in response to this change.

Studies of striped bass kills provide more evidence of possible toxicity problems. In May and June each year, up to hundreds or thousands of dead adult bass are in the estuary, particularly in Carquinez Strait. In 1985, researchers from UC-Berkeley discovered that moribund striped bass collected in a die-off showed liver disease disfunction, a possible indication of chronic problems from toxins (Brown *et al* 1987). This hypothesis is supported by Cashman *et al* (1992), who found that livers from moribund striped bass were greatly contaminated by chemicals compared to those from healthy fish caught in the Delta and Pacific Ocean. Contaminants included a variety of industrial, agricultural, and urban pollutants, and no one causative agent could be identified.

Other evidence of toxic contamination comes from D. Hinton and W. Bennett of UC-Davis. About 26% of the striped bass larvae they sampled in the Delta in 1988 and 1989 exhibited liver abnormalities characteristic of exposure to toxic chemicals. However, no quantitative estimates of mortality were made (Bennett *et al* 1993). Liver histology studies have been funded by the Interagency Program to determine whether toxins are a significant problem for delta smelt (Sweetnam 1992).

Finally, research from the San Joaquin River basin indicates subsurface agricultural drain water may be toxic to juvenile fish. Saiki *et al* (1992) demonstrated that water samples collected from an agricultural drain south of the Delta could cause mortality of juvenile Chinook salmon and striped bass. Although the samples were collected considerably upstream of delta smelt spawning areas, drain water may comprise a significant portion of the streamflow in the San Joaquin River during the irrigation season.

Although experimental studies of the effects of contaminants on delta smelt have not been conducted, indications of potential adverse effect are quite strong. Concentrations of toxins in the central Delta and Suisun Bay may be highest in dry years and could, therefore, explain some of the apparent relationship between year type and delta smelt abundance. Although the demonstrated effects of contaminants on striped bass larvae and juvenile Chinook salmon may be argued to be only indirect evidence of a potential effect on delta smelt, demonstrated impacts on relatively robust indicator species such as juvenile Chinook salmon and striped bass argue strongly for impacts to larval delta smelt. In human health, similar findings of toxicity in laboratory indicator species are considered adequate for formulation of public health policy. There is good, though indirect, evidence to suggest that contaminants may play a role in delta smelt abundance.

Disease and Parasites

Potential impacts from disease and parasites on fish range from relatively mild impairment of health to mortality. No doubt a relatively small percentage of infections are known, and for these the knowledge is incomplete. A major concern is that widespread introductions of pathogens have occurred through discharge of ballast waters from ships, intentional introductions for specific purposes, and the ornamental or aquatic pet trade (Stewart 1991). Given the large number of exotic fish and invertebrates introduced into this estuary (Hymanson 1992), new pathogens have likely entered the system, but there is little evidence as to whether disease or parasites significantly affect the abundance of delta smelt or impede species recovery. The limited observations are discussed in the following sections.

Disease

In some years, disease is thought to cause widespread mortality of carp and white catfish in the estuary, but mortality of delta smelt has not been specifically observed (Stevens *et al* 1990). Continuing studies at UC-Davis may help to resolve this issue. In particular, recent attempts to culture delta smelt have been hampered by several parasitic and bacterial infections. The most serious problem is *Mycobacterium*, a genus of bacteria known to cause chronic infections in fish and other species. The disease appears to be the major cause of delta smelt mortality in the laboratory, and it may cause deaths among wild fish as well.

The Interagency Program is funding studies by UC-Davis that include estimation of the incidence of infection among wild populations and evaluation of water temperature effects on bacterial infections (Hendrick 1993).

Parasites

Information about parasites is limited to general studies on other Delta species. Edwards and Nahhas (1968) and Hensley and Nahhas (1975) found that many types of protozoans, trematodes cestodes, nematodes, and crustaceans infect at least 28 species of Delta fish. Fish and Game (1989) also reports that striped bass in the Delta are more heavily infested with parasites than those on the Atlantic coast, indicating that the Delta fish may be more susceptible to infection (possibly because of greater environmental degradation from toxicants and pollutants) or that the species has poor defenses against endemic parasites.

Interbreeding with Wakasagi (Pond Smelt)

Under the assumption that delta smelt and wakasagi were the same species, wakasagi was introduced in 1959 from Japan into several California lakes and reservoirs as a forage fish for trout (Wales 1962). Wakasagi are present in Folsom Lake, American River, Sacramento River, Mokelumne River, and Cache Slough. Adults have been observed in Folsom Lake (1992), PG&E's Pittsburg and Contra Costa power plants (1990), and at the SWP and CVP (1994) (J. Wang, pers comm). If wakasagi were to become established in delta smelt spawning and rearing habitat, delta smelt could be out-competed and displaced.

Due to the immigration of wakasagi from Central Valley reservoirs to the estuary, Sweetnam and Stevens (1993) suggested that the possibility of genetic dilution of delta smelt by wakasagi has increased. For genetic dilution to occur, delta smelt and wakasagi must be able to interbreed. Results from electrophoretic studies confirm that delta smelt and wakasagi are distinct species, and there is as yet no indication of hybridization (Stanley *et al* 1993). However, Wang has reported a morphology of smelt showing characteristics of both delta smelt and wakasagi; the "question-mark smelt", as they are now referred to, cannot be identified to species (J. Wang, pers comm). Electrophoretic studies are scheduled to be conducted on the unidentifiable smelt. If hybrids are forming, they are likely to be sterile (P. Moyle, pers comm). The presence of large numbers of hybrids in the population could, nonetheless, reduce reproductive success if "pure" strains attempt to spawn with these individuals.

Misidentification due to the similarities between the two taxa poses another significant problem. It is virtually impossible to distinguish between delta smelt and wakasagi larvae less than 30 mm (J. Wang, pers comm). The "question-mark smelt", which may be a hybrid of delta smelt and wakasagi or an entirely different species of smelt, makes identification even more difficult.

Spawning Stock Size and Year-Class Strength

Examination of year-class strength as a potential factor controlling delta smelt abundance is based on the stock-recruitment theory. Year-class strength is the measure of recruitment, or the numbers of young alive at some future time that were produced by the adult stock. The stock-recruitment relationship defines the stock's ability to replenish itself as stock size is reduced by exploitation (Koslow 1992).

In general, attempts to relate recruitment in fish and other populations to parent stock size have been largely unsuccessful on an empirical level (Hankin 1980). Lack of definable stock-recruitment relationships is a consequence of the early life history strategy of fish, high fecundity and high mortality rates. Given that mortality is an exponential process, small deviations in mortality lead to large changes in survivorship, which may obscure the stock-recruitment relationship (Koslow 1992). Therefore, recruitment may appear to be not related to adult stock size or only weakly and linearly related to stock size, except when spawning stock is exceptionally high or low.

No fishery is known to significantly affect the abundance of delta smelt. However, fishing harvest may not be limited to angling or netting, but could also be considered as salvage catch or entrainment at water diversions. Due to the 1-year life cycle of delta smelt, adult smelt abundance may be limited by abundance and, consequently, egg production of adults in the previous year. Moreover, historical relationships between adult abundance and juvenile production could provide a valuable tool for development of take limits.

The stock-recruitment relationship for delta smelt has been examined in Stevens *et al* (1990), Moyle *et al* (1992), Kimmerer (1992b), Sweetnam and Stevens (1993), and most recently by Water Resources (1993). These analyses differed in the types of abundance indices used, the years analyzed, and the types of statistical analysis (Table 7).

Table 7
SUMMARY OF STOCK-RECRUITMENT ANALYSES FOR DELTA SMELT
Level of significance tested not given unless noted.

Analysis	Type of Analysis	Index	Years	r^2	N
Stevens *et al* (1990)	Nonlinear Regression	Tow-Net	1959-1990	0.067	26
	Nonlinear	Tow-Net/Fall Midwater Trawl	1968-1988	0.096	18
	Nonlinear	Fall Midwater Trawl	1967-1989	0.236	19
Moyle et al (1992)	Not Stated	Fall Midwater Trawl	1967-1989	0.24	19
Kimmerer (1992)	Linear Regression	Composite[1]	1959-1991	0.79**	32
	Linear	Fall Midwater Trawl	1967-1991	0.392**	20
Sweetnam & Stevens (1993)	Nonlinear	Fall Midwater Trawl	1967-1992	0.23	21
	Linear	Fall Midwater Trawl	1967-1992	0.24	21
Sweetnam (1994)	Linear	Fall Midwater Trawl	1967-1993	0.171	22
Department of Water Resources	Nonlinear	Fall Midwater Trawl	1967-1991	0.32	20
	Linear	Fall Midwater Trawl	1967-1991	0.392**	20
	Nonlinear	Fall Midwater Trawl	1967-1992	0.227	21
	Linear	Fall Midwater Trawl	1967-1992	0.266*	21
	Spearman Rank Correlation Test	Fall Midwater Trawl	1967-1992	r=0.62**	21
	Linear	Fall Midwater Trawl	1967-1993	0.179*	22
	Linear	Fall Midwater Trawl/Tow-Net	1967-1994	0.245*	24
	Linear	Tow-Net	1960-1994	0.262**	31
	Linear	Tow-Net/Fall Midwater Trawl	1967-1993	0.394	23

* $p < 0.05$
** $p < 0.01$
1 Composite index was calculated as the first principal component of three indices: tow-net, midwater trawl, and SWP salvage. To fill data gaps, multiple regression was used, which included indices not missing for that year and the previous year's composite index.

Analysis by Stevens *et al* (1990) using midwater trawl data, which was also presented in Moyle *et al* (1992), inadvertently included two pairs of SR data in which the measure of recruitment occurred 2 years later than the stock measurement. This may have affected results, given the 1-year lifespan for most delta smelt. Fish and Game updated this analysis using corrected data points and revised midwater trawl indices through 1992 (Sweetnam and Stevens 1993), superseding the earlier efforts.

Analysis of the stock-recruitment relationship for this assessment reviewed the analyses of midwater trawl data by Kimmerer (1992b) and Sweetnam and Stevens (1993). The SR relationship using the midwater trawl data in Table 8 was examined using nonlinear regression (Beverton-Holt SR model), linear regression and log transformation techniques, and nonparametric statistics.

Stevens *et al* (1990) analyzed the SR relationship using the striped bass summer tow-net data for 1959 to 1990, a combination of summer tow-net and fall midwater trawl data, and the midwater trawl data for 1967 to 1989 (Figure 82). They found a weak SR relationship for all three datasets, but no indication was given whether the relationship was significant or not. The best SR relationship could account for about one-fourth (r^2=0.236, N=19) of the variability in recruitment abundance based on midwater trawl data only.

More recent examinations of the relationship based on midwater trawl data again found spawning stock accounted for about one-fourth of the variability (r^2=0.23, N=21) in Sweetnam and Stevens (1993) (Figure 83) and in our analysis ($p<0.05$, r^2=0.227, N=21) (Table 7).

Table 8
FALL MIDWATER TRAWL ABUNDANCE INDICES USED IN STOCK-RECRUITMENT ANALYSIS
(Data from Department of Fish and Game)

Year*	Stock	Recruitment
1968	415	697
1969	697	316
1970	316	1678
1971	1678	1305
1972	1305	1267
1973	1267	1146
1976	698	338
1977	338	480
1978	483	572
1981	1651	375
1982	375	346
1983	346	132
1984	132	182
1985	182	109
1986	109	212
1987	212	280
1988	280	126
1989	126	366
1990	366	363
1991	363	689
1992	689	157
1993	157	1078

* Year recruitment was measured. No stock abundance data were available for recruitment years 1967, 1975, and 1980, which are not included in this analysis.

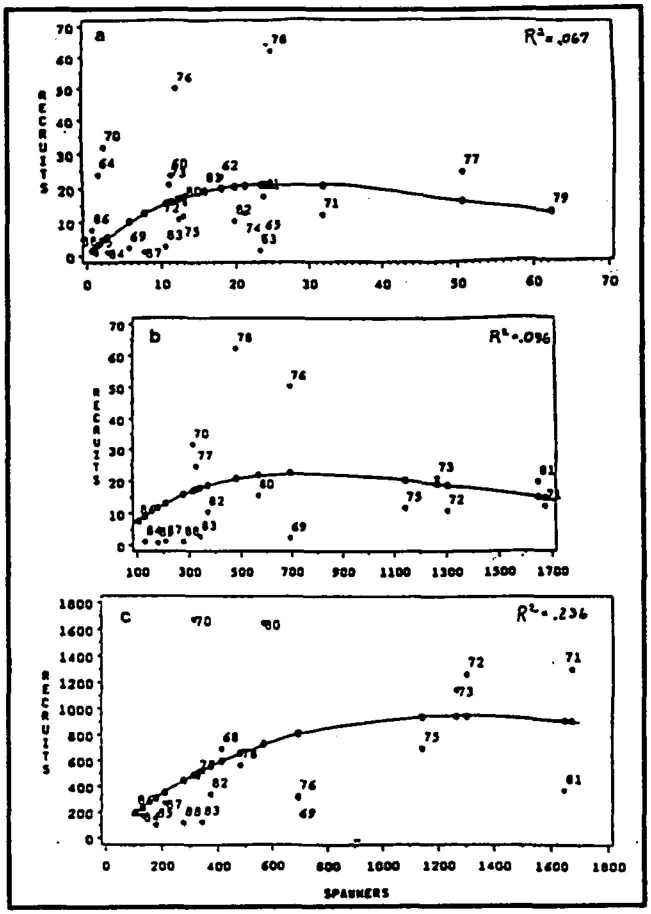


Figure 82
SPAWNER-RECRUIT RELATIONSHIPS FOR DELTA SMELT
A. Tow-net index (spawners) and tow-net index for the following years (recruits).
B. Midwater trawl index (spawners) and tow-net index the following year (recruits).
C. Midwater trawl index (spawners) and midwater trawl index the following year (recruits).
Source: Stevens *et al* 1990.

The strength of the relationship suggests environmental factors other than stock size are limiting delta smelt abundance, but stock size may be a contributing factor. Sweetnam and Stevens (1993) indicated that spawning stock size may be more important than previously thought, in that losses of adult spawners may have played an important role in the delta smelt decline and may inhibit recovery.

Another statistical method used was linear regression and both log-transformed and untransformed datasets. Kimmerer (1992b) found a significant relationship between recruitment and parent stock size for delta smelt based on his composite index of summer tow-net, fall midwater trawl, and SWP salvage operation data and to a lesser extent based on the midwater trawl abundance indices (Figure 84). The composite index, calculated as the first principal component of the three indices, explained 79% of the variance in the three indices ($p<0.01, r^2=0.79, N=20$) and is, therefore, regarded as a surrogate for all three in representing the general trend in smelt abundance. His analysis of midwater trawl data for recruitment years 1968 to 1991 showed a larger and significant portion ($p<0.01, r^2=0.392, N=20$) of the variance in recruitment could be explained by adult stock size.

Our results using the same database support Kimmerer's findings based on midwater trawl indices ($p<0.01, r^2=0.39, N=20$). Recently, however, these indices have been revised for some years. Inclusion of the 1992 recruitment data and revised indices resulted in a decline in the amount of variability in recruitment attributed to spawning stock size from 39% to 27% ($p<0.05, r^2=0.266, N=21$). A similar analysis by Sweetnam and Stevens (1993) using

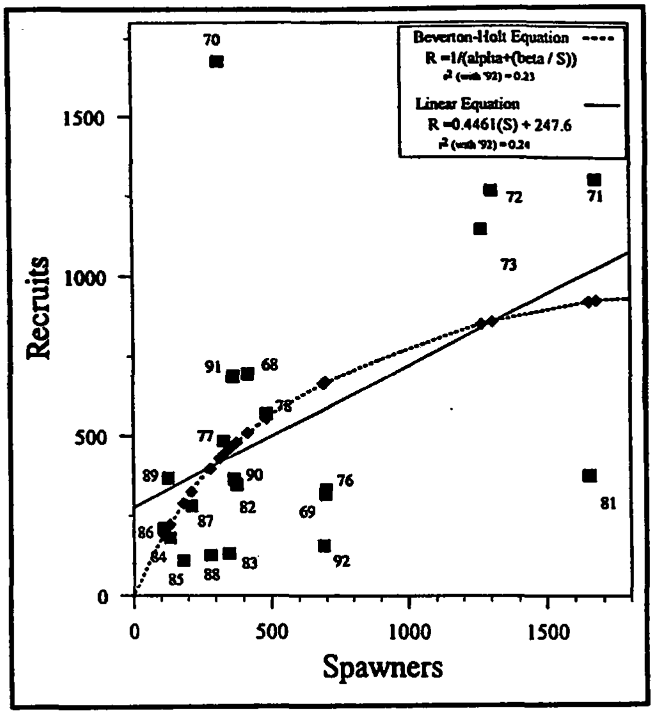


Figure 83
SPAWNER-RECRUIT RELATIONSHIPS FOR DELTA SMELT
BASED ON THE
FALL MIDWATER TRAWL ABUNDANCE INDEX
Spawners are represented by the abundance index.
Recruits are represented by the abundance index for the following year.
Source: Sweetnam and Stevens 1993.

nontransformed data found spawning stock accounted for 24% of the variability in recruitment (no level of significance stated, r^2=0.24, N=21).

Because stock and recruitment are not typically normally distributed, the significance of the SR relationship was also examined nonparametrically using Spearman's rank correlation test. A significant positive association ($p<0.01$, Spearman's correlation coefficient = 0.622, N=21) was found between stock and recruitment for 1967 to 1992.

The updated stock-recruitment relationship based on the midwater trawl index through 1993 indicates that a small but marginally significant amount (fall-fall: r^2=0.179, $p<0.05$, n=22) of the variability in recruitment can be attributed to spawning stock size (Table 7). However, Fish and Game's analysis of the fall-fall relationship was not significant (r^2=0.171, p=0.056, n=22) (D. Sweetnam pers comm). The difference in results may be due to differences in rounding of the index values by computer.

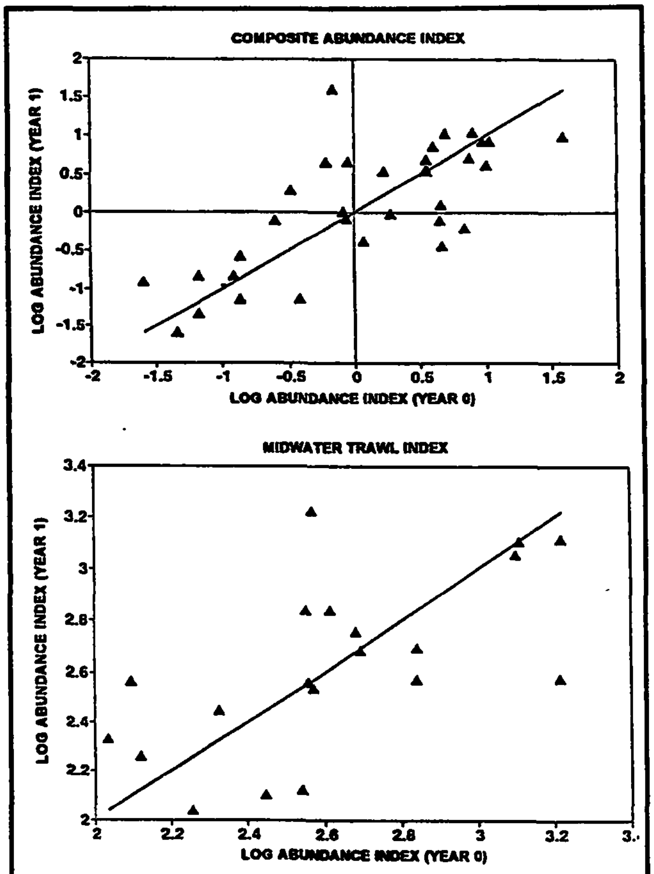


Figure 84
DELTA SMELT STOCK-RECRUITMENT RELATIONSHIP
USING THE COMPOSITE ABUNDANCE INDEX AND THE
MIDWATER TRAWL INDEX
The midwater trawl regression is significant ($p<0.01$, r^2=0.39).
Source: Kimmerer 1992.

The previous analysis of the fall index through 1992 yielded a slightly stronger relationship between stock and recruitment (r^2=0.266, $p<0.05$, n=21). Despite a small spawning stock in 1992, there was a dramatic rebound in delta smelt abundance (recruits) in 1993. Similarly, recruitment was the highest on record in 1970, yet the spawning stock was fairly low (Table 8, Figure 82). Thus, the spawning stock may not need to be large for the species to perpetuate itself, as postulated by Moyle and Herbold (1989). Conversely, a large spawning stock does not necessarily result in a large recruitment, as the 1981 recruitment indicates. Based on stock-recruitment data from 1967 to 1993, it does appear that smaller delta smelt stocks will, in general, produce low to moderately low recruitment, but good environmental conditions could create large year classes despite small spawning stocks.

Additional analysis using the fall midwater trawl index and summer tow-net index also indicate that stock size is an important contributing factor to recruitment (Table 7). About 25% of the variability in recruitment in the summer (tow-net index) can be attributed to the spawning stock size in the previous fall (midwater trawl index) (fall-summer: $r^2=0.245$, $p<0.05$, $n=24$). Similarly, summer stock size accounts for a significant amount of the variability in recruitment the following summer (summer-summer: $r^2=0.262$, $p<0.01$, $n=31$). It is also important to note that summer smelt abundance explains about 40% of the variability in abundance of delta smelt in the fall (summer-fall: $r^2=0.394$, $p<0.01$, $n=23$).

In summary, the strength of the relationship still suggests factors other than stock size (*ie*, environmental) are limiting delta smelt abundance, but stock size may be a contributing factor. Application of this stock-recruitment theory to the delta smelt population suggests that below some level of spawning stock the ability of the population to continue is probably hindered and recruitment significantly impaired. This supports the basic conclusions of Stevens *et al* (1990) and Moyle *et al* (1992). Fish populations are typically regulated mainly by highly variable factors (*ie*, predation, environmental variability, food availability) unrelated to stock size, except at extremes in population size (Strong 1986, cited by Koslow 1992). Sweetnam and Stevens (1993) also suggest that environmental factors cause much of the annual variation in delta smelt abundance but indicated that losses of spawning stock size may be more important than previously thought, in that losses of adult spawners may have played an important role in the population's recent decline and may inhibit recovery.

Chapter 6

BASIC BIOLOGY AND LIFE HISTORY OF SACRAMENTO SPLITTAIL

Taxonomy

The Sacramento splittail (*Pogonichthys macrolepidotus*; Family: Cyprinidae) is one of California's largest native minnows. First described in 1854 by W.O. Ayres as *Leuciscus macrolepidotus* and by S.F. Baird and C. Girard as *Pogonichthys inaequilobus*, the official genus name *Pogonichthys* was accepted in recognition of its distinctive characteristics (Hopkirk 1973). The genus consists of two species, *P. ciscoides* and *P. macrolepidotus*. However, *P. ciscoides*, or the Clear Lake splittail, which were only known from Clear Lake, Lake County, California, became extinct in the early 1970s (Moyle *et al* 1989; Moyle 1976).

Morphological characteristics of the Sacramento splittail have been described by Moyle (1976) and Moyle *et al* (1989) as follows:

> Splittail are large cyprinids, growing in excess of 300 mm SL (up to 400 mm maximum), and are distinctive in having the upper lobe of the caudal fin larger than the lower lobe. The body shape is elongate with a blunt head. Small barbels may be present on either side of the subterminal mouth. They possess 14 to 18 gill rakers, and their pharyngeal teeth are hooked and have narrow grinding surfaces. Dorsal rays number from 9-10, pectoral rays 16-19, pelvic rays 8-9, and anal rays 7-9. The lateral line usually has 60-62 scales, but ranges from 57-64. The fish are silver on the sides and olive grey dorsally. Adults develop a nuchal hump. During the breeding season, the caudal, pectoral, and pelvic fins take on a red-orange hue and males develop small white nuptial tubercles in the head region.

Some taxonomists believe the splittail is related to native cyprinids of Asia (Howes 1984). Sacramento splittail are thought to be one of the most primitive North American cyprinids (Hopkirk 1973).

Historical and Current Distribution

Sacramento splittail are endemic to California and were once widely distributed in lakes and rivers throughout the Central Valley (Moyle 1976; Moyle *et al* 1989; Rutter 1908). Splittail were one of the most abundant minnows in the Sacramento-San Joaquin Delta up through the 1970s (Moyle 1976; Caywood 1974). Their historical range in the Sacramento Valley included the Sacramento River as far north as Redding, the Feather River upstream to Oroville, and the American River upstream to Folsom. In the southern Central Valley they ranged to the Merced River at Livingston and the San Joaquin River at Fort Miller (Friant Dam site) (Rutter 1908). Snyder (1905) reported collecting splittail from southern San Francisco Bay and at the mouth of Coyote Creek in Santa Clara County. No other splittail have been collected in this part of San Francisco Bay (Leidy 1984; Wang 1986); however, in 1982, the Department of Fish and Game reported catching larval splittail in central San Francisco Bay near Berkeley Marina following high outflows (K. Hieb, DFG Stockton, pers comm, reported in Wang 1986).

Sacramento splittail distribution currently includes Suisun Bay, Suisun Marsh, Napa River, Petaluma River, Sacramento River from Knights Landing upstream to Princeton, portions of the Sacramento-San Joaquin Delta, and other tributaries to the Bay/Delta estuary (Caywood 1974; Moyle 1976; Daniels and Moyle 1983; Meng 1993; Moyle *et al* 1989; Spaar 1988; Wang 1986; IEP 1994; FWS 1994). Splittail are restricted to the lower Sacramento River below Red Bluff Diversion Dam apparently due to an inability to negotiate the structure (Moyle *et al* 1989). Splittail have been found in San Pablo Bay and Carquinez Strait from February through April when salinity was less than 5 ppm (Messersmith 1966; Moyle 1976; Wang 1986). Recent stream surveys in the San Joaquin

Valley reported observations of splittail in the San Joaquin River below the mouth of the Merced River and upstream of the confluence of the Tuolumne River (Saiki 1984 cited in Moyle *et al* 1993). Further surveys are necessary to determine the extent of splittail range in the San Joaquin River and tributaries. An Interagency Program study is planned for summer 1994 to help address this question (Baxter 1994).

Life Cycle

Life history characteristics and ecology of splittail have been described by Caywood (1974), Daniels and Moyle (1983), Moyle (1976), Moyle *et al* (1989), and Wang (1986). Splittail are endemic to California, with a moderately complex life cycle tied to seasonal flooding in the Central Valley. Figure 85 is a simplified life-cycle representation; Figure 86 is a generalized periodicity chart of life stages.

Apparently unique for minnows, adult splittail seem to have a distinct upstream migration in late fall and early winter prior to spawning. Their life cycle consists of mature adults (generally year 2+) spawning over an extended period from mid-winter through mid-summer (July; Wang 1986), eggs and larvae from early spring to summer, and juveniles from summer through fall sometimes up to 3 years old before maturing. Specific life history characteristics and requirements for adults, eggs and larvae, and juveniles are discussed below.

Adults

Sacramento splittail are a relatively long-lived minnow, reaching ages of 5 and possibly up to 7 years (Moyle *et al* 1989; Caywood 1974). Both males and females usually reach adult sexual maturity in their second year, at 180-200 mm (Daniels and Moyle 1983). The adult growth rate ranges from 5 to 7 mm per month. During gonad development, primarily between September through February, the growth rate slows to less than 5 mm per month (Daniels and Moyle 1983). The largest recorded splittail have measured about 400 mm (Caywood 1974; Daniels and Moyle 1983).

Adult splittail reach sexual maturity at about 2 years (Caywood 1974; Daniels and Moyle 1983). Variation in the age of maturity was described by Caywood (1974), observing that some males mature at the end of their first year and a few females mature in the third year. Wang (1986) noted male sexual maturity by the end of the first year and female maturity by the first or second year. Gonad development is usually initiated in fall, and gonads reach full maturity by late winter or early spring. Fully developed ovaries can account for up to 18% of the total female body weight as compared to the testes of males, which approach only 2% of their total body weight (Daniels and Moyle 1983). The ova apparently mature at different rates. Wang (1986) found eggs of various sizes and stages of development from females collected in the estuary, indicating that spawning may occur over extended periods.

Splittail have high fecundity, like most cyprinids. Caywood (1974) documented fecundity ranging from 5,000 to 100,800 eggs per female. Daniels and Moyle (1983) measured fecundity of 20 females 175 mm SL or larger collected from January through March in Suisun Marsh and found from 17,500 to 266,000 ova per female. It was also observed that fecundity increased with length and weight of the female. Generally, female splittail produce more than 100,000 eggs each year (Moyle *et al* 1986).

The spawning period of splittail seems to vary depending on environmental conditions such as water temperature, photoperiod, seasonal runoff, and possibly endogenous factors. Splittail may have a protracted spawning period based on the observed variations in size and development of eggs sampled from individual females (Wang 1986) and on salvage results for young-of-the-year splittail and the CVP and SWP fish facilities.

Timing of splittail reproduction has varied between different locations during separate investigations. In the upper Delta in 1973 and 1974, splittail spawned in early March through mid-May (Caywood 1974). In a Suisun Marsh study from 1979 to 1982, splittail spawned in late April or early May, with young-of-the-year fish collected in late May or early June (Daniels and Moyle 1983). From 1978 to 1983, samples of larvae collected indicate that splittail spawned in tidal freshwater and oligohaline habitats such as Montezuma and Suisun sloughs and San Pablo Bay, from late January or early February through July (Wang 1986).

Environmental factors, including water temperature and photoperiod, influence the timing of reproduction for many fish species (Bye 1984; Crim and Glebe 1990; Lam 1983; Bromage and Duston 1986). Daniels and Moyle (1983) stated that increasing water temperature and photoperiod with the onset of spring and summer appear to trigger spawning activity for splittail in the Bay/Delta estuary. However, they also found that spawning success was correlated with outflow. The relationship with temperature and day length may be less important. Splittail spawning occurs in water temperatures from 9 to 20°C between January and July (Caywood 1974; Wang 1986).

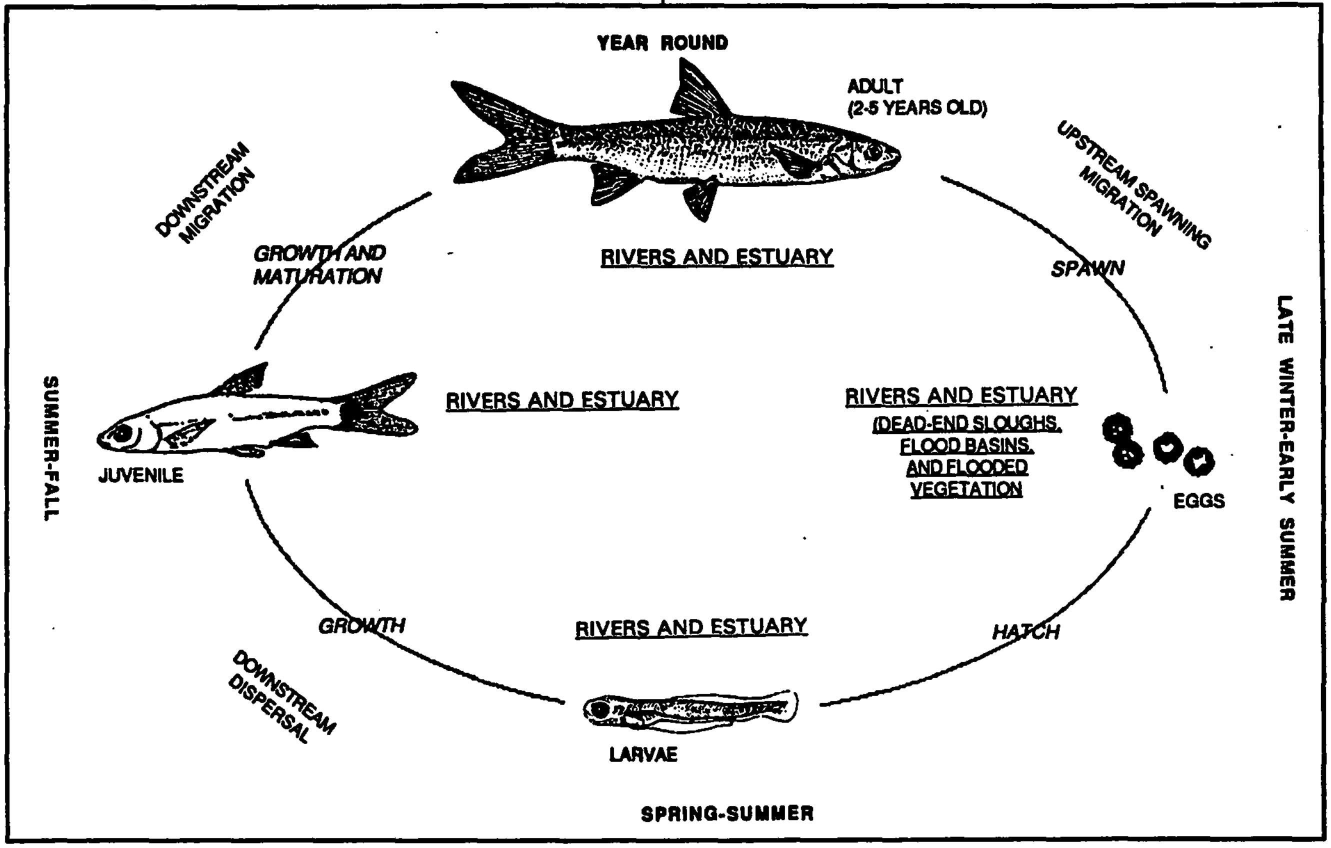
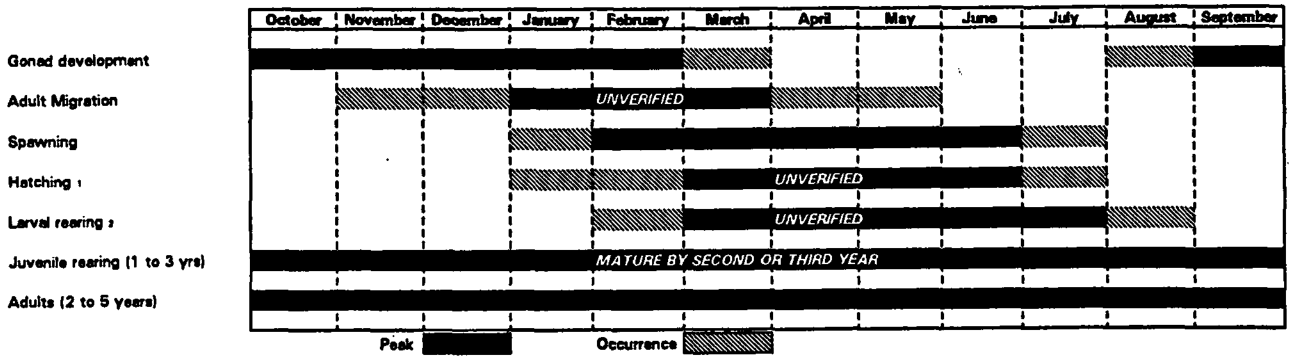


Figure 85
LIFE HISTORY OF SACRAMENTO SPLITTAIL



[1] Preliminary results of laboratory culturing studies show hatching at 4 to 10 days @ 19 C (H. Bailey, pers comm, U C Davis)

[2] Estimate period of growth from prolarvae to pre-juvenile approximately 10 to 20 days (J. Wang, pers comm, June 1, 1994)

Figure 86
PERIODICITY CHART, SACRAMENTO SPLITTAIL

Timing and magnitude of winter and spring runoff may be more significant in determining the spatial and temporal distribution of splittail spawning in the estuary (Caywood 1974; DFG 1992; Daniels and Moyle 1983; Meng 1993, 1994; Moyle 1976; Moyle *et al* 1989; Wang 1986). This is supported by correlations of strong year classes with annual, monthly, and seasonal high outflows that flood peripheral areas of the estuary (Daniels and Moyle 1983; Meng 1993, 1994). Spawning activity of splittail occurs during high runoff in winter and spring, concurrent with flooding of low-lying floodplains. Normally, runoff patterns in the Central Valley peak in winter during large storms and again in spring during snowmelt. The possible effect of these events on the spawning migration of splittail is discussed in Chapter 8. Flooding during these periods provides the shallow water areas of submerged vegetation that create spawning habitat for splittail (Caywood 1974; Daniels and Moyle 1983).

Endogenous cycles of the fish can control spawning behavior and timing despite environmental conditions. Some indication of internal factors influencing splittail spawning is seen in variability of splittail spawning period associated with the age of adults. Caywood (1974) observed that older individuals spawn earlier in the season than younger fish.

The range in spawning periods observed in previous studies and the variation in development and size of eggs and collection of fry and juvenile fish over several months support the theory of protracted spawning periods for splittail. Further research could determine the influence of internal factors and environmental conditions on splittail reproductive behavior, timing, and success.

Habitat Preference

Studies from Suisun Marsh indicate that splittail are found in small dead-end sloughs fed by freshwater streams and in the larger sloughs such as Montezuma and Suisun (Daniels and Moyle 1983; Meng 1994; Moyle *et al* 1986; Wang 1986). Juveniles and adults utilize shallow edgewater areas lined by emergent aquatic vegetation. Submerged vegetation provides abundant food sources and cover to escape from predators. Shallow, seasonally flooded vegetation is also apparently the preferred spawning habitat of adult splittail (Caywood 1974; Daniels and Moyle 1983; Moyle 1976; Moyle *et al* 1986; Wang 1986). During summer otter trawl surveys in Suisun Marsh, splittail were caught at temperatures of 15-23°C (Moyle *et al* 1986).

Sacramento splittail are one of the few freshwater cyprinids that are tolerant of brackish water (Daniels and Moyle 1983; Moyle 1976; Meng 1994; FWS 1994). Historically, the species was found extensively in freshwater habitats of rivers draining to the Delta (Caywood 1974; Moyle 1976; Rutter 1908). Life history studies have also found these fish populating tidal freshwater and euryhaline low-velocity rivers and sloughs in the Delta, concentrating in and around Suisun Marsh (Caywood 1974; Meng 1993; Moyle 1976; Daniels and Moyle 1983; Moyle *et al* 1989; Spaar 1988; Wang 1986; IEP 1994). In Suisun Bay, Meng (1993) consistently found all sizes of splittail in shallow water at less than 2-3 ppt salinity. However, splittail have been collected at salinities as high as 12-18 ppt (Meng 1994; Messersmith 1966; Moyle 1976; Daniels and Moyle 1983). Baxter (1994) suggests that the western Delta and Suisun Bay regions may provide only marginal habitat except in above-normal and wet years. Drought-related salinity increases in the bay may have created unfavorable habitat conditions and may explain some of the change in distribution. As salinity increases, splittail move to lower salinity or fresh water. This movement was observed in Petaluma Marsh; when salinity was high, splittail were not collected (Caywood 1974).

Further sampling in a range of shallow fresh- and brackish-water habitats through all seasons would help describe the preferred habitat of the species under existing environmental conditions in the Central Valley. Environmental tolerance testing now underway by researchers at UC-Davis should define environmental requirements for the species and, specifically, whether brackish water is actually required during any life stage of the species for optimum survival. The Interagency Program sampled a variety of habitat types at several locations in the Central Valley and San Francisco Bay area. Results will be available in fall 1994.

Spawning Habitat

Delta fisheries sampling programs and other studies indicate that adult splittail probably congregate in dead-end sloughs to spawn over shallow flooded or emergent and submergent vegetation. Caywood (1974) sampled adult splittail during early spring in upper Delta sloughs and river channels and Napa and Suisun marshes. A number of sexually mature splittail were collected from two natural unnamed Cosumnes River sloughs near the Mokelumne River confluence. Spawning adult splittail were collected in sampling nets set over and near areas dominated by emergent and floating vegetation. Eggs were also observed adhered to aquatic vegetation collected in the nets. During the sampling period, the entire floodplain of the Cosumnes and Mokelumne rivers was under receding floodwaters. Vegetation at the sampling sites consisted of tules (*Scirpus* sp.) and water primrose (*Jussiaea* sp.) in 1 to 3 meters of water.

These Cosumnes River sloughs and associated floodplain were relatively undisturbed except for cattle grazing. The riparian environment was in a natural state, with well vegetated, unleveed shorelines that experience regular seasonal winter or spring flooding. Aquatic habitat consisted of mud or peat substrates and aquatic and submerged terrestrial vegetation. Tidal fluctuations mix high-quality, fresh water from the river with water in the sloughs. Caywood concluded that spawning occurs primarily over flooded vegetation in fresh water. This was based on the collection of spawning individuals in the Cosumnes River sloughs and observations of splittail fry collected from the Sacramento River at Miller Park.

Recent collections of mature adult and young-of-the-year splittail from the temporarily flooded Sutter Bypass in February and March 1993 support Caywood's conclusions that seasonally inundated, vegetated floodplains are used as spawning and rearing habitat (Jones and Stokes 1993).

Food Habits

Daniels and Moyle (1983) used a fullness index to evaluate diel and seasonal feeding activity of splittail. The fullness index was based on methods described by Windell (1968) and measured food consumption based on stomach content analysis and weight of food items from fish sampled over a 24-hour period. Fullness indices were calculated for individual fish and averaged for all fish collected in each period. The indices were used as an indirect measure of diel and seasonal activity. Feeding activity was highest in the morning and early afternoon. Mean fullness indices were greatest between 6 am and 2 pm and lower from 6 pm to 10 pm. Seasonally, mean fullness indices of fish collected midday were greater in summer but similarly low for fall, winter and spring. The diet of splittail is discussed in detail in Chapter 8.

Eggs and Larvae

Little is known about factors that influence splittail egg and larval development. Wang (1986) provides detailed descriptions of morphological characteristics of splittail eggs, larvae, and juveniles and general information on life history and ecology. Culturing procedures being tested at UC-Davis are providing preliminary information on early life history requirements and development.

Mature splittail eggs are 1.3 to 1.6 mm diameter with a smooth, transparent, thick chorion (Wang 1986). The eggs are adhesive or become adhesive soon after contacting water (Caywood 1974; Bailey 1994). Eggs appear to be demersal, and it is assumed that they are laid in clumps and attach to vegetation or other submerged substrates (Caywood 1974; Wang 1986). Under laboratory conditions fertilized eggs incubated in fresh water at 19°C (±0.5°) start to hatch after about 3-5 days. Asynchronous hatching of egg batches from single females has been observed in preliminary culturing tests. Eggs laid *en masse* were first to hatch. Eggs not in contact with other eggs developed normally but took longer to hatch (Bailey 1994).

Early hatched larvae are 6 mm long and have not developed eye pigment. Larvae are 7.0-8.0 mm TL when they complete yolk-sac absorption and become free swimming 5-7 days post-hatch; post-larvae are up to 20 mm (±4.2 mm) TL (Bailey 1994; Daniels and Moyle 1983; Wang 1986). Feeding begins after 5 days post-hatch. Preliminary observations of newly hatched larvae indicate they have undeveloped mouths at 48 hours post-hatch

(Bailey 1994). Well-developed mouths are observed in post-larvae after 96 hours post-hatch at 7.8 to 10.4 mm (Bailey 1994; Wang 1986). First-scale formation appears at lengths of 22 mm SL or 25-26 mm FL (Caywood 1974; Daniels and Moyle 1983).

Juveniles

Juvenile splittail are individuals that are not yet sexually mature.

Young-of-the-year splittail collected through May and June in the lower Sacramento River and west to Antioch by Caywood (1974) and in Suisun Marsh by Daniels and Moyle (1983) ranged from 24 to 40 mm FL (mean 29 mm) and 23 to 54 mm SL (mean 32 mm), respectively. Daniels and Moyle (1983) found young-of-the-year grew about 20 mm/month from May through September and then decreased to <5 mm/month through February. In their second season, they grew at about 10 mm/month until the fall, when body growth declined and gonadal development began.

Males and females apparently can mature at different rates, which increases the size ranges of splittail classified as juvenile fish. Caywood (1974) collected fish from the 1973 year class in April 1974, and the majority (97%) were immature, with a mean size of 147 mm FL. Three fish (3%) were larger males (mean FL 169 mm) that had matured within the first year. Caywood also found that females did not reach sexual maturity until August of their second year. Daniels and Moyle (1983) found both males and females matured by their second winter at minimum lengths of 180-200 mm. Based on back-calculated lengths at annuli formation (in March 1979 and February 1980), mean size was 111.4 mm SL for first-year fish and 171.2 mm SL for second-year fish (N=210; YOY to age 5).

Young-of-the-year splittail appear to seek out shallow, vegetated areas protected from strong currents near spawning grounds and move downstream as they grow (Caywood 1974; Wang 1986). They apparently move or are carried with higher spring flows downstream into the estuary and bays, where they are captured regularly by midwater trawl sampling in Suisun Bay near Montezuma Slough, in the vicinity of Pittsburg Power Plant near New York Slough, near Antioch, and sometimes as far downstream as Carquinez Straight and San Pablo Bay (DFG MWT data, 1967 to 1993; Caywood 1974; Wang 1986). There is also a record of larval splittail collected near Berkeley Marina in San Francisco Bay in April 1982 (Wang 1986).

Splittail salinity requirement analyses for this assessment (Water Quality section, Outflow/Bay Study evaluation) showed that the highest catches of splittail for all age classes occurred in fresh water. Young-of-the-year splittail seasonally shift to higher salinity habitats, but reasons for the shift are unclear. The fish may be distributed downstream by high seasonal flows and may remain in less optimal salinities if other conditions (*eg*, food abundance) are more beneficial.

Chapter 7

HISTORICAL ABUNDANCE AND DISTRIBUTION OF SACRAMENTO SPLITTAIL

There have been no systematic, rangewide surveys to sample the splittail population. Additional surveys are needed before trends in splittail abundance and distribution can be accurately identified.

Abundance data for splittail are available from databases from the summer tow-net survey, fall midwater trawl survey, Delta Outflow/San Francisco Bay study, beach seine survey, Suisun Marsh survey, and fish salvage operations at the State Water Project and Central Valley Project. A general description of these surveys was provided in Chapter 4. Results from these and other shorter-term surveys for splittail are discussed in this chapter. Each of the surveys has a number of limitations and possible biases noted in this chapter. Particular concern is that none of the surveys covers the complete range of this species, and many catch relatively few fish. Proposed Interagency Program studies may help to resolve some of these issues related to adult splittail sampling (Baxter 1994). Until new studies are completed, the survey results shown in Figure 87 (young-of-the-year), Figure 88 (year 1), and Figure 89 (year 2+) represent the best available data.

Due to the limitations with each database, abundance trends should be examined concurrently rather than focusing on individual indices. However, more weight should be given to results from the salvage facilities, beach seine surveys, and Suisun Marsh surveys because adequate numbers of splittail were captured.

Abundance indices analyzed to date suggest there was a decrease in splittail recruitment during 1987-1990. Most of the surveys suggest recruitment improved in 1991 and 1993. Evidence from the FWS beach seine — the survey that provides the broadest coverage of the range of splittail — shows that 1993-1994 abundance was exceptionally high. It also appears that juvenile splittail abundance is frequently (but not always) highest in wet years such as 1982, 1983, 1986, and 1993. There is evidence that the FWS beach seine does not show this trend, suggesting that abundance in upstream areas may be determined by different processes.

In most surveys, the number of adult splittail has been variable since 1979, without a discernible trend. The major exception is the UC-Davis Suisun Marsh survey, which showed a major decline after 1981, with little or no resurgence since then. Young-of-the-year and year-1 trends were similar over this period. This finding suggests that the Suisun Marsh population may be influenced by other factors (or to a greater degree) than splittail from other parts of the system. The Delta Outflow/San Francisco Bay study and CVP indices seem to show that abundance was relatively high in 1993. This finding is consistent with increases in the young-of-the-year indices in 1991 for the summer tow-net, midwater trawl, CVP, SWP, and Outflow/Bay otter trawl.

Independent surveys by PG&E and DFG confirm that adult splittail were the second most abundant fish species captured in Suisun Bay, the region identified by FWS (1994) as the center of the range of splittail. Other surveys described in this chapter demonstrate the breadth of splittail distribution. In addition, studies on the American River (Hanson Environmental 1991) suggest that collecting samples during the daytime only, as done for most of the surveys, significantly underestimates fish abundance. The surveys should, nonetheless, be a valid source of information about relative trends.

Splittail distribution maps for the Delta and San Francisco Bay for years before 1988 (Figure 90) and after 1988 (Figure 91) are based on the midwater trawl, tow-net survey, Delta Outflow/Bay study, surveys by DFG Region 3, the Suisun Marsh survey, and selected FWS beach seine stations. Data for all surveys extend through 1992, except for the beach seine, which was through June 1994. The maps do not include observations upstream of the Delta, and not all stations were sampled in all years.

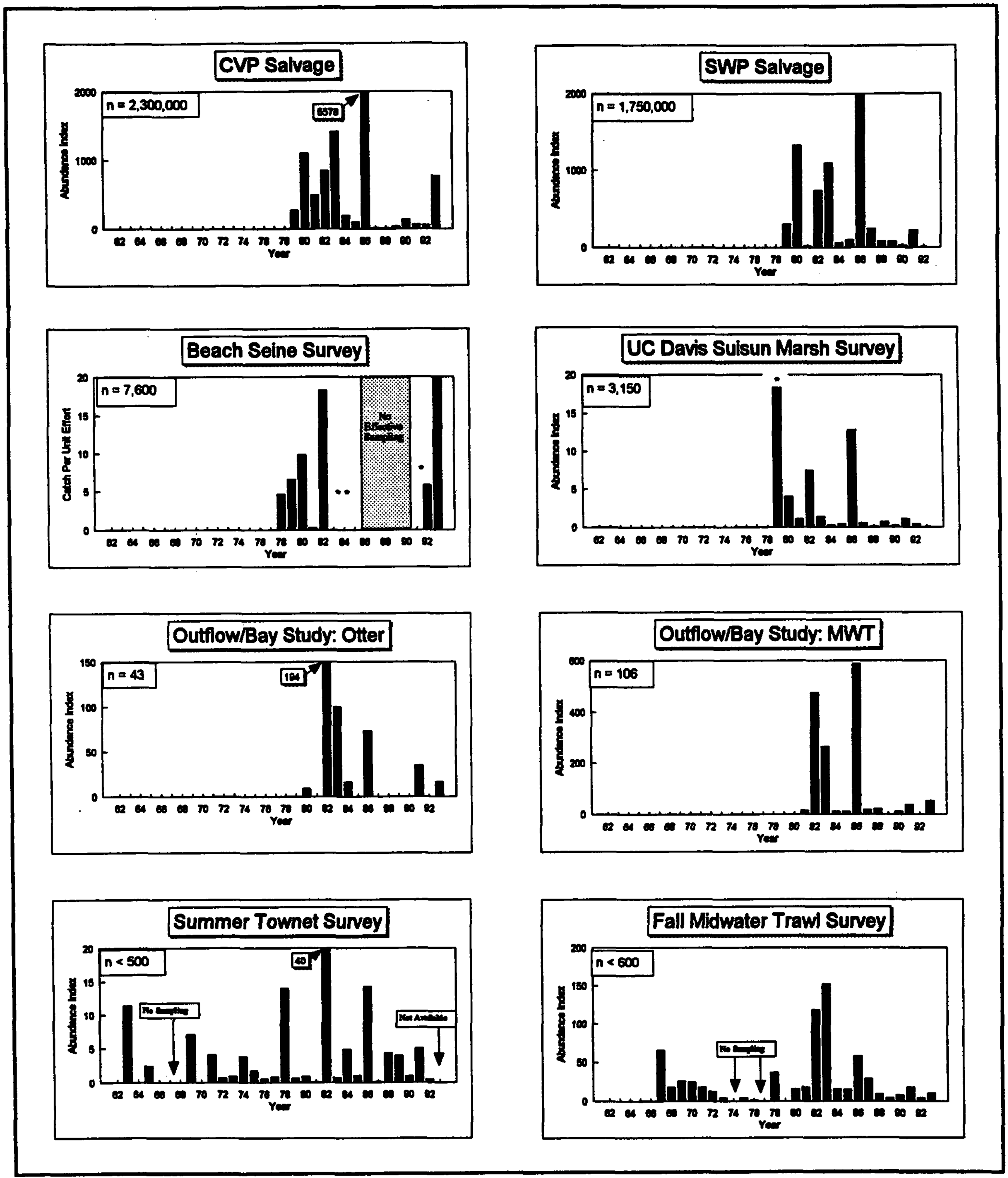
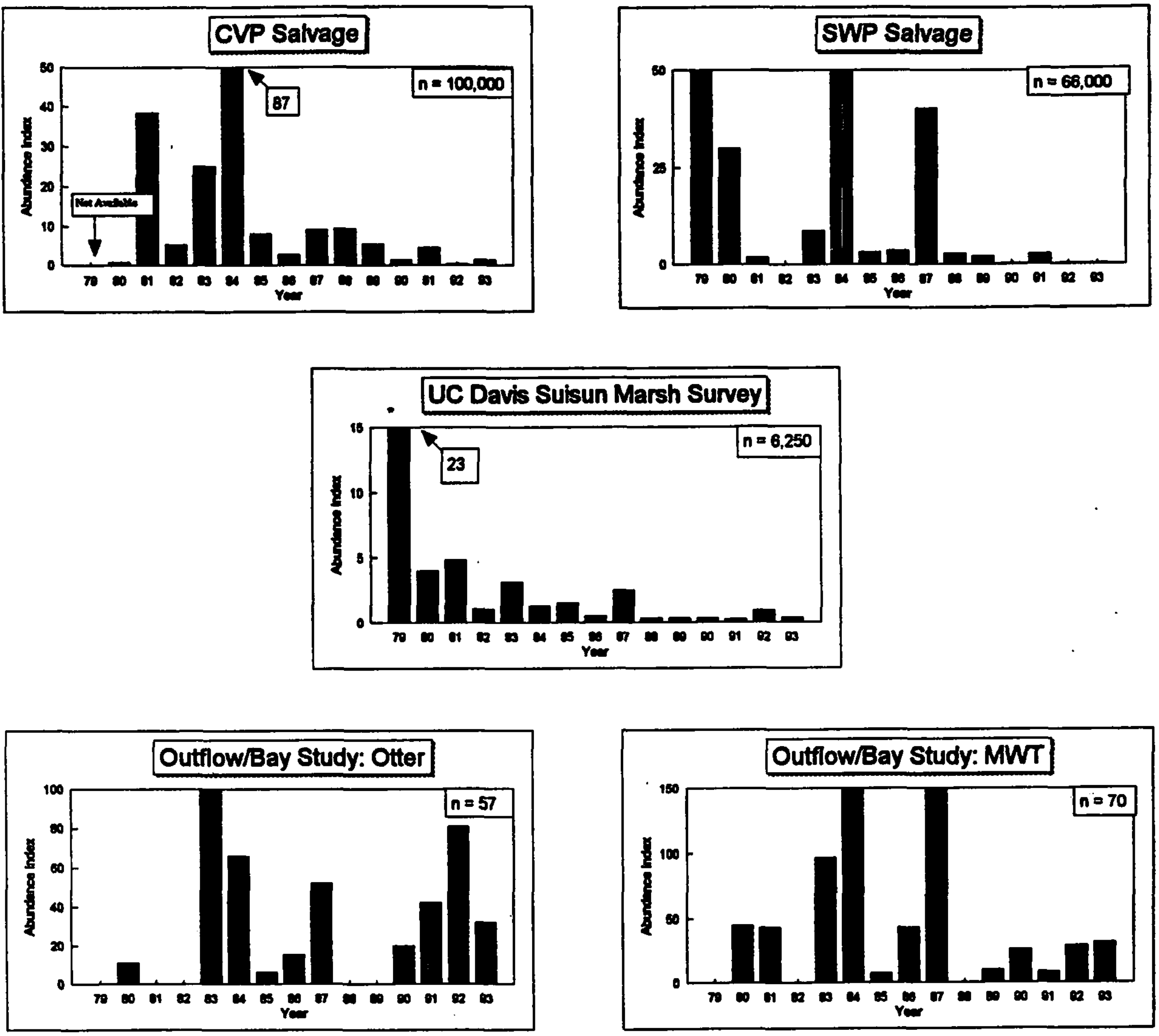


Figure 87

TRENDS IN YOUNG-OF-THE-YEAR SPLITTAIL ABUNDANCE, AS INDEXED BY EIGHT INDEPENDENT SURVEYS


CVP Salvage

SWP Salvage

UC Davis Suisun Marsh Survey

Outflow/Bay Study: Otter

Outflow/Bay Study: MWT

Figure 88
TRENDS IN YEAR 1 SPLITTAIL ABUNDANCE, AS INDEXED BY FIVE INDEPENDENT SURVEYS

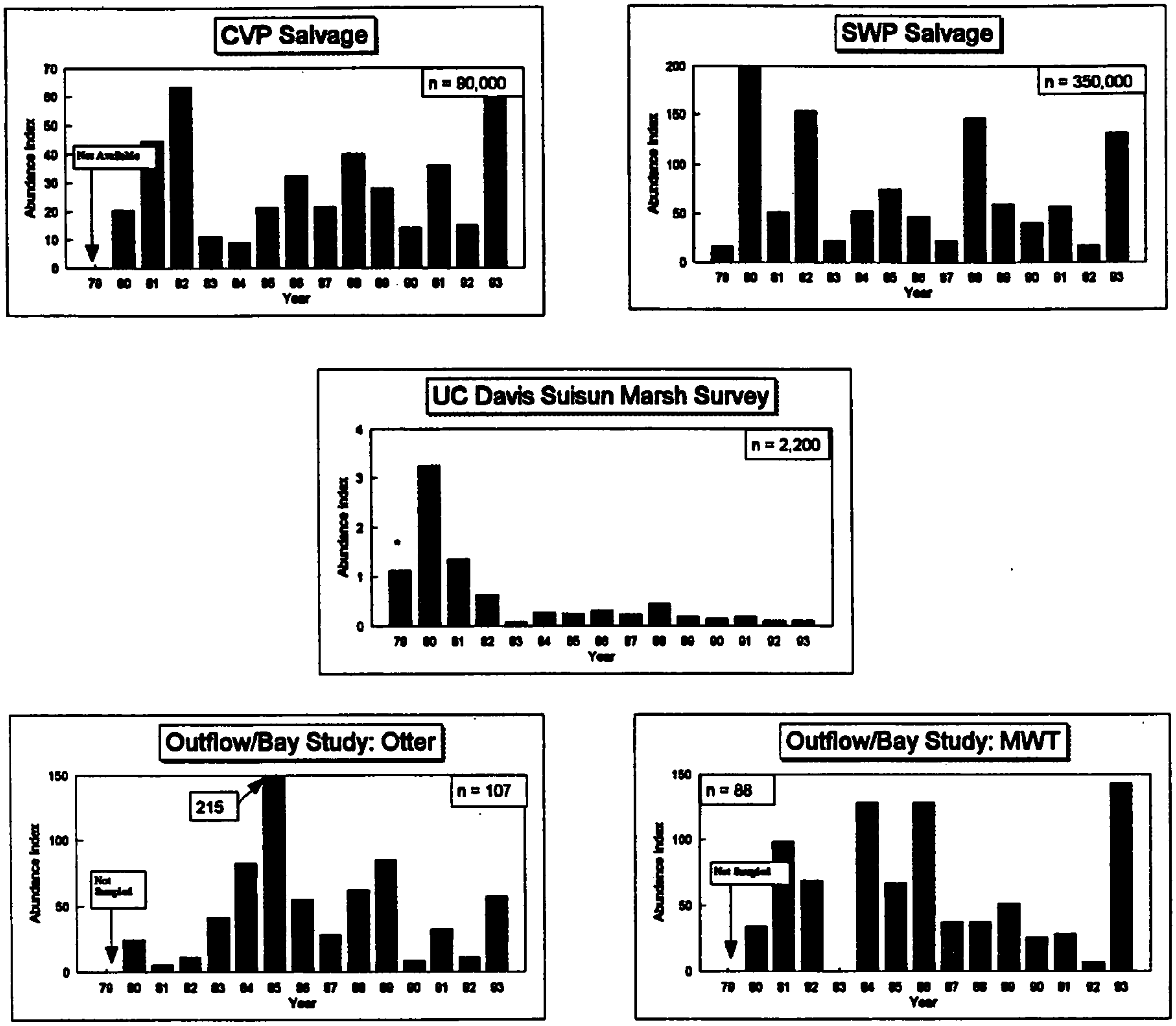


Figure 89
TRENDS IN YEAR 2+ SPLITTAIL ABUNDANCE, AS INDEXED BY FIVE INDEPENDENT SURVEYS

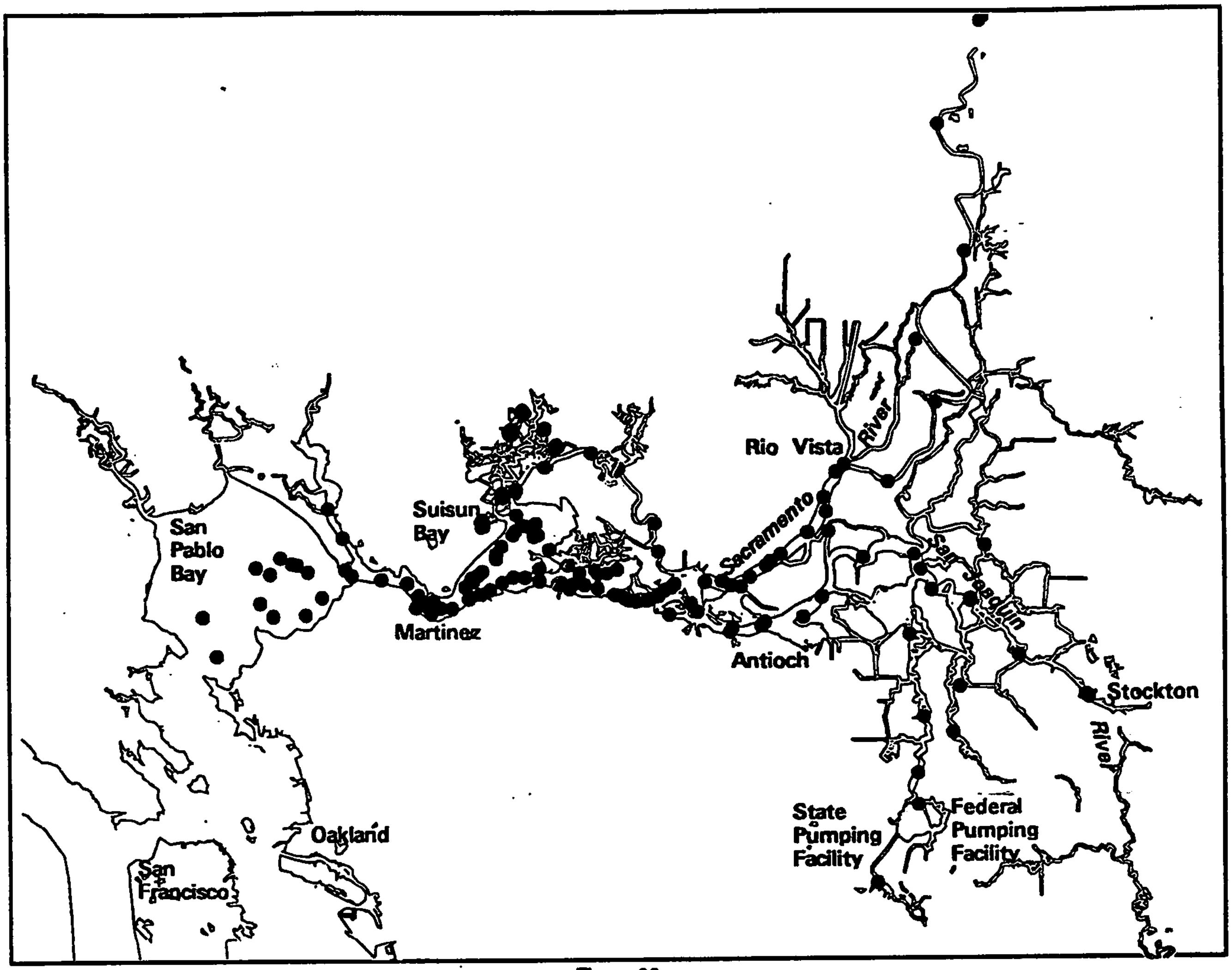


Figure 90

PRE-1988 DELTA AND SAN FRANCISCO BAY DISTRIBUTION OF SPLITTAIL

Based on the midwater trawl, tow-net survey, Delta Outflow/Bay study, Suisun Marsh survey, and selected FWS beach seine stations.
Each dot represents at least one observation of splittail.
Note that the map does not include observations upstream of the Delta.

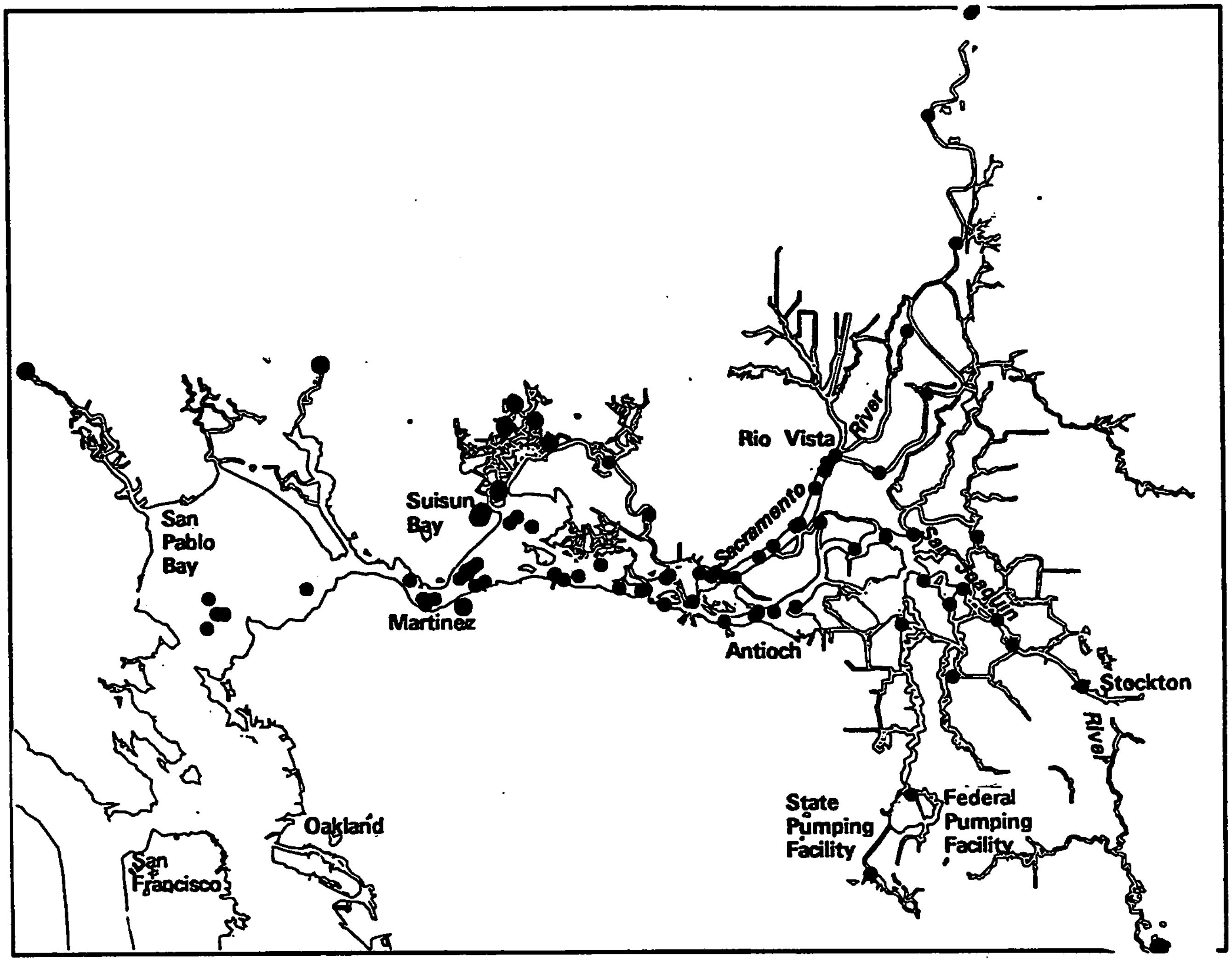


Figure 91

POST-1988 DELTA AND SAN FRANCISCO BAY DISTRIBUTION OF SPLITTAIL

Based on the midwater trawl, tow-net survey, Delta Outflow/Bay study, DFG Napa River survey, Suisun Marsh survey, and selected FWS beach seine stations.

Each dot represents at least one observation of splittail.

Note that the map does not include observations upstream of the Delta.

CVP and SWP Salvage

Details about the CVP and SWP fish salvage facilities were provided in Chapters 2 and 4. A major advantage of the salvage facilities with regard to their use to index abundance is that large numbers are counted and measured relative to all the other surveys. This makes it possible to estimate the monthly distribution of a number of year classes. A limitation of the database is that salvage levels may vary depending on screening efficiency, exports, flows, and the number of predators present. Like a number of other surveys, the salvage facilities sample only a small portion of the range of splittail, and could, therefore, be sensitive to shifts in species distribution. Finally, abundance indices from salvage data presently combine all fish 2 years and older into a single group. This provides an estimate of the number of spawners, but more detailed data are needed on the abundance of specific year classes of adults.

Annual abundance indices for different age classes of splittail were estimated from records of salvage at Tracy and Skinner fish facilities for 1979-1993, the period of most accurate data. Analysis of daily size measurements of splittail indicate there are generally at least two distinct length groups in late winter and early spring at the CVP (examples are provided in Figure 92). The SWP data show a similar trend. The salvage data were separated into age classes using tentative size criteria developed using data from Skinner Fish Facility and the DFG Outflow/Bay study. Frequency distributions for each of these databases are provided in Appendix B. The salvage and Outflow/Bay studies both show highly distinctive monthly divisions between young-of-the-year and year 1. Separations between year 1 and year 2+ age classes are also reasonably clear, particularly in the Outflow/Bay database. The criteria shown in Appendix B represent the best estimate of young-of-the-year, year 1, and year 2+ size ranges on a monthly basis. Age separations using these criteria are considered most reliable for young-of-the-year. As a partial validation, the criteria used were found to be similar to size-frequency distributions reported by Caywood (1974). The distributions are also reasonably comparable to Daniels and Moyle (1983) for February 1979 to October 1981 in Suisun Marsh.

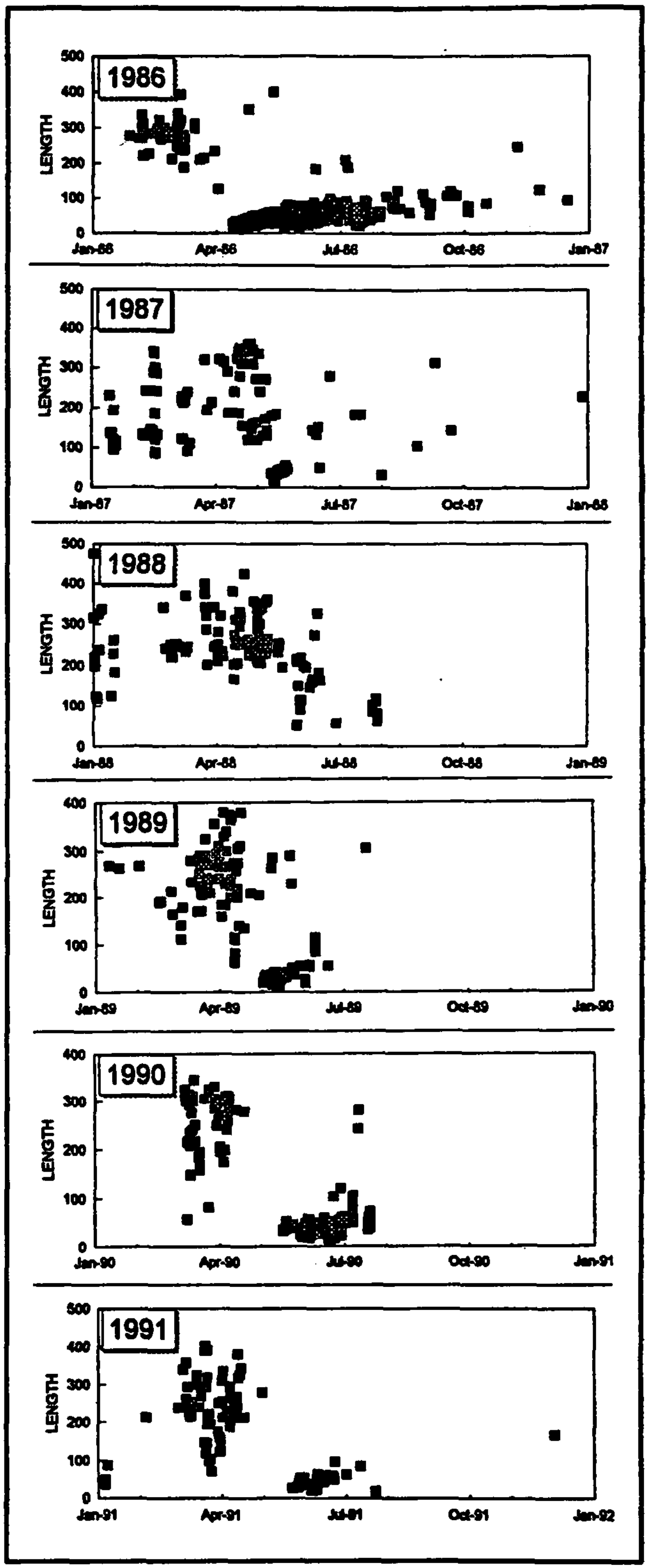


Figure 92
DAILY SIZE MEASUREMENTS OF INDIVIDUAL SPLITTAIL, 1986-1991

Total salvage per 1,000 acre-feet of water diverted at each facility was calculated by dividing total monthly salvage for each year class by average monthly export levels from the DAYFLOW database (DWR 1992). Results for young-of-the-year, juveniles, and adults are discussed below.

Estimated monthly salvage per 1,000 acre-feet of young-of-the-year splittail is summarized in Figure 93 for the CVP and Figure 94 for the SWP. With few exceptions, young-of-the-year splittail are salvaged during April to July. Annual abundance indices were calculated for young-of-the-year by summing salvage for April-July, dividing by the average export rate for this period, and multiplying the result by 1,000, a convenient scaling factor. Results are shown in Figures 95 and 96. Annual abundance indices show similar variability for both facilities, with major peaks in 1980, 1983, and 1986, followed by consistently low recruitment until 1993, when larger numbers were observed at the CVP.

Year 1 salvage was fairly erratic through the year. Salvage was generally highest April-July, but large numbers were sometimes observed in February and March (Figures 93 and 94). Abundance indices for April-July were developed using an approach similar to that described for young-of-the-year. The CVP and SWP indices both suggest that year 1 abundance was highest in 1984 and relatively low in 1982, 1985, 1986, and all years after 1987 (Figures 95 and 96). Results are somewhat incongruous for the other years.

Year 2+ salvage was usually highest in February-April, with occasionally high levels in January (Figures 93 and 94). Annual abundance indices calculated from total January-April salvage are shown in Figures 95 and 96. Although the highest indices at the CVP were in 1981 and 1982 and at the SWP were in 1980 and 1982, there does not appear to be a consistent trend in year 2+ abundance. There is some indication that adult abundance may have decreased from 1988 through 1990, but indices from both facilities show a resurgence in 1991. In addition, even the lower 1989 and 1990 indices were comparable to half the years in the record. The 1993 index was the second highest on record at the CVP and the third highest at the SWP.

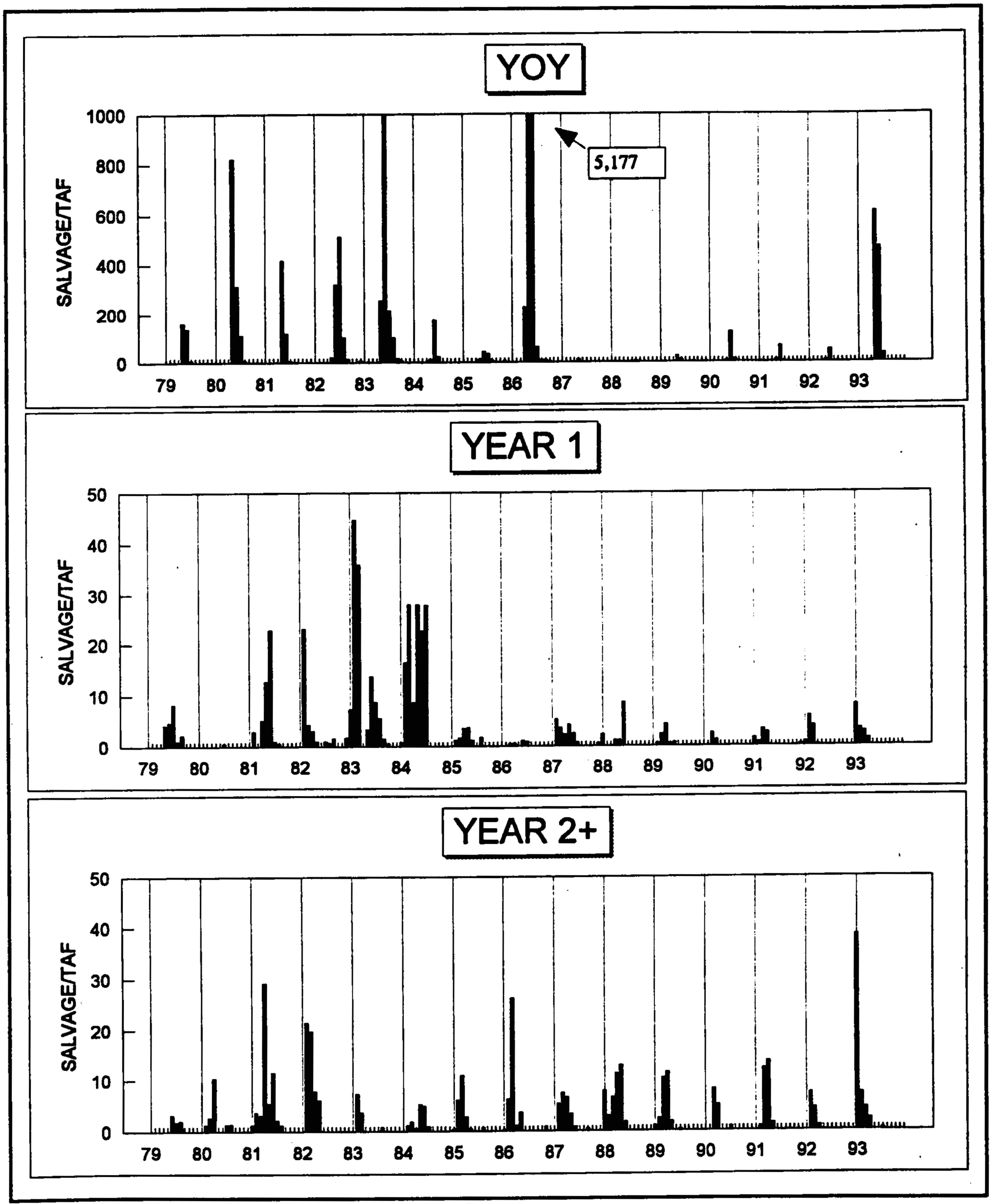


Figure 93
TOTAL MONTHLY SALVAGE OF DIFFERENT AGE CLASSES OF SPLITTAIL AT TRACY FISH FACILITY, MAY 1979 TO DECEMBER 1993

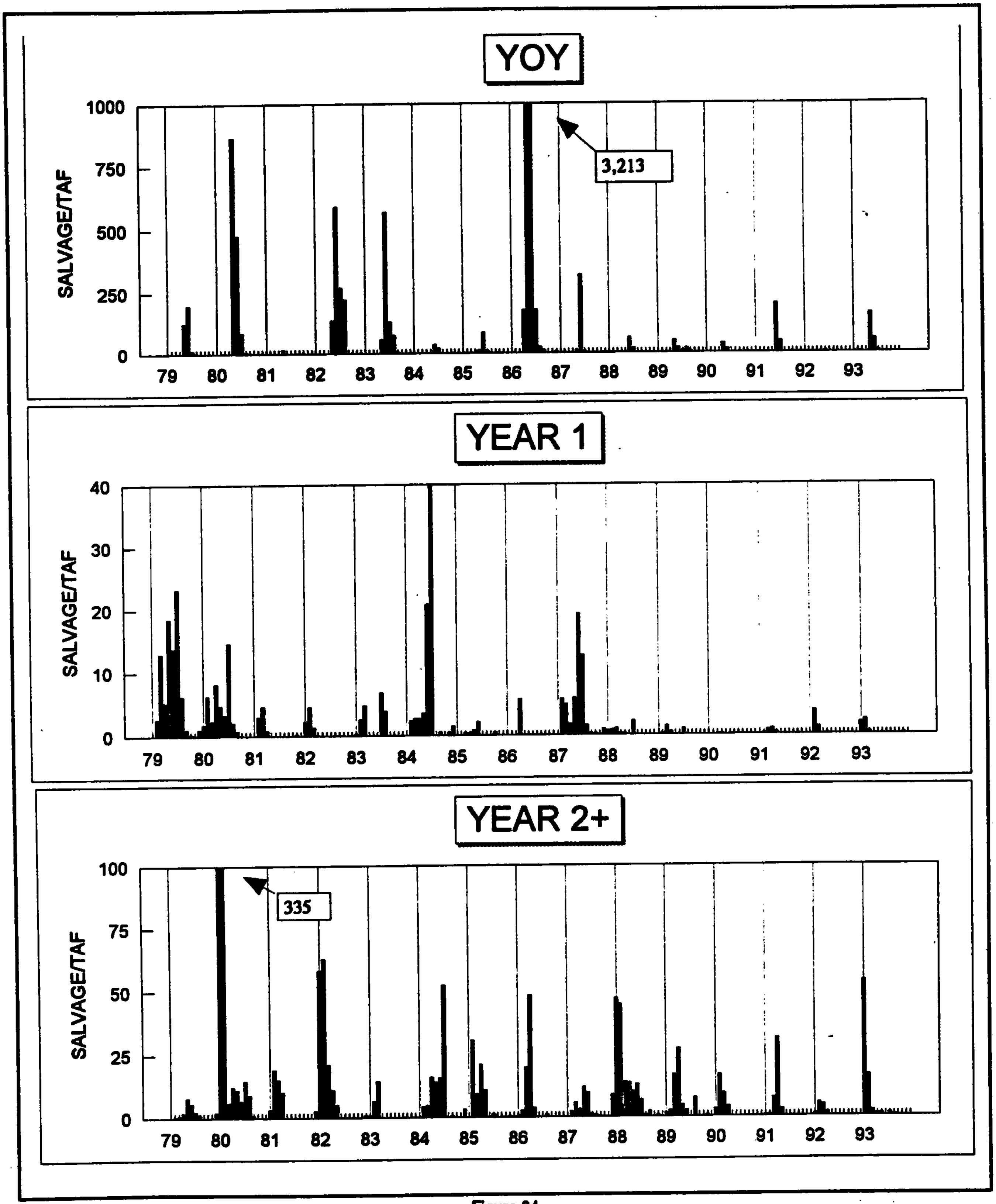


Figure 94
TOTAL MONTHLY SALVAGE OF DIFFERENT AGE CLASSES OF SPLITTAIL AT SKINNER FISH FACILITY, MAY 1979 TO DECEMBER 1993

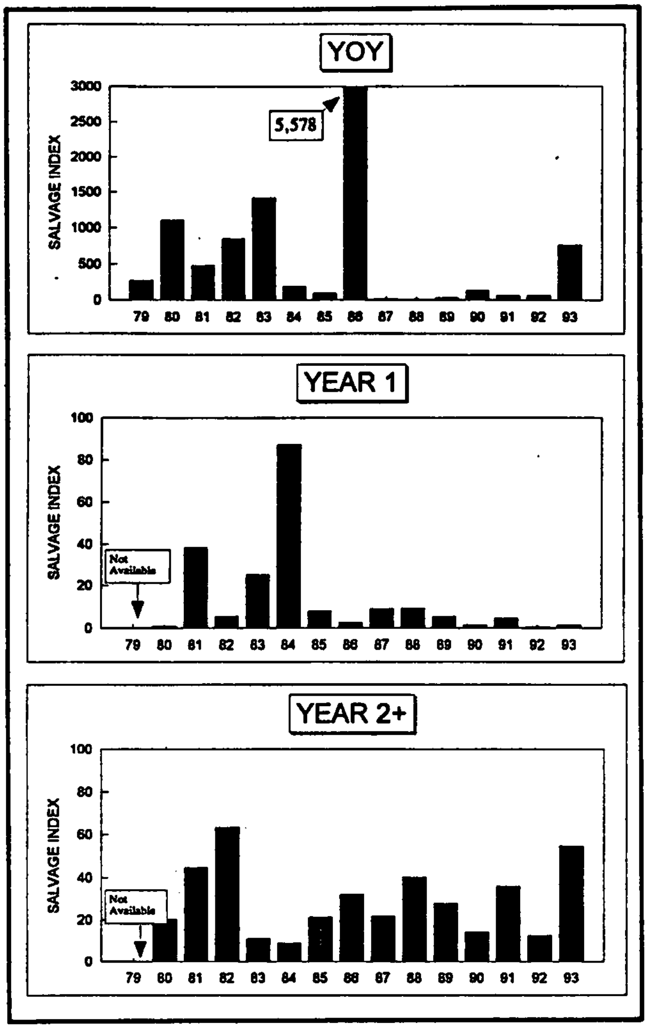


Figure 95
ANNUAL SALVAGE INDICES FOR DIFFERENT AGE CLASSES OF SPLITTAIL AT TRACY FISH FACILITY, 1980-1993

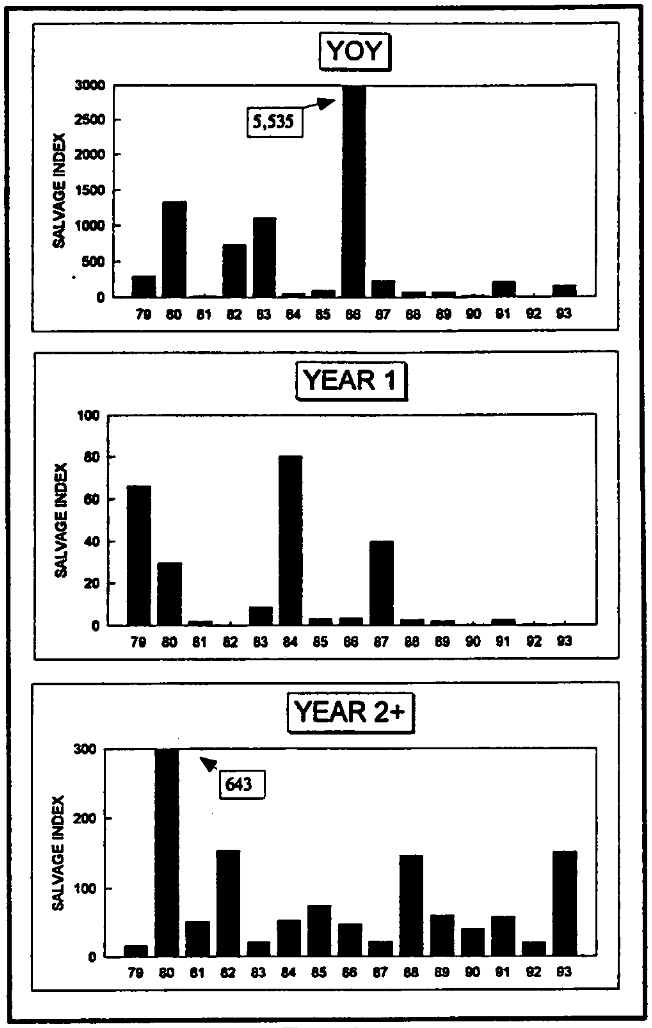


Figure 96
ANNUAL SALVAGE INDICES FOR DIFFERENT AGE CLASSES OF SPLITTAIL AT SKINNER FISH FACILITY, 1980-1993

Beach Seine Survey

The beach seine survey provides the broadest geographical coverage of the range of splittail for any of the sampling programs. A 50-foot beach seine has been used since 1976 to cover shoreline areas in Central, San Pablo, and Suisun bays, the Delta, the Sacramento River up to Redding, and the San Joaquin River south to Stockton. New stations south of Stockton were added in 1994 up to the San Joaquin River's confluence with the Tuolumne River. Another major advantage of this survey is the large number of splittail (over 11,000) collected. Most of those captured were young-of-the-year.

The beach seine survey has few stations in Suisun, Grizzly, and Honker bays and the Suisun Marsh area, and sampling did not occur south of Stockton until 1994. Data for 1976 and 1977 may not be comparable to later years because sampling was shifted to boat ramps following extensive riprapping of the initial beach seine sites. Another limitation of the database is that sampling was frequently not performed at Delta sites during summer months because of high water temperatures. This is unfortunate, since splittail abundance levels often appear higher in June. The beach seine does not effectively catch adult splittail.

Annual abundance for the beach seine survey was estimated using data from the 17 core stations, listed below (codes are FWS station codes). Although many other stations have been sampled over the years, these sites provide the most consistent records.

Northern Delta	
Brannon Island	TM001N
Clarksburg	SR043W
Discovery Park	SR060E
Garcia Bend	SR049E
Isleton	SR017E
Koket	SR024E
Rio Vista	SR014E
Stump Beach	SR012E
Central Delta	
Antioch Dunes	SJ001S
B&W Resort	MK004W
Dads Point	SJ041N
Delta Cross Channel	XC001N
Eddo's	SJ005N
Georgiana Slough	GS010E
Kings Island	DS002S
Terminous	LP003E
Southern Delta	
Woodward Island	MR010W

Catch per unit effort was calculated as the total catch of splittail at the core stations in May and June divided by the number of seines. Years before 1978 were ignored because of concerns about changes in sampling sites. It was not possible to develop abundance estimates for 1985 to 1991 because there was no sampling in May and June. CPUE for 1983, 1984, and 1992 was calculated based on May only because there was no sampling in June; since catch levels are often higher in June, CPUE estimates for these years may be low but they are considered a useful approximation.

Figure 87 shows that abundance was higher in 1993 than in any other year in the survey for which data are available. Abundance relative to 1985-1991 is unknown. Although the 1994 data are still being analyzed, results through June 2 indicate catch levels are relatively high.

There is some evidence that beach seine data do not show a consistent response to outflow. The relatively low CPUE in 1983 and 1984 are a major contrast to other wet years (1980, 1982, 1993), when abundance was high. There was no sampling in June 1983 and 1984, but the catch in May was exceptionally low. If the May results are indeed representative of abundance trends, a possible explanation is that most splittail may be transported downstream in some wet years.

The substantial catch of splittail at the core stations shows that the Delta provides important habitat for young splittail in all water year types. Large numbers of splittail have also been observed in upstream tributaries.

Initial results also show that the species was more widely distributed in 1993 than in any other year of the beach seine sampling program for which data are available since at least 1980. Splittail were distributed from Sacramento River mile 184 (upstream of Princeton) in the north to Stockton in the south.

Suisun Marsh Survey

The Suisun Marsh survey is performed monthly by UC-Davis staff and students under contract to Water Resources. Sampling methods are described by Meng *et al* (1994). The survey represents one of the best long-term sampling programs for splittail and has been used by Meng (1993) as an indicator of abundance trends. A limitation of this database is that it covers a relatively small portion of the range of splittail and, therefore, may not be representative of abundance trends throughout the system.

Splittail size and number for 1979-1993 were obtained from the original UC-Davis data sheets and entered into a computer database. Age classes were estimated using the monthly size criteria shown in Appendix B. Note that the Suisun Marsh criteria are slightly different than sizes used for SWP and CVP salvage data because fish are measured based on standard length rather than fork length.

Average monthly catch per trawl of each age class was calculated for each of the following core locations: Montezuma Slough, Boynton Slough, Goodyear Slough, Suisun Slough, Cutoff Slough, Peytonia Slough, and Spring Branch. There was some variability in the site codes and number of sampling sites within each of these sloughs over the course of the survey. To standardize abundance estimates, all sites within each location were treated as replicate observations based on recommendations of staff that performed the surveys (L. Meng, FWS, pers comm; B. Herbold, EPA, pers comm). Monthly catch per trawl for the marsh system was then calculated as the average of the seven core locations. As summarized in Appendix C, there are a number of gaps in the monthly data for the core stations. Whenever possible, abundance was estimated as the average of all sites sampled within a given month, but in a number of months there were no data for any site.

Monthly plots of each age class were prepared to examine abundance trends (Figures 97-99). Catch per trawl of young-of-the-year peaked during June-August, followed by a steady decline through the end of the year as a result of mortality and/or change in distribution. Analyses of year 1 splittail revealed an initial peak in abundance in January or

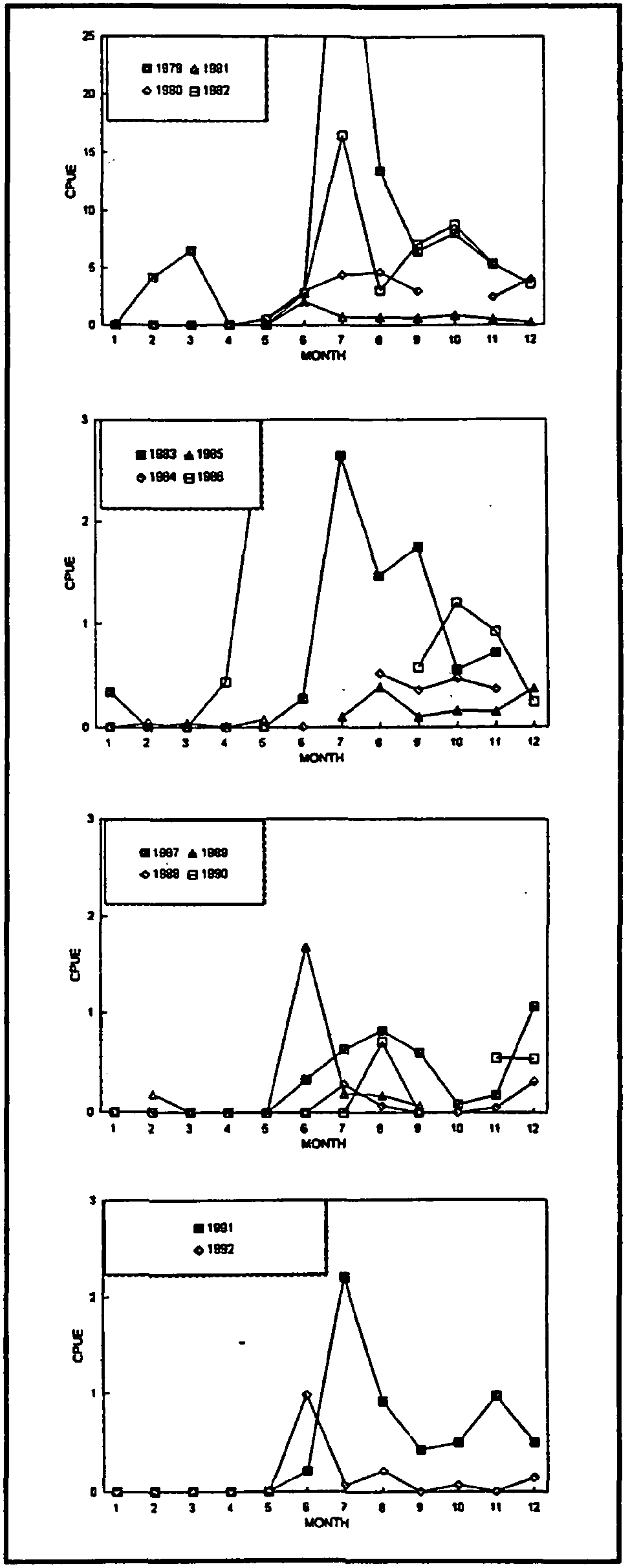


Figure 97
YOUNG-OF-THE-YEAR SPLITTAIL ABUNDANCE TRENDS IN SUISUN MARSH, 1979-1992

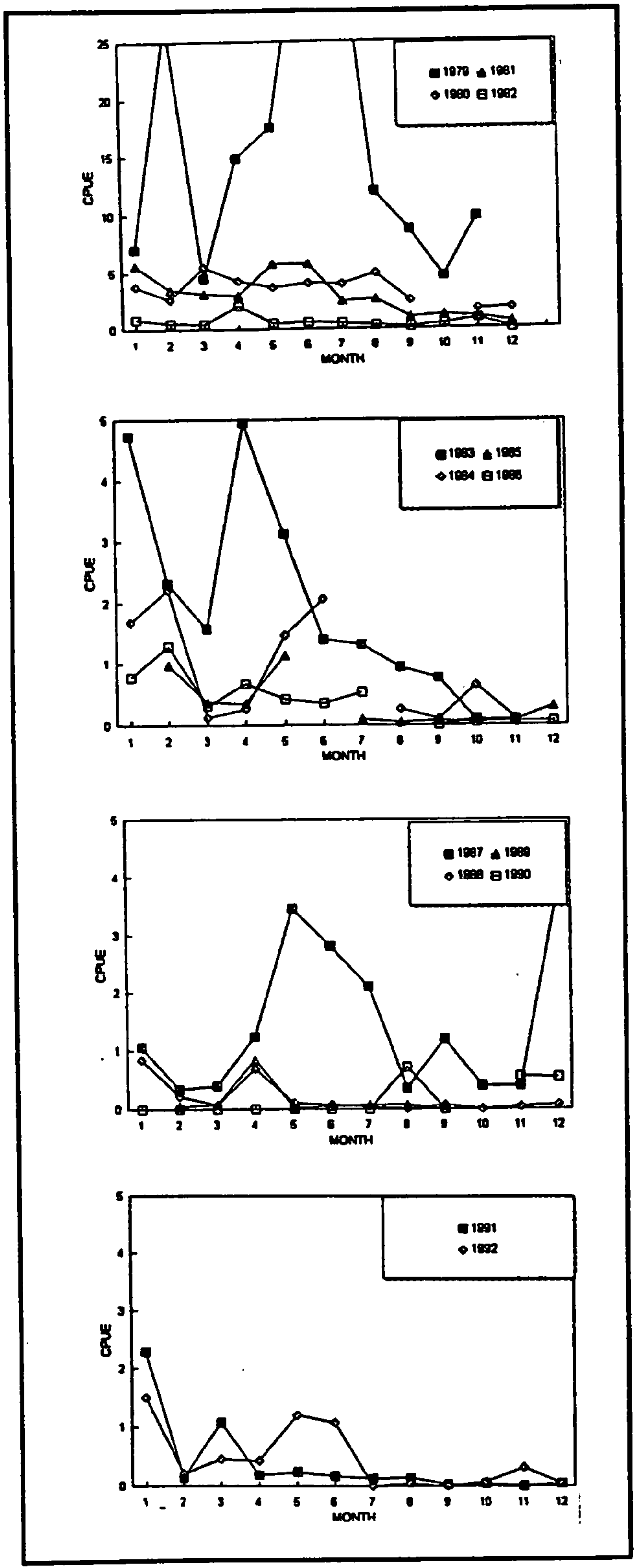


Figure 98
YEAR 1 SPLITTAIL ABUNDANCE TRENDS IN SUISUN MARSH, 1979-1992

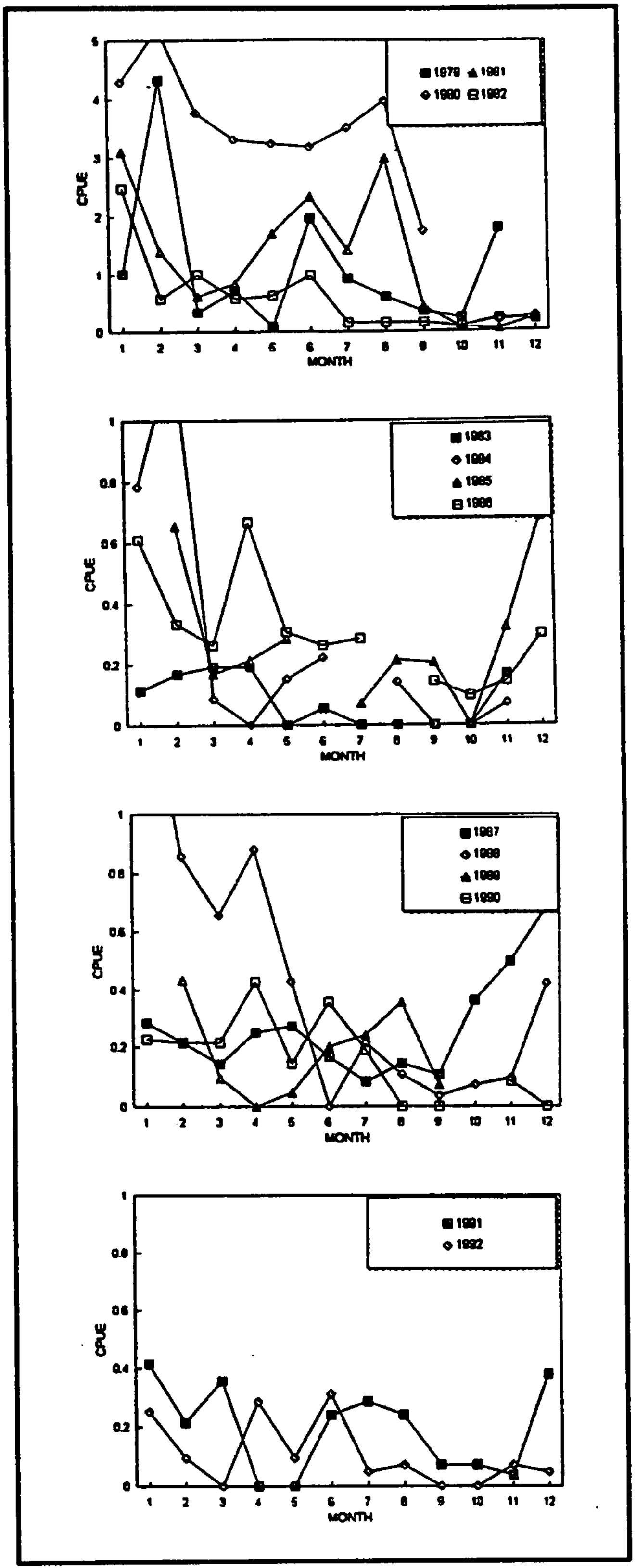


Figure 99
YEAR 2+ SPLITTAIL ABUNDANCE TRENDS IN SUISUN MARSH, 1979-1992

February in many years, perhaps due to maturation of YOY from the previous year. A second, stronger peak was usually observed during April-June, followed by a decline over the rest of the year. As for young of the year, the decrease in catch in the second half of the year could be due to mortality or change in distribution, but it is unclear why there should be a dip in year-1 abundance between winter and spring. Adult abundance was highly variable over the course of the year, but there were often detectable peaks in winter (December-February) and summer (June-August). Reduced abundance in spring may be a result of upstream spawning migration.

Annual abundance indices were calculated as the average catch per trawl for the core stations during June-August for young-of-the-year and April-June for year 1. Because year 2+ catch showed high variability between months, annual abundance indices were calculated as the average of all months. Results for each age group are summarized in Figures 87-89 and Figure 100. Abundance estimates for 1979 should be considered tentative because they were based on relatively few core sites.

As for many other surveys in the estuary, young-of-the-year abundance was higher in 1982 and 1986, both wet years, and relatively low throughout most of the 6-year drought (Figure 100). Year-1 abundance generally mirrored these trends one year later. However, there does not appear to be a consistent association between abundance and outflow; young-of-the-year abundance was relatively high in 1979, a dry year, and comparatively low in 1983, 1984, and 1993, all wet years.

In contrast to all of the other abundance estimates, year 2+ levels appear to have declined substantially in Suisun Marsh after 1980. There was a modest increase in year 2+ abundance in 1988, two years after a strong year class of young splittail, but levels have remained comparatively low since the early 1980s (Figure 89). This suggests that the Suisun Marsh population may be regulated by different factors or to a greater degree than splittail captured in other parts of the estuary.

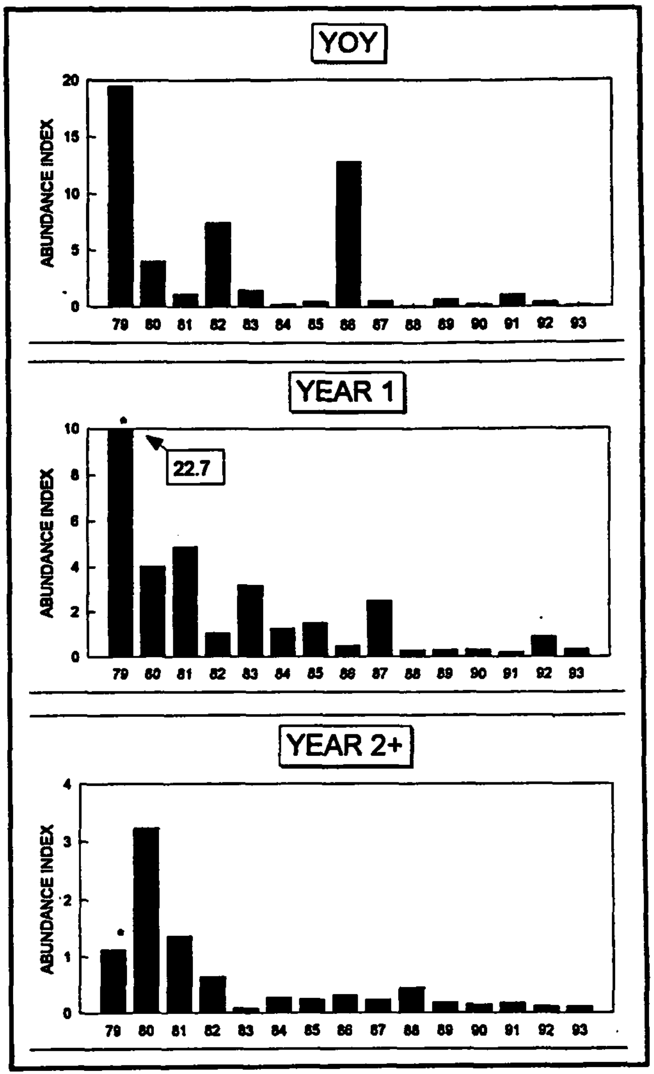


Figure 100
ABUNDANCE ESTIMATES FOR DIFFERENT AGE CLASSES OF SPLITTAIL IN THE SUISUN MARSH SURVEY
The 1979 estimate was developed from an incomplete dataset.

Delta Outflow/San Francisco Bay Study

As part of the Interagency Program, Fish and Game has sampled 42 locations from South Bay to the western Delta as part of the Delta Outflow/San Francisco Bay study. Sampling includes 5-minute tows using an otter trawl and 12-minute tows using a midwater trawl. The splittail catch was separated into young-of-the-year, year 1, and year 2+ age groups using size criteria similar to that shown in Appendix B. Monthly catch-per-unit-effort for each embayment was calculated as catch/10,000 m^2 for the otter trawl and catch/10,000 m^3 for the midwater trawl. Monthly abundance indices were calculated by multiplying catch-per-unit-effort for each embayment by area (otter trawl) or volume (midwater trawl) weighting factors shown in Table 9, then summing the embayment indices. Annual splittail abundance indices for each trawl were calculated as the sum of the monthly indices for the following periods of peak abundance: young-of-the-year (May-October), year 1 (February-October), and year 2+ (February-October).

A weakness of this database is that the area east of Antioch is not sampled, so an important part of the species' range is excluded. Because the study area is the lower range of splittail distribution, abundance measurements may be sensitive to shifts in distribution. Like a number of the other trawls, the survey may not sample shallow areas sufficiently to accurately follow splittail abundance (Baxter 1994). Moreover, relatively few splittail have been caught since 1980. Nonetheless, the high frequency of samples taken using different gear types and catches of multiple year classes provide a valuable source of information about splittail trends. Abundance data for young-of-the-year, year 1, and year 2+ are summarized below and in Figures 101 and 102.

Table 9
EMBAYMENT WEIGHTS USED TO CALCULATE ABUNDANCE INDICES FOR THE DELTA OUTFLOW/SAN FRANCISCO BAY STUDY

Embayment	Otter Trawl Area Weight	Midwater Trawl Volume Weight
South Bay	250.15	1505.38
Central Bay	216.34	2865.13
San Pablo Bay	153.54	861.40
Suisun Bay	55.29	471.64
Western Delta	28.01	253.68

Otter and midwater trawl indices both indicate that recruitment to the lower estuary has been poor since 1987. Peak abundance was in 1983 and 1987. Annual abundance indices for year 1 splittail were generally consistent with young-of-the-year catch in the previous year using the same gear type. Higher young-of-the-year catches in the otter trawl in 1982, 1983, 1986 and 1991 were followed by large numbers of year 1 in the following year. Relatively poor catches of young-of-the-year in 1980, 1985, and 1987-1989 were followed by low year 1 indices the next year. In the midwater trawl, high young-of-the-year indices in 1982, 1983, and 1986 and low indices in 1981, 1984, 1985, and 1987-1992 were also mirrored the by year 1 abundance the subsequent year.

Otter and midwater trawl indices for year 2+ splittail have been highly variable throughout this survey. In general, there is no evidence of a decline in abundance since the early 1980s. Both surveys show higher abundance of year 2+ in 1993, indicating a possible population increase. A resurgence in adult abundance in 1993 is consistent with relatively higher catches of young-of-the-year in 1991 than in previous years, 1987-1990. Year 2+ abundance appears to reflect young-of-the-year abundance 2 years earlier in a number of cases. For example, low year 2+ indices in the otter trawl in 1980 and 1985 and high indices in 1982 and 1983 followed similar trends in young-of-the-year 2 years earlier. Another explanation for the apparent increase in adult abundance in 1993 is that the distribution of splittail may have shifted downstream, increasing the vulnerability of splittail to this survey.

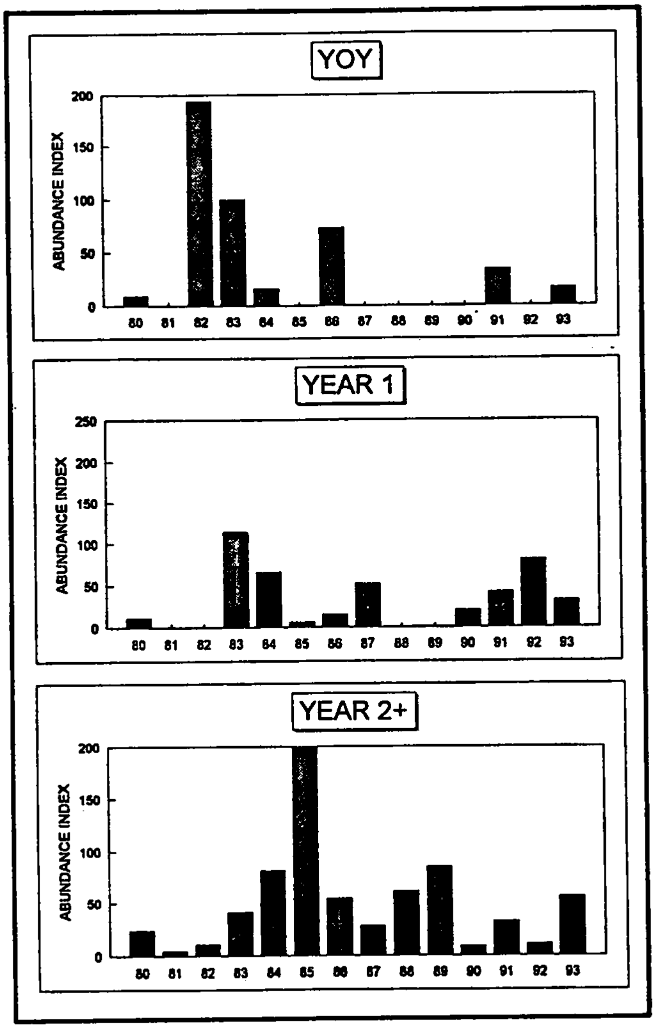


Figure 101
ANNUAL INDICES FOR DIFFERENT AGE CLASSES OF SPLITTAIL FOR THE OUTFLOW/BAY STUDY OTTER TRAWL, 1980-1993

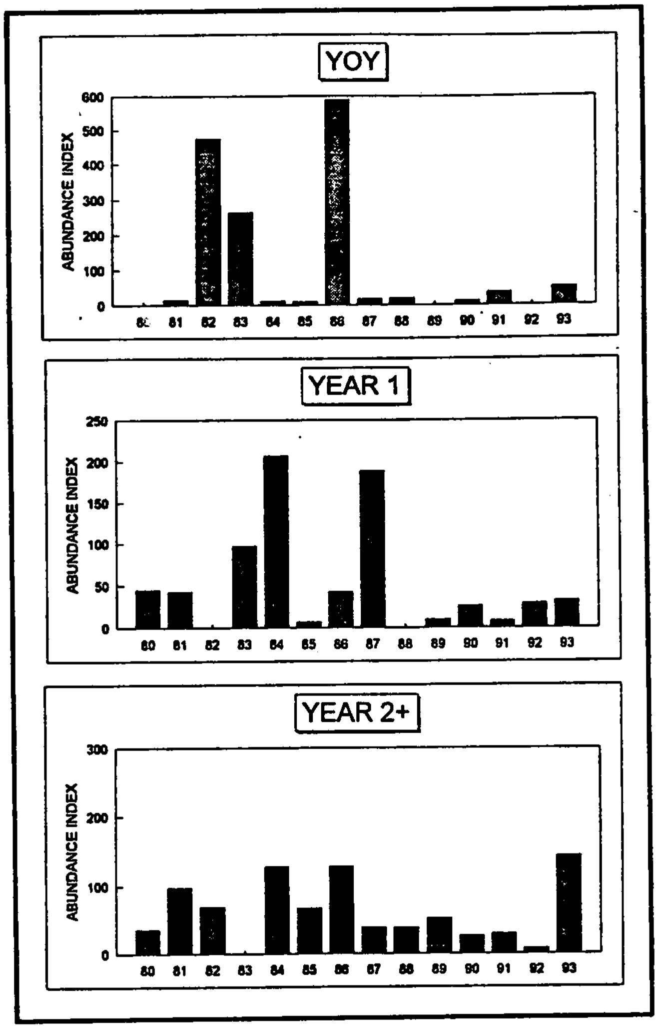


Figure 102
ANNUAL INDICES FOR DIFFERENT AGE CLASSES OF SPLITTAIL FOR THE OUTFLOW/BAY STUDY MIDWATER TRAWL, 1980-1993

Fall Midwater Trawl Survey

The fall midwater trawl survey, conducted since 1967, represents one of the longest and most geographically extensive measures of splittail abundance. However, the midwater trawl is relatively inefficient at catching splittail; from 1967 to 1992, less than 500 splittail were caught. Analysis of length frequency data for 1980 to 1992 indicates most of those were young-of-the-year, but at least 30% were year 1 or older. Baxter (1994) suggests that the relatively large size of 1-year-olds and adults may allow them to successfully avoid open-water trawls. The present indices are calculated based on all sizes combined; additional analyses are needed to separate young-of-the-year, year 1 and year 2+ fish in the databases.

Another concern is that samples are collected principally from higher-velocity, mid-channel areas. Yet splittail are generally found in shallow-water areas or in channel margins (Baxter 1994).

Calculated indices shown in Figure 87 were assumed to primarily represent trends in young-of-the-year. The limitations in this assumption are discussed above. Splittail appear to have been most abundant in 1967-1972 and 1980-1987. Recruitment apparently was particularly low during the 1976/1977 drought and has remained fairly low in most years since 1987. However, Fox and Britton (1994) tested this dataset using least-squares regression and found no significant trend in splittail abundance (p>0.9). Nonetheless, population declines are not necessarily detectable using regression analysis.

Summer Tow-Net Survey

The summer tow-net survey has been conducted since 1959 in all years except 1967 and 1968. Like the fall midwater trawl survey, the summer tow-net survey is geographically extensive but relatively inefficient at catching splittail. Since 1959, less than 500 splittail have been caught. Length-frequency analysis of the data indicate the survey catches almost exclusively young-of-the-year splittail. Abundance measurements for this survey are likely to have most of the same limitations noted for the midwater trawl. The highest tow-net indices were in 1963, 1978, 1982, and 1986. In contrast to a number of other surveys, abundance levels since 1987 have not been particularly low relative to other years. For example, the 1991 index (5.0) was the sixth highest on record.

Other Surveys

Additional information on splittail abundance and distribution is available from a number of shorter-term studies within the range of splittail. These data are summarized below.

PG&E

Monthly surveys were conducted in 1978-1979 (PG&E 1981a, b) and 1991-1992 (PG&E 1992b) in Suisun Bay and the lower San Joaquin River using bottom (otter) trawl, gill-net, fyke-net, and beach seine methods. Species composition, based on the percentage of Sacramento splittail within the composite catches, is summarized below.

	1978-1979		1991-1992	
Location	% Comp.	Rank	% Comp.	Rank
Suisun Bay	14	2	12	2
Lower San Joaquin	3	6	4	5

The percent composition of the fishery community represented by splittail during the two surveys appears to be stable. At the very least, these results demonstrate that splittail remain a dominant part of the fishery communities in these regions. However, the similarity in percent composition between the surveys is not necessarily representative of absolute splittail abundance.

This issue was examined in further detail with data from other surveys. It was hypothesized that if other surveys in the same region showed no decrease in splittail abundance over a similar period, the composition data may reflect actual abundance trends. The best available data for this period is from the Outflow/Bay study station 837, near Pittsburg Power Plant. Insufficient numbers of splittail were caught at station 535 and at all midwater trawl survey stations in this area to examine abundance trends. The analysis focused on the numbers of year 1 and year 2+ splittail, since the PG&E

(1981b) survey found that most of the catch was larger than 150 mm, the size range expected for year 1 or older fish. Although the catch data at station 837 was irregular (Figure 103), there is no evidence that splittail abundance has decreased in this region. In fact, the data suggest abundance may have actually increased near Pittsburg Power Plant.

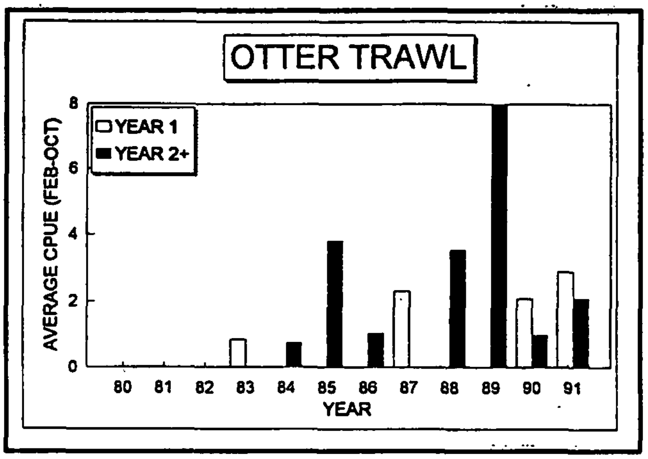


Figure 103
AVERAGE CATCH-PER-UNIT-EFFORT NEAR
PITTSBURG POWER PLANT FOR
YEAR 1 AND YEAR 2+ SPLITTAIL

Suisun Marsh Salinity Control Gates Predator Surveys

A monitoring program has been conducted at Suisun Marsh Salinity Control Gates since 1987 to address questions about juvenile salmon predation. Although the sampling program is designed primarily to monitor abundance of fish predators in the area, large numbers of splittail are also captured. Sampling is performed during the daytime in spring and summer using stationary and drift gill-nets at sites upstream and downstream of the structure. A reference site was added to the monitoring program in 1993.

Catch-per-unit-effort was calculated based on the total catch of splittail divided by the number of hours sampled at the upstream and downstream site (DFG 1994). Abundance could not be calculated for 1987 because no data were recorded for splittail. Examination of the length data indicated that all splittail captured were in the year 2+ size range. Splittail were the second most abundant species in most years; in 1988 they were the most abundant species caught. Catch-per-unit-effort data are summarized in Figure 104. Monitoring results indicate that adult abundance has been variable but has not declined since 1988. This is consistent with results of UC-Davis monitoring in Montezuma Slough over the same period using an otter trawl. However, the UC-Davis survey noted a major decline in this region in the early 1980s. There is some evidence of a peak in abundance in 1991, followed by a decrease 1992-1993; however, 1993 abundance was similar to 1988. It is not known how levels of year 2+ in 1988 compare to previous years, but evidence from other surveys indicates this was a relatively strong year class. Other surveys in this section (*eg*, midwater trawl and tow-net survey) consistently demonstrate that exceptionally large numbers of splittail young were produced in 1986 and reached maturity in 1988.

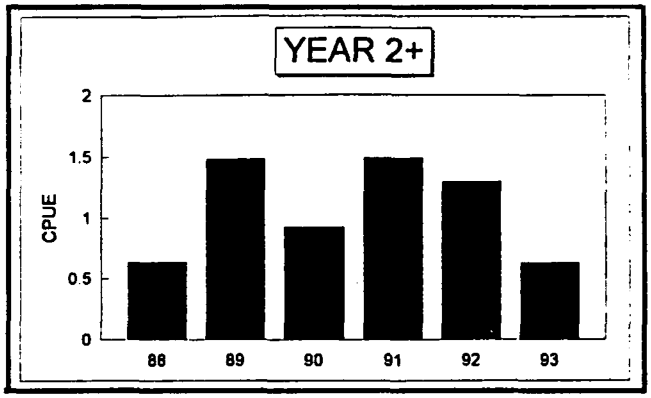


Figure 104
AVERAGE CATCH-PER-UNIT-EFFORT FOR
SUISUN MARSH SALINITY CONTROL STRUCTURE
GILL-NET STUDIES, 1987-1993

San Pablo Bay and Suisun Bay Sampling, 1963-1964

Ganssle (1966) describes an intensive survey conducted in the early 1960s using a 25-square-foot midwater trawl, a 25-foot otter trawl for deepwater stations, and a 450-foot gill-net, and a 16-foot otter trawl for shallow water. The shallow-water stations in Grizzly, Honker, western Suisun, and northeastern San Pablo bays. The larger trawls were fished in deep channel sections from central San Pablo Bay and Carquinez Strait upstream to near the San Joaquin confluence. Gill-netting was conducted from June 1963 through May 1964, and trawling was performed in January 1963-1964.

The catch of splittail totaled 291, with only 2 captured in San Pablo Bay. Most of the fish were captured in Grizzly and Honker bays. Western Suisun Bay contributed an undefined number. Sampling effort at these three locations totaled 179.7 hours of gill-netting and the equivalent of 210 ten-minute tows.

This dataset is valuable because it provides perspective on catch levels before SWP pumping began. The types of gear used and areas fished are similar to many of the current sampling protocols. Results of this study indicate that historically, even with some fairly intensive sampling, San Pablo Bay, Carquinez Strait, and (to a lesser extent) western Suisun Bay did not appear to have major concentrations of splittail.

Gill-Net Sampling, Napa River and Lower American River

On October 4-5 and October 18, 1989, DFG and FWS staff conducted two short-term gill-net surveys in the Napa River (DFG 1989b). In the first survey, adult splittail were the most abundant fish species captured, comprising 66% of the total catch. Exceptionally large numbers of splittail (76 adults/3 net sets) were also captured in the second survey.

In May 1991, gill-net sampling was conducted in the lower American River as part of studies by East Bay Municipal Utility District, Sacramento County, and DFG (Hanson Environmental 1991). Sampling at two locations captured significant numbers of splittail (25 adults/7 hours) during nighttime sampling but none in the daytime. However, there were some differences in techniques used day and night sampling, so the results may not be strictly comparable.

These short-term data are not useful for determining abundance trends, but they do show that large numbers of splittail are found in locations not sampled by any of the routine surveys. Moreover, these surveys were in the middle of a 6-year drought, when abundance data from other locations suggest a decline in the numbers of young. Therefore, it appears that use of different gear types and sampling locations and times could change our understanding of splittail abundance and distribution.

Chapter 8

FACTORS THAT MAY INFLUENCE SACRAMENTO SPLITTAIL ABUNDANCE AND DISTRIBUTION

In its proposed rule for Sacramento splittail, the Fish and Wildlife Service (1994) identified altered hydraulics and reduced outflow from exports as the principal causes of the population decline. Additional threats were listed as loss at pumping plants and diversions, loss of spawning and nursery habitat as a consequence of draining and diking for agriculture, reduction in the availability of highly productive brackish-water habitat, urban and agricultural pollution, introduced species, and exacerbation of these factors as a result of 6 years of drought.

Analyses performed for the present assessment indicate that the recent drought is the primary cause of recent lower abundance of young splittail in the estuary based on a strong correlation with Delta outflow. Abundance is also well-correlated with floodplain inundation, which may provide a large amount of additional spawning, rearing, and foraging habitat in very wet years. Little flooding has occurred in the range of splittail since 1986, leading to a series of weak year classes.

Because floodplain inundation occurs when uncontrolled flows are in the system, the project-related changes to the hydraulics of the estuary may not have a major effect on recruitment success in wet years.

Of the other factors listed by the Fish and Wildlife Service, urban and agricultural pollution and introduced species remain potentially major but poorly understood threats to splittail. There is, however, no evidence to support the conclusion that loss at pumping plants significantly affects abundance. Analysis of salvage data demonstrates that entrainment occurs primarily when large numbers of splittail are present in the system. Although diking and draining of floodplain areas for agriculture have resulted in loss of splittail spawning and nursery habitat, most of this activity occurred well before recent observations of poor recruitment. In addition, it is questionable whether loss of brackish water habitat constitutes a risk for splittail. The present and historical range of this species extends far upstream of the entrapment zone and over a broad range of salinities. Although splittail abundance was negatively correlated with salinity for a number of regions in the estuary, specific conductance co-varies with factors such as outflow and floodplain inundation, making it difficult to identify specific causes.

A number of other potential factors not identified by the Fish and Wildlife Service have also been also examined. Splittail appear to rely heavily on *Neomysis* shrimp as a food source, at least in Suisun Marsh, but terrestrial and other aquatic food sources are also utilized. Food limitation as a result of declines in *Neomysis* abundance and reduced access to terrestrial food sources in the floodplain in dry years cannot be ruled out. An additional concern is that a reduction in the number of spawners may lead to poor recruitment. No stock-recruitment relationship was found for this species, indicating that abundance is controlled by environmental conditions. There is, however, evidence of the opposite relationship: poor recruitment leads to a reduction in the number of spawners. Historical abundance trends indicate that the species has the capacity to rebound dramatically following successive weak year classes. Finally, recreational harvest of adult splittail remains a possible minor threat to the population.

Many of these factors have been analyzed with indices such as the fall midwater trawl that have major limitations. Until better abundance measures can be developed, all conclusions based on these surveys should be considered tentative.

Effects of Flow on Splittail Abundance

Few species in the estuary appear to respond as dramatically to wet years as splittail. The correlation between flow and splittail production was noted by Daniels and Moyle (1983), who found a relationship between total Delta outflow and midwater trawl abundance. The Department of Fish and Game (1993) performed regression analyses using midwater trawl data through 1990 and found a significant relationship with March-May outflow (r^2=0.78). Similar relationships between young-of-the-year abundance and outflow were also reported by Meng (1993) for the Chipps Island and Outflow/Bay surveys using regression analysis.

An update of the relationship between midwater trawl abundance and outflow through 1993 is shown in Figure 105 (r^2=0.68, $p<0.01$). The relationship remains highly significant (r^2=0.50, $p<0.01$) if the abundance and outflow data are log-transformed. Note that the present analysis included February in the regression because this month appears to be important for spawning (Chapter 6).

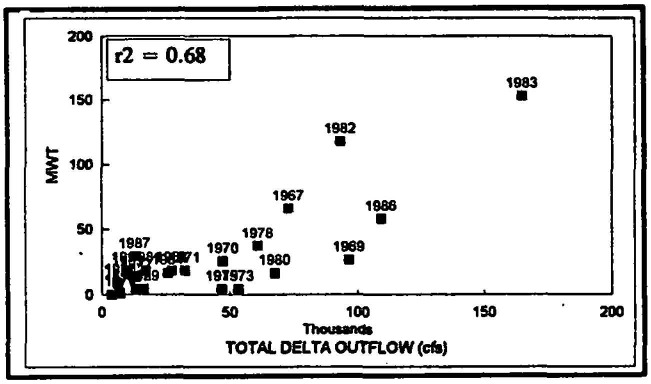


Figure 105
RELATIONSHIP BETWEEN FALL MIDWATER TRAWL INDEX
FOR SPLITTAIL AND
AVERAGE DELTA OUTFLOW, FEBRUARY-MAY 1967-1993

The correlation between wetter years and juvenile splittail abundance is supported using non-parametric statistical methods. If midwater trawl and summer tow-net data are grouped into "dry" (critical-below normal) and "wet" (above normal-wet), differences are statistically significant using a Mann-Whitney U-test ($p<0.05$) (Figures 106 and 107).

There is also evidence that hydrology affects the abundance of adults. Regression analysis of the Outflow/Bay study otter trawl index for year 2+ versus the log of February-May flows 2 years earlier showed a significant relationship (r^2=0.53, $p<0.01$; Figure 108). This relationship is surprisingly strong considering the fact that the adult population represents diverse age classes. However, the relationship is not statistically significant if 1985, when year 2+ abundance was highest, is ignored (r^2=0.08).

Although high outflow years clearly benefit splittail, it is likely that abundance does not actually respond as a continuous linear function, as suggested by the Fish and Wildlife Service (1993, page 863). The relationships in Figure 105 and those described by Meng (1993) are fairly "flat" until average February-May outflows surpass about 25,000 cfs, where abundance sharply increases. There appears to be little difference in recruitment in dry to moderate outflow years.

The most likely explanation for this trend is that exceptionally strong year classes may only be produced when major storms inundate vegetation in the floodplain, thereby creating a large amount of spawning, rearing, and foraging habitat. This hypothesis was presented by Caywood (1974) based on observations that flooded vegetation is usually associated with splittail spawning. Moreover, terrestrial foods such as earthworms occasionally comprise a significant portion of their diet. Caywood (1974) suggested that nutrition prior to reproduction may depend on the availability of terrestrial organisms. In addition, splittail have been observed in two of the major floodplain areas in the basin: Yolo and Sutter bypasses. Caywood (1974) noted that splittail are common in Yolo Bypass when it floods and occasionally in Sutter Bypass. Jones and Stokes (1994) also collected adult and juvenile splittail in Sutter Bypass during 1993.

The possible importance of Yolo Bypass and other floodplain areas is supported by the statistical analysis shown in Figure 109. The data indicate a highly significant relationship ($p<0.01$) between the number of days this area is flooded in winter and spring and the midwater trawl index. The relationship remains statistically significant (r^2=0.19, $p<0.05$) when the years of heaviest flooding, 1982 and 1983, are ignored. Gage data were not available to perform a similar analysis for Sutter Bypass. These results do not necessarily indicate that the bypasses are the primary spawning and rearing areas, but they at least provide an index of the inundation of floodplains throughout the basin.

Regression analysis also indicates that floodplain inundation could be related to adult abundance. The r^2 values for the year 2+ otter trawl indices versus bypass flooding 2 years earlier ($p<0.01$) was 0.55 for the Yolo Bypass (Figure 110). However, as

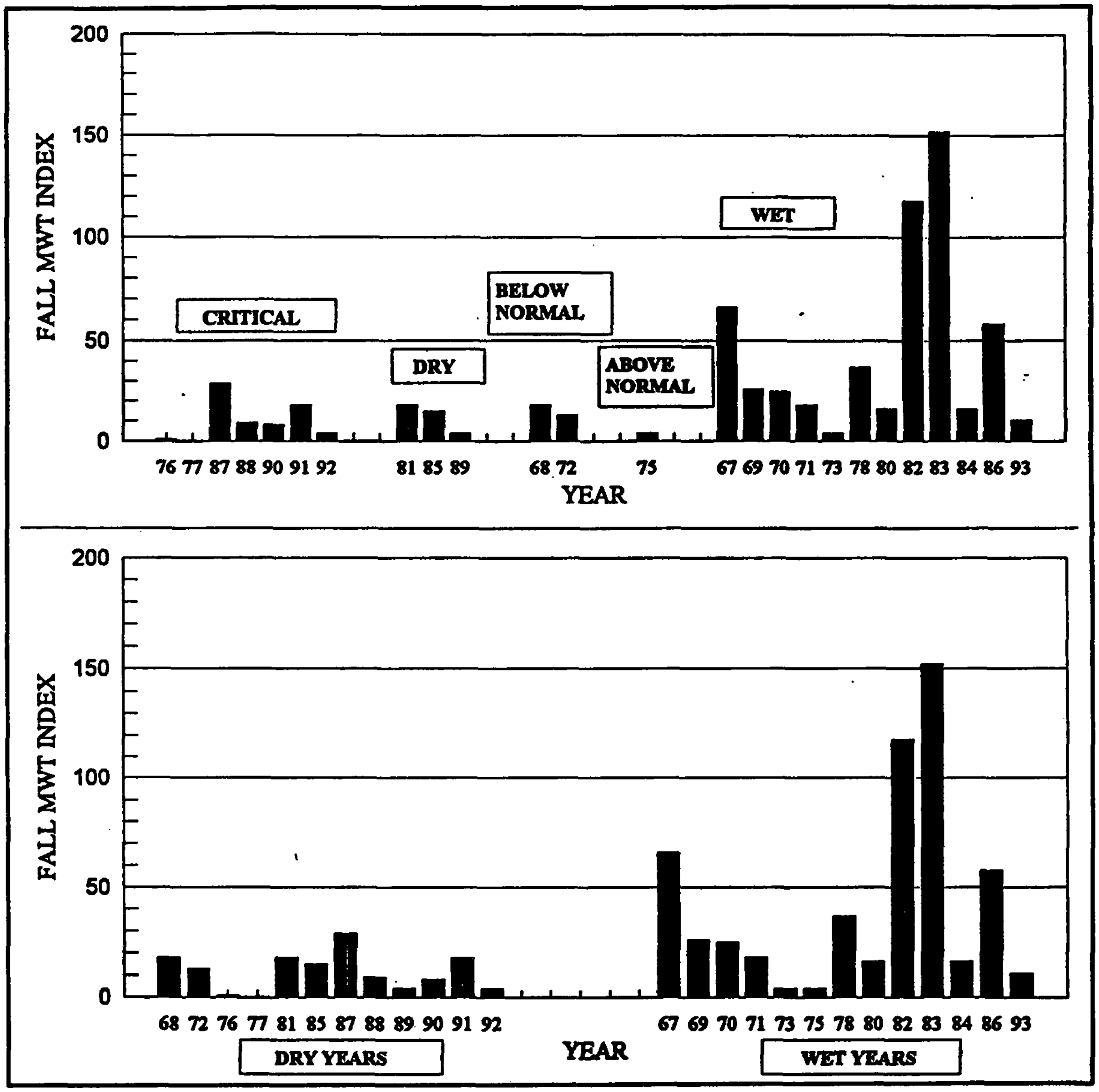


Figure 106
COMPARISON OF DRY AND WET YEARS FOR SPLITTAIL MIDWATER TRAWL INDEX

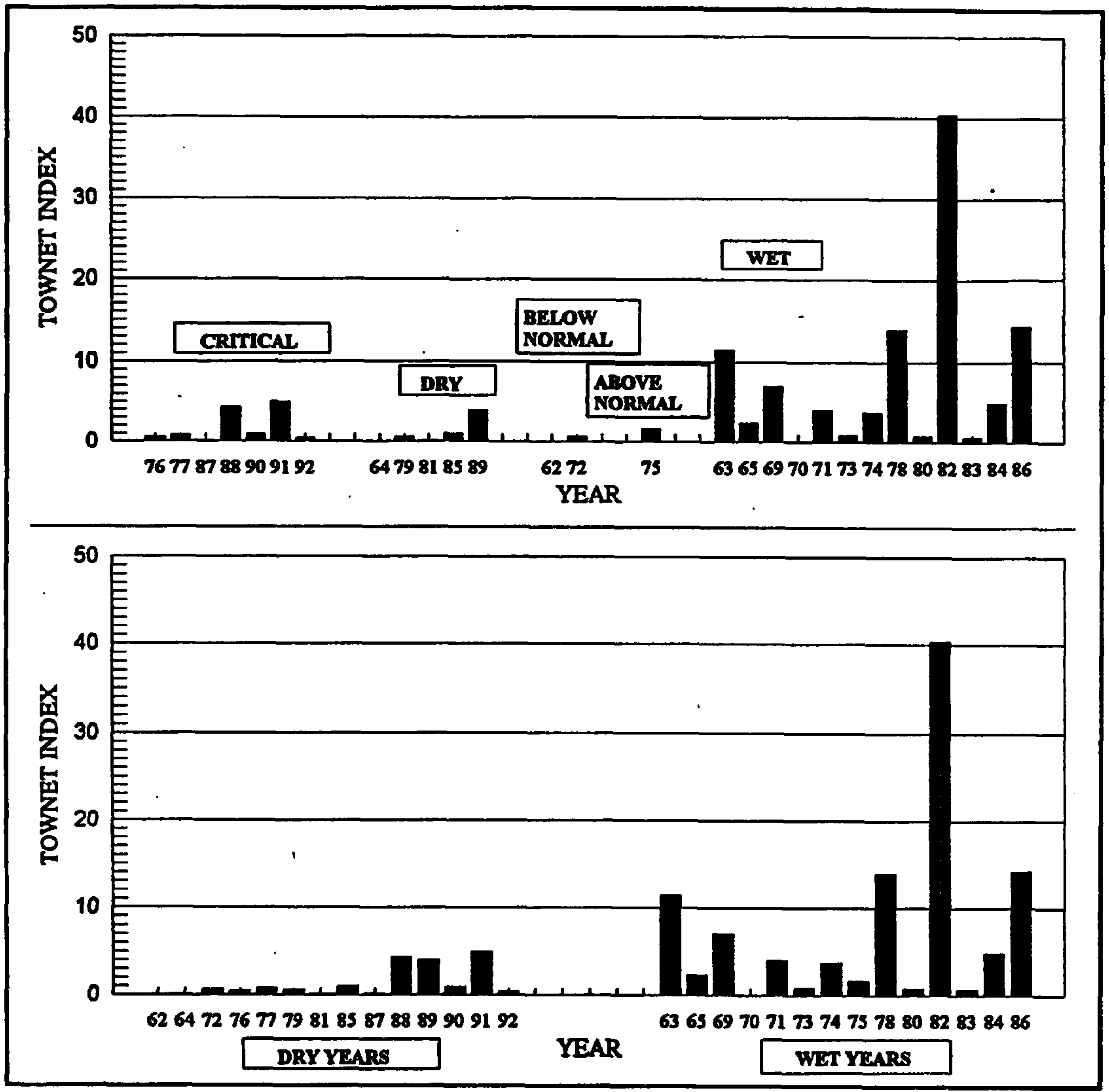


Figure 107
COMPARISON OF DRY AND WET YEARS FOR SPLITTAIL TOW-NET INDICES

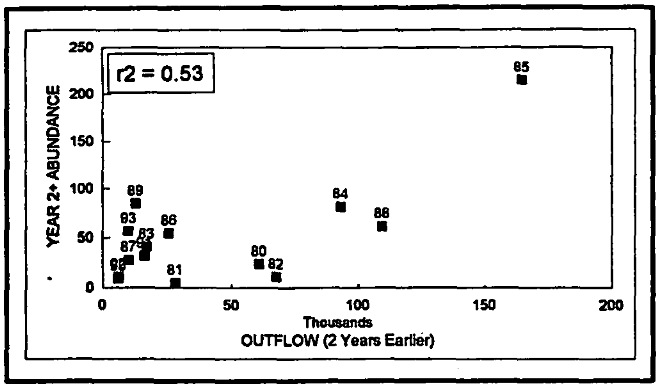


Figure 108
RELATIONSHIP BETWEEN
OTTER TRAWL INDEX FOR YEAR 2+ SPLITTAIL AND
TOTAL DELTA OUTFLOW 2 YEARS EARLIER,
FEBRUARY-MAY 1980-1993
Data labels correspond to years when adult abundance was measured.

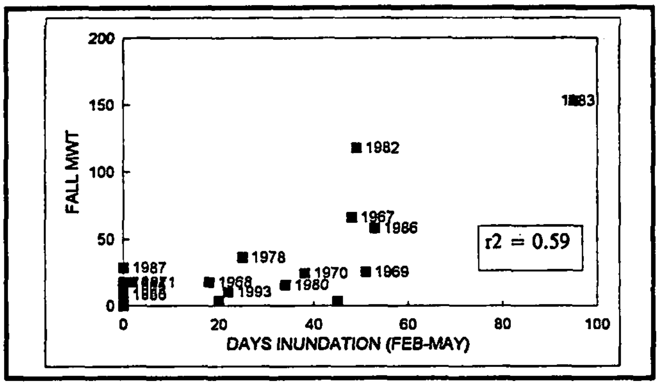


Figure 109
ESTIMATED NUMBER OF DAYS IN FEBRUARY-MAY THAT
YOLO BYPASS WAS INUNDATED VERSUS
SPLITTAIL FALL MIDWATER TRAWL

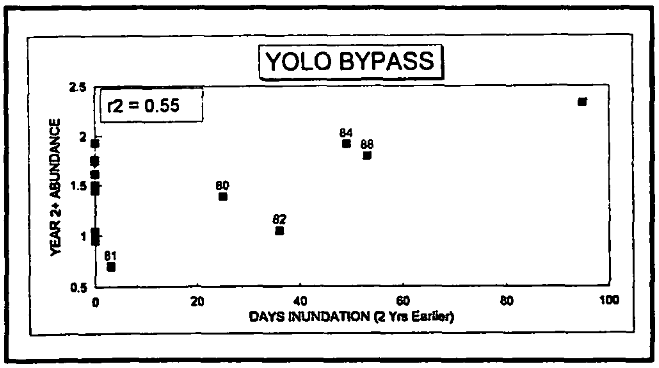


Figure 110
RELATIONSHIP BETWEEN
OTTER TRAWL INDEX FOR YEAR 2+ SPLITTAIL AND
ESTIMATED NUMBER OF DAYS INUNDATION
2 YEARS EARLIER, FEBRUARY-MAY
Data labels represent the years in which year 2+ abundance was measured.

for the analysis for outflow (Figure 108), the relationship is not significant if 1985 is ignored (r^2=0.12).

The floodplain inundation hypothesis offers a possible explanation for why splittail year-class strength is not always strong in wet years. Meng (1993) noted that young-of-the-year abundance was relatively low in 1993 compared to other wet years and suggested that the abundance/outflow relationship may be "decoupling". However, Figure 109 shows there was little inundation of the floodplain in 1993 despite the year being classified as wet. Outflow was relatively evenly distributed across winter and spring 1993, and reservoirs had a large amount of unused storage capacity following the 6-year drought, so the Yolo and Sutter bypass areas were not needed for long-term flood control. Therefore, inundation of spawning habitat appears to have been relatively low compared to 1982, 1983, and 1986, when the bypasses and other floodplain areas were used extensively for flood control. An alternative or contributing factor to explain the low index in 1993 is that the spawning stock may have been reduced by 6 successive years of drought, but there is no evidence of this trend in any of the year 2+ abundance indices except in Suisun Marsh.

Another possibility is that the 1993 midwater trawl index is not representative of population trends throughout the system. Results from the beach seine, which samples upstream of the midwater trawl, show that 1993 abundance was exceptionally high. In any case, further studies are needed to define the extent to which floodplain may provide additional habitat. For example, Jones and Stokes (1994) found that young were stranded in Sutter Bypass as water receded in 1993, indicating that floodplain habitat may be marginal in some locations or time periods.

In summary, there is a significant relationship between Delta outflow and abundance. Delta inflow and associated flooding also offer an explanation of why strong year classes are produced in very wet years.

Effects of Flow on Splittail Distribution

Young splittail and delta smelt appear to be distributed differently in response to high outflow years. As described in Chapter 5, tow-net and midwater trawl indices suggest that a greater percentage of the delta smelt population is west of the Delta (*ie,* in Suisun Bay) in wetter years. However, Hanson (1994) found no relationship between the percentage of the Suisun midwater trawl index for splittail and outflow (Figure 111). This conflicts with the hypothesis by Meng (1993) that splittail abundance is related to the amount of shallow brackish-water habitat in Suisun Bay. A possible explanation for the lack of a relationship for the midwater trawl is that the indices used did not differentiate between adults and juveniles, possibly confounding the analysis.

Description of the distribution patterns of adults is complicated by the fact that the species migrates during spawning periods. Changes in adult abundance were examined by plotting the monthly salvage per thousand acre-feet (see section on abundance) versus average monthly total Delta inflow from DAYFLOW (DWR 1992). Results for the CVP and SWP are presented in Figures 112 and 113. Abrupt increases in the level of year 2+ splittail frequently coincide with rapid increases in Delta inflow. The trend is most consistent in dry years (water year 1980, 1985, and 1987-1991), with more variable results in wetter years. By contrast, the patterns of year 1 abundance show no detectable trends.

These results suggest that adult migration may be triggered at least in part by increases in streamflow from the tributaries. Year 2+ splittail were probably

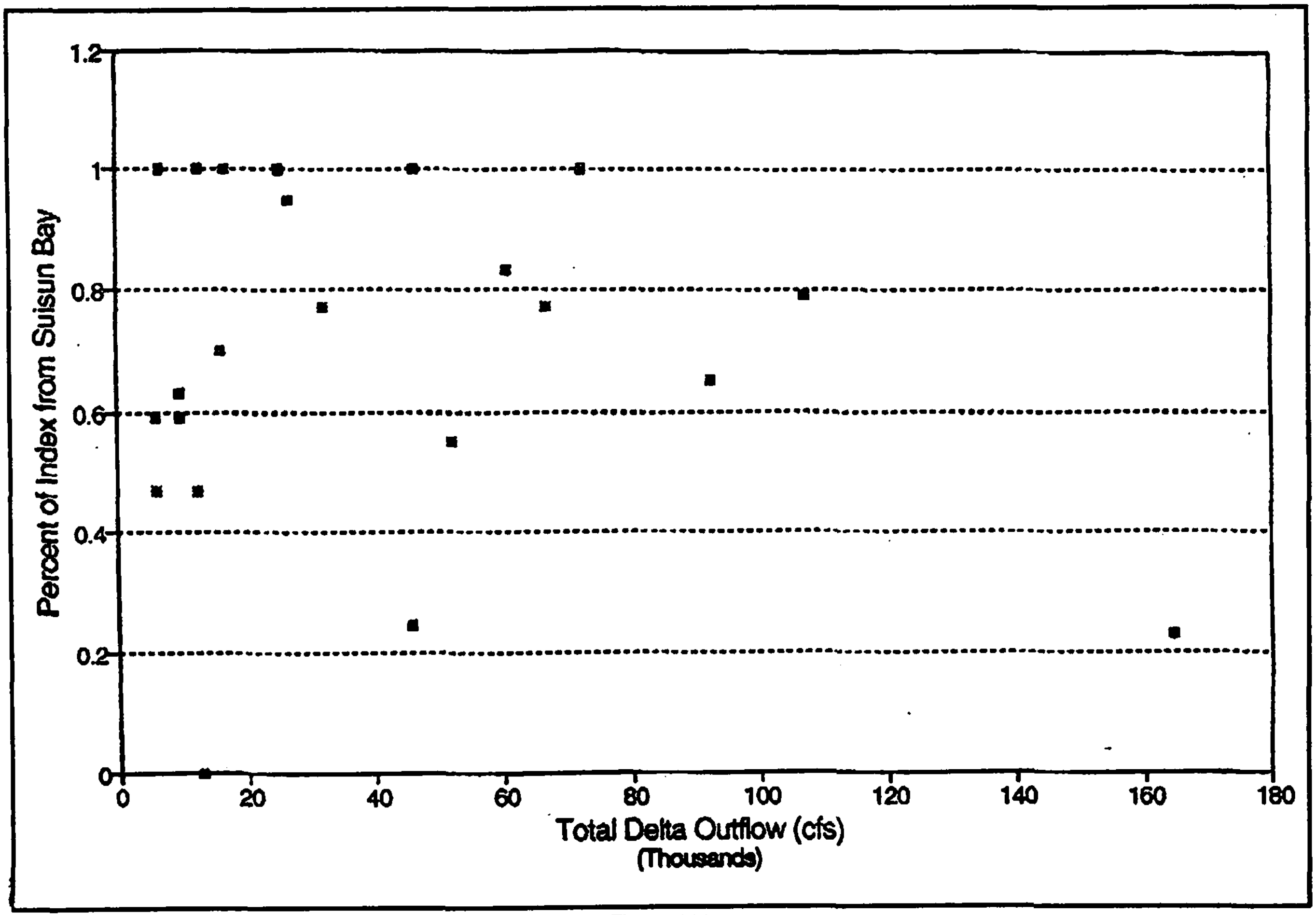


Figure 111

CORRELATION BETWEEN THE PROPORTION OF THE MIDWATER TRAWL INDEX FROM SUISUN BAY AND AVERAGE TOTAL DELTA OUTFLOW DURING THE PREVIOUS FEBRUARY TO MAY

SOURCE: Hanson (1994)

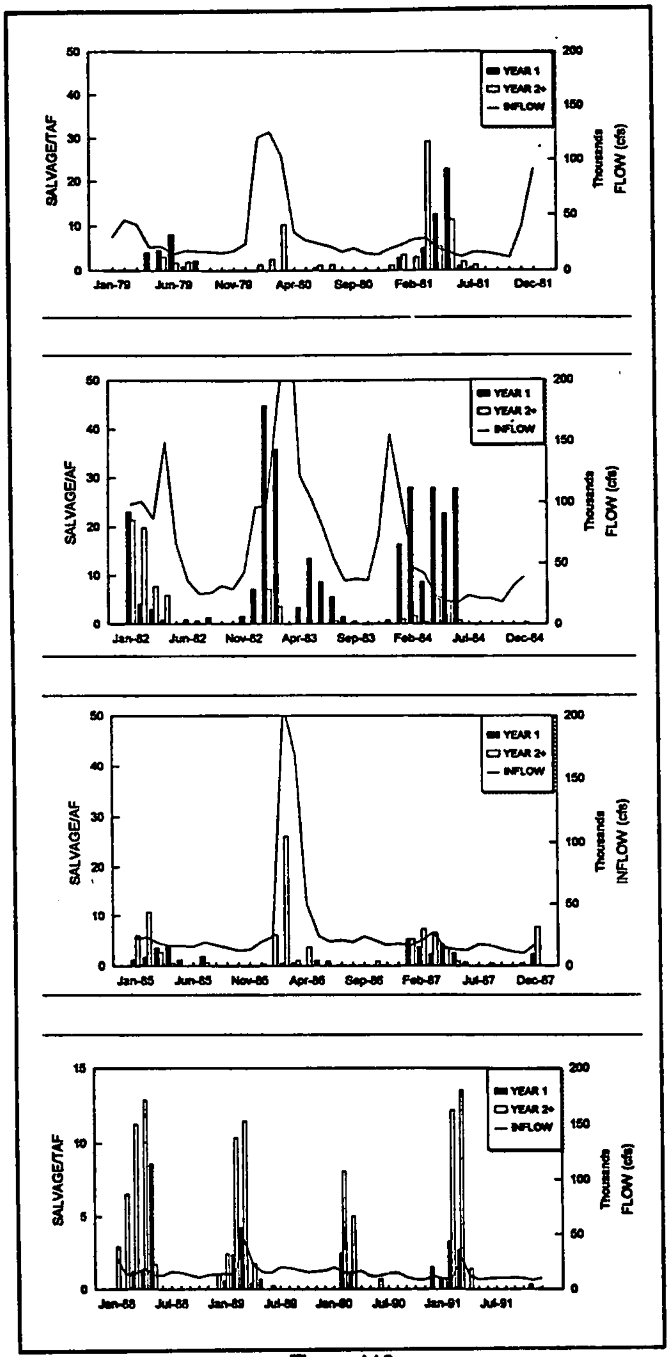


Figure 112
SPLITTAIL SALVAGE PER ACRE-FOOT AT TRACY FISH FACILITY VERSUS DELTA INFLOW

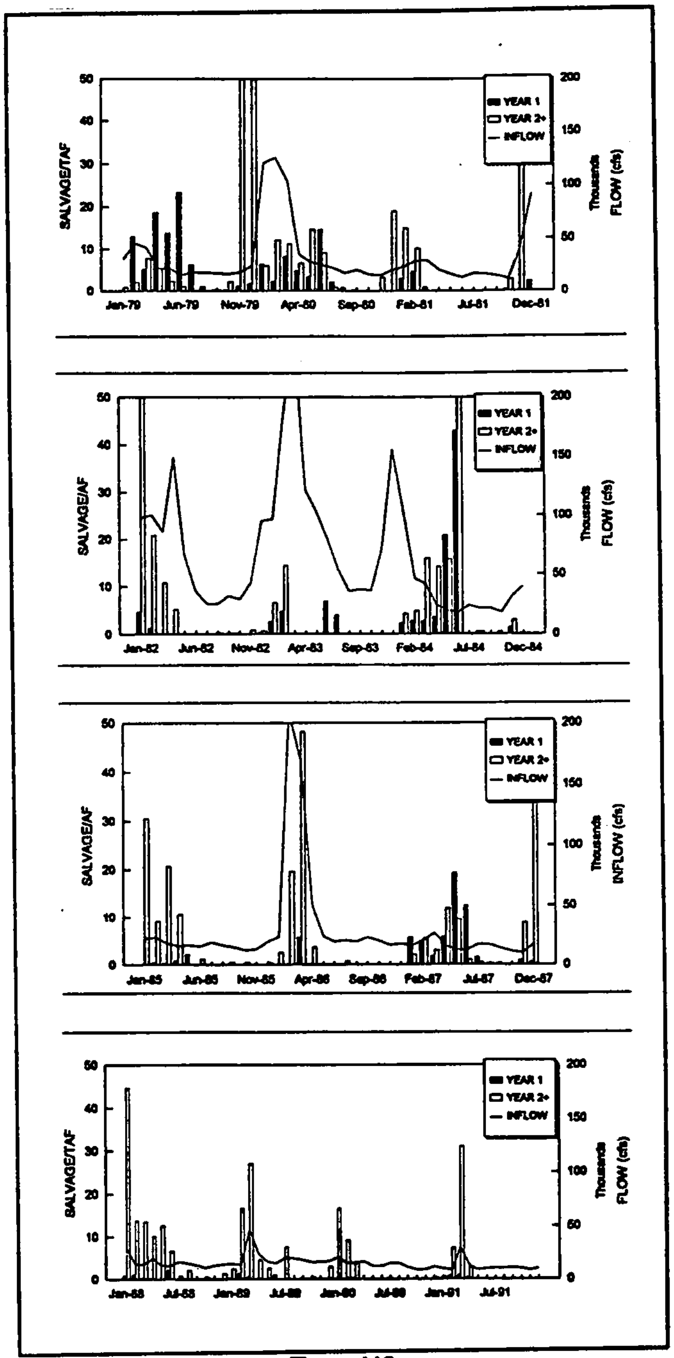


Figure 113
SPLITTAIL SALVAGE PER ACRE-FOOT AT SKINNER FISH FACILITY VERSUS DELTA INFLOW

entrained at the export facilities during their migration to or from spawning areas. The lack of trend for year 1 fish would be expected since most of these fish are too young to spawn. A stronger relationship between flow and the timing of entrainment in dry years is reasonable because a higher percentage of Delta inflow is diverted during these years. If upstream migration is cued toward a native tributary, increased Delta diversion of water originating from a basin could result in more adults straying toward the export facilities. Variability in the distribution of adults in wetter years may be partly a result of the timing of streamflow. For example, sharp increases in streamflow in November 1981 and 1984 may have been too early for spawning. Other cues such as day length and water temperature may be important associated factors.

Effects of Entrapment Zone Position

In its proposed rule for Sacramento splittail, the Fish and Wildlife Service (1994) states that the species is "adapted for life in the entrapment zone". The major evidence for this assertion is an analysis by Meng (1993), which appears to show that the peak distribution of splittail is in Suisun Bay, an area where the entrapment zone was often historically located (Figure 114).

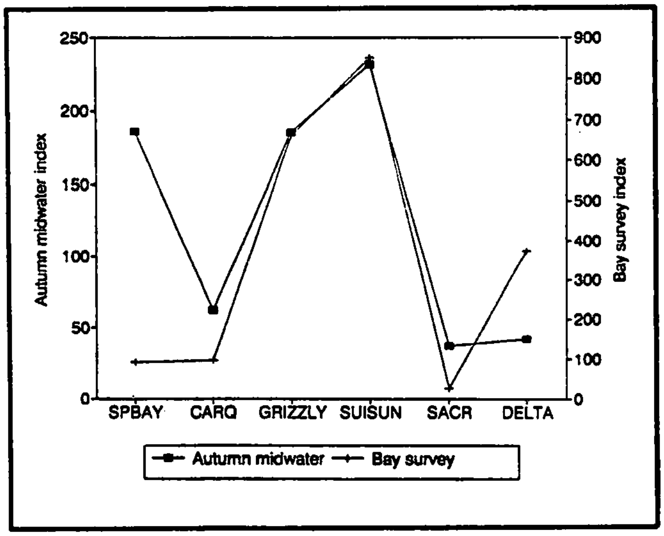


Figure 114
SPLITTAIL DISTRIBUTION AND
NUMBERS OF SPLITTAIL CAUGHT BY EACH STUDY
SOURCE: Meng, unpublished data.

The Department of Fish and Game's Bay/Delta Division is examining distribution of splittail using data from the FWS beach seine survey. Analyses are not yet complete, but preliminary results are shown in Figure 115. Substantial numbers of young were caught in upstream areas including the Sacramento River, northern Delta, and central Delta through June 1993, a high outflow year. This indicates that significant spawning took place in the Delta (Baxter 1994). The fact that there is no clear decrease in CPUE between April and June at these sites also suggests that many of these fish could be rearing in this region well after peak flows subsided.

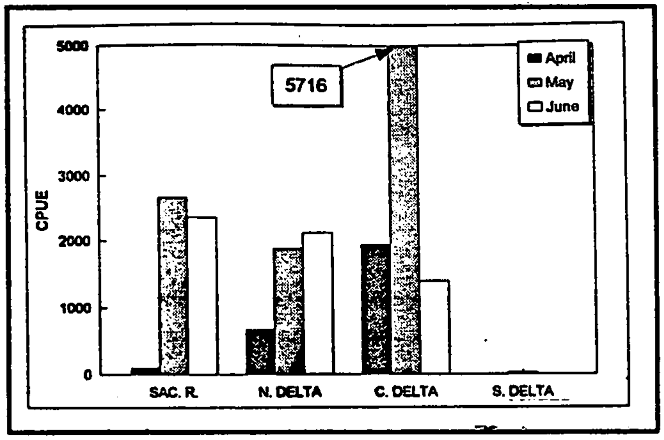


Figure 115
CATCH-PER-UNIT-EFFORT (TRAWL) OF
YOUNG-OF-THE-YEAR SPLITTAIL BY THE
FWS BEACH SEINE SURVEY FOR FOUR REGIONS, 1993

Higher catches of young-of-the-year in the Delta and upstream areas are consistent with the distribution of splittail relative to specific conductivity. As discussed in the Water Quality section of this chapter, high catches of splittail in the Outflow/Bay study occur at 0 ppt, not the 2 ppt level used as an index of entrapment zone position (Baxter 1994). In addition, higher density of splittail in fresh water is more consistent with the historical range from Redding to Fresno, far away from the entrapment zone.

It should be noted, however, that there is a statistically significant relationship between an indicator of entrapment zone location, X2, and splittail abundance. Fox and Britton (1994) used generalized linear models to develop a relationship between splittail midwater trawl abundance and the location of X2 during February-June ($r^2=0.61, p<0.05$). This observation is not surprising given the close relationship between outflow and entrapment zone position (Kimmerer and Monismith 1993). Splittail abundance increases in high outflow years, when floodplains are inundated and salinity decreases throughout the estuary. Thus, the relationship between X2 and abundance could simply be a result of covariance with hydrology, rather than functional.

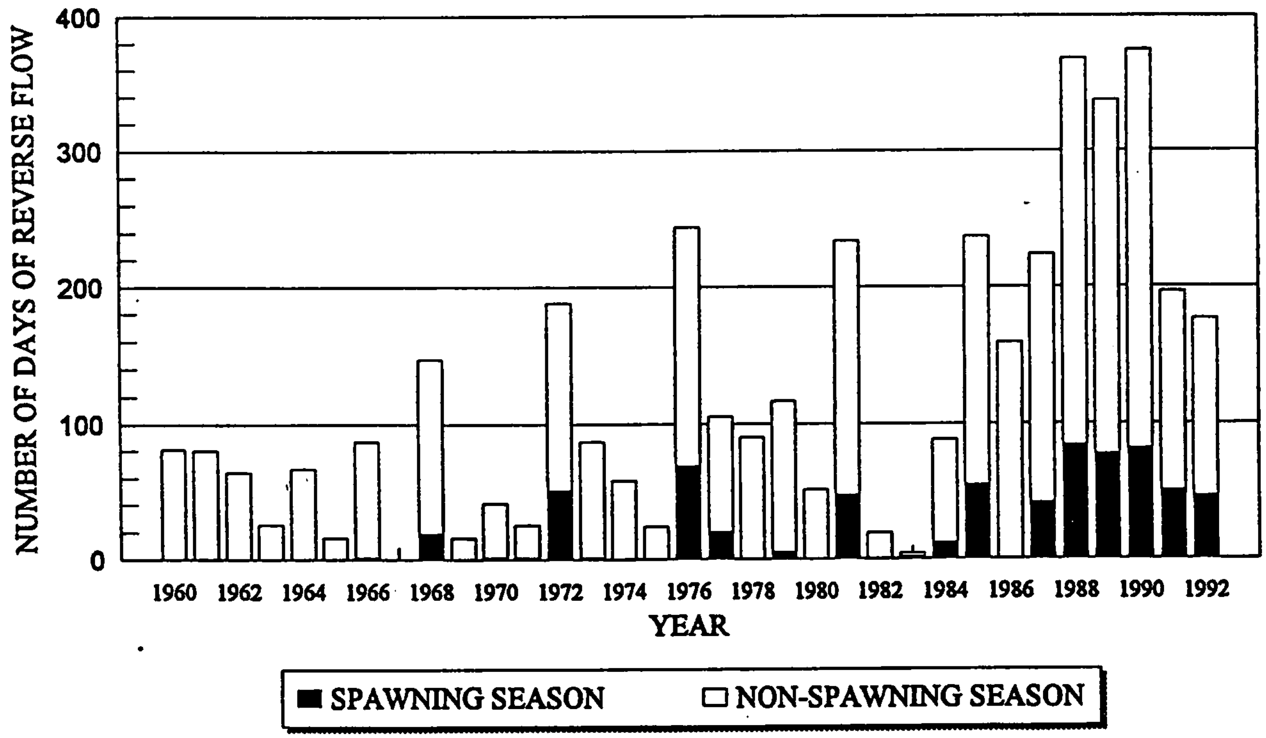
Effects of Reverse Flow

Net reverse flow occurs in the Delta when inflow from upstream tributaries is insufficient to meet export and local agricultural diversions. Water is pulled from downstream areas and in some channels upstream tidal flow can be intensified and also cause net upstream flows where they would otherwise not occur.

From 1985 to 1992, net reverse flows have characterized the lower San Joaquin River for more than 150 days of the year, and, in every year except 1986, reverse flows have occurred for 15-85 days of the splittail spawning season (February-May) (Figure 116) (also see Chapter 5 and Moyle *et al* 1992). The proposed "threatened" listing for splittail (FWS 1993) suggests that reverse flow negatively impacts splittail by disorienting larvae and juveniles, leading to mortality at the export facilities.

Recent particle tracking studies by Department of Water Resources, described in Chapter 5, demonstrate that a calculated index of reverse flow, QWEST, is not a good indicator of entrainment risks. Entrainment of tracers occurred despite high positive values of QWEST. The degree to which the simulation is representative of young fish is not known, but the model provides at least an indication of the major physical processes.

An alternative explanation is that there is a region in the interior Delta where entrainment risks are much higher. This region has not been well characterized, but it likely depends on different tributary inflows, export pumping, Delta Cross Channel operations, Clifton Court Forebay operations, and consumptive uses.



The black portion of each bar shows the number of days during the splittail spawning season (February to May).

Figure 116
NUMBER OF DAYS OF REVERSE FLOW IN THE SAN JOAQUIN RIVER, WATER YEARS 1960-1992

Splittail are also reported to be at risk because "changes in salinity and reverse flow of water has shifted the distribution of individuals upstream and has caused the fish to be vulnerable to State and Federal pumping plants" (FWS 1994). There is indeed good evidence that this process is important for delta smelt with respect to salinity, but splittail do not appear to respond similarly. As noted in the sections on outflow and streamflow, there is no significant relationship between outflow and the portion of the splittail population in Suisun Bay, where entrainment risks are markedly lower. Because reverse flow is frequently associated with low inflow, there is no reason to believe that a negative QWEST is responsible for a population shift toward the pumps. This hypothesis was tested statistically, and there was no significant relationship between reverse flow and salvage. No significant association was found between the number of days of reverse flow in March-July and young-of-the-year salvage at the SWP (r^2=0.11; n=13) or the CVP (r^2=0.21; n=12). The association was not significant between February-May reverse flow and SWP salvage of year 1 (r^2=0.26; n=13) or year 2+ fish (r^2=0.22; n=12) or CVP salvage of year 1 (r^2=0.022; n=13) or year 2+ fish (r^2=0.0022; n=12).

Although there is no evidence that reverse flow enhances entrainment, it is possible that this variable could alter splittail habitat and abundance. This question was examined by comparing splittail abundance indices with frequency of reverse flows (QWEST). Two splittail abundance datasets were used: the midwater trawl index (1967-1992) and the summer tow-net index (1962-1992). Analyses showed a significant negative association between the midwater trawl index and the annual total days of reverse flow (r^2=0.23; n=24, $p<0.05$) and number of days of reverse flow during the February-May spawning period (r^2=0.19; n=24, $p<0.05$). The greatest amount of variability in the midwater trawl index explained by reverse flow was for March-July (r^2=0.25; n=24, $p<0.05$). The association was not significant between the tow-net index and the annual total days of reverse flow (r^2=0.079; n=28), February-May reverse flow (r^2=0.062; n=28), or March-July reverse flow (r^2=0.096; n=28).

Like a number of other analyses presented in this assessment, statistically significant relationships with abundance do not necessarily prove cause and effect. In the case of reverse flow, this variable explains relatively little of the variability in the midwater trawl index compared to other parameters such as Delta outflow and floodplain inundation. The correlation with abundance may be primarily a result of covariation between reverse flow and streamflow. Reverse flows occur more frequently during low-inflow years, when splittail abundance is significantly lower.

Effects of the Central Valley Project

Possible effects on splittail of CVP facilities, including Tracy Pumping Plant, Contra Costa Canal, and the Delta Cross Channel, are reviewed below.

Tracy Pumping Plant

The most apparent effect of the Central Valley Project is entrainment of fish at Tracy Pumping Plant. Actual losses of juveniles and adults salvaged at the CVP cannot be reliably calculated because there is no information for splittail pre-screening loss (predation rates) or on efficiency of the louver screens for splittail. Salvage provides a relative index of loss rates between years. However, salvage levels may be influenced by seasonal or annual changes in predation and exports or by screening efficiency.

Monthly salvage levels of different age classes of splittail at Tracy Fish Facility are summarized in Figure 117 (see Chapter 7 for discussion of salvage database). Based on the salvage data, it appears that at least limited entrainment occurs throughout the year, with peak levels from February through August. These data were examined to determine the effect of CVP operations on different life stages of splittail and to determine what environmental parameters influence splittail salvage.

Regression analyses for CVP salvage during the period of peak young-of-the-year salvage (May-July) are shown in Figure 118. Salvage levels were positively correlated with total Delta outflow ($p<0.01$) but showed no relationship with CVP exports ($p>0.005$). An explanation for the relationship with outflow is that more young splittail are produced in wetter years. Because midwater trawl indices are also significantly correlated with total Delta outflow, higher salvage levels at the CVP are probably a result of an increase in the number of

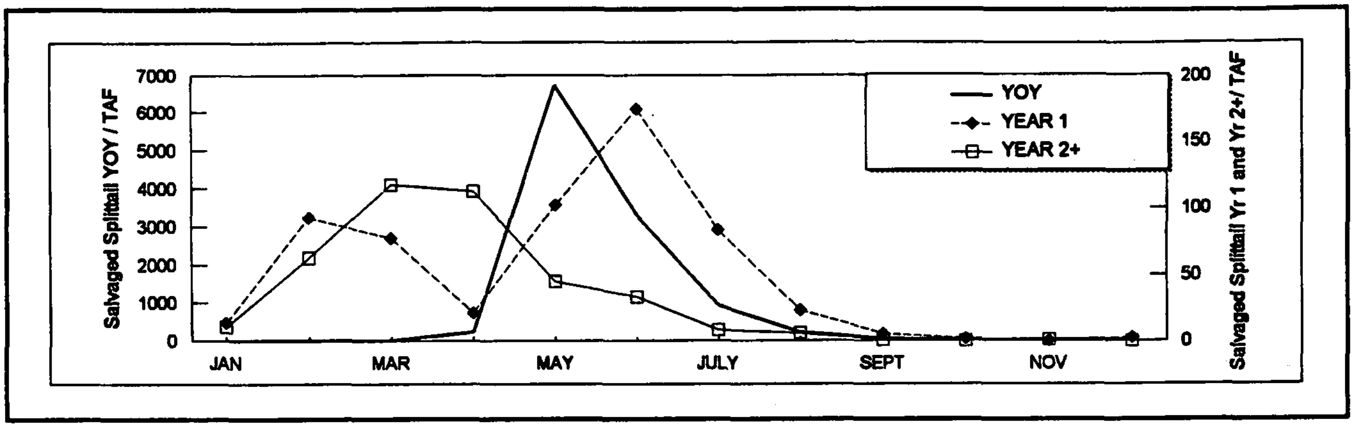


Figure 117
ESTIMATED MONTHLY AVERAGE SPLITTAIL SALVAGED PER THOUSAND ACRE-FEET EXPORTED BY THE CENTRAL VALLEY PROJECT, 1980-1991

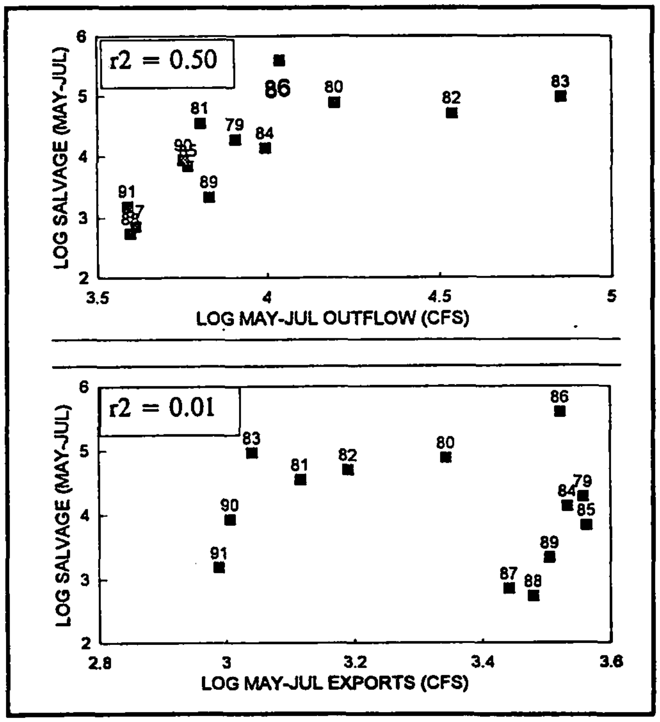


Figure 118
RELATIONSHIP BETWEEN AVERAGE CVP SALVAGE, AVERAGE TOTAL DELTA OUTFLOW, AND AVERAGE CVP EXPORTS, MAY-JULY 1979-1991

splittail in the system. As evidence, Figure 119 shows a significant relationship between the midwater trawl index and salvage of young-of-the-year at the CVP and SWP ($p<0.05$). Thus, it appears that splittail recruitment has a greater effect on the magnitude of entrainment-related losses at the CVP than operations or changes in the distribution of splittail.

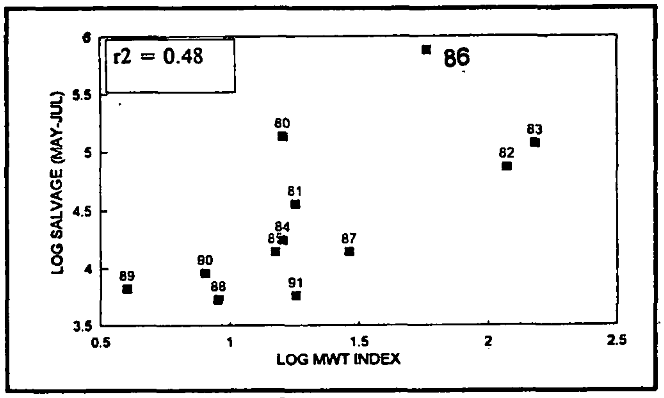


Figure 119
SALVAGE OF YOUNG-OF-THE-YEAR SPLITTAIL AT THE CVP AND SWP VERSUS THE FALL MIDWATER TRAWL INDEX, 1980-1991

The question still remains whether the relative impact to the population increases in dry years. To examine this issue, entrainment indices for splittail were calculated using methods similar to those described for delta smelt (Chapter 5). Monthly young-of-the-year salvage at Tracy Fish Facility were divided by the midwater trawl index to correct salvage data for year class strength. The indices shown in Figure 120 do not support the Fish and Wildlife Service (1994) conclusion that the projects have the greatest effect on young-of-the-year abundance in dry years. Indeed, the entrainment indices suggest that the relative impact of entrainment on young-of-the-year was actually lower during the recent drought than in previous years. Therefore, there is no evidence that entrainment losses are responsible for the recent decline of splittail recruitment.

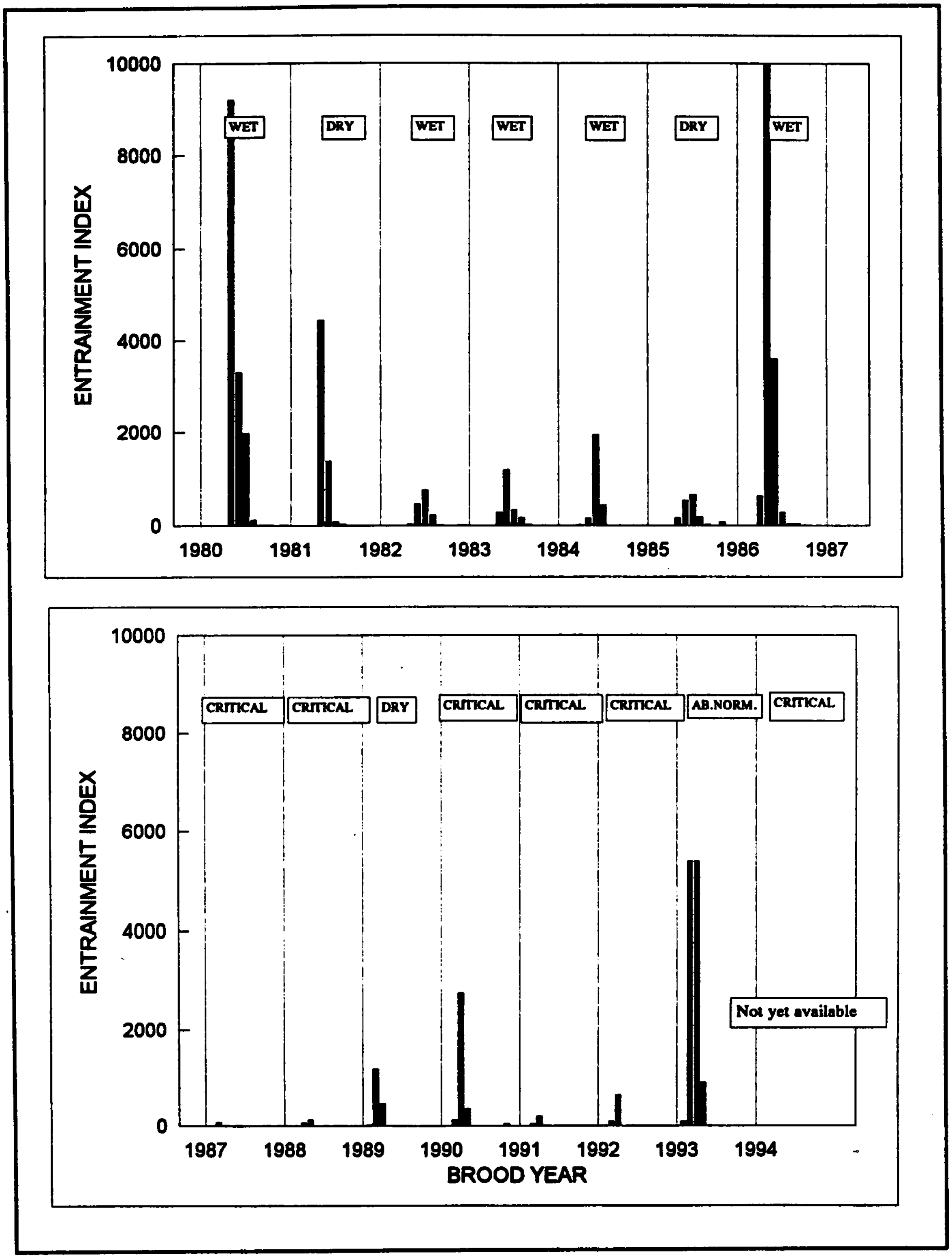


Figure 120

MONTHLY SPLITTAIL ENTRAINMENT INDICES AT TRACY FISH FACILITY FOR 1980-1993 BROOD YEARS, SEPARATED USING SALVAGE AND SIZE-FREQUENCY DATA

The entrainment index equals monthly young-of-the-year salvage divided by annual midwater trawl index.

Information on CVP entrainment of larval splittail is available from the DWR Egg and Larval Entrainment study for 1992 and 1993. Larval splittail entrainment was estimated beginning in 1992 as a requirement of the U.S. Army Corps of Engineers permit for the South Delta Temporary Barriers Project. However, catch data are available from 1988, when identification of splittail to the species level began. Seven sites are sampled in the southern Delta (sites 91-96, 98), and in 1992 five sites in the central Delta were added (sites 930-934) (sites are shown on Figure 43, page 77).

In general, splittail larvae may be present in the southern Delta from late March through June, but occurrence may vary within this period from year to year. Splittail appear to be more a resident species in the southern Delta. They do not seem to be present primarily due to transport from the central Delta, as appears to be the case for delta smelt. In general, splittail larvae are most common at the CVP and SWP intake sites (92, 96) and to the east (93, 94, 98), but they are occasionally collected at sites that could be indicative of larval transport from the central Delta (91, 95, 930, 931, 934). Overall, results suggest few splittail larvae occur in the southern Delta, even though suitable spawning habitat is available.

In 1992, splittail were collected near the CVP intake (site 96) on April 16; in Grant Line Canal (sites 94, 98) on March 27, April 1, and April 6; and in Old River upstream of the CVP intake (site 93) on April 4 and 8 (Spaar 1993). No splittail were collected on Old River north of Clifton Court Forebay (site 91) or in North Canal (site 95). In comparison, splittail were collected only at central Delta sites 930 and 934 on April 14 and 16. Similarly, in 1993 splittail were collected in Grant Line Canal (site 98) on April 4, 6, and 10 and June 3 and in Old River (sites 92, 93) on June 15 and April 6, but were not collected north of the forebay (sites 91, 95) (DWR 1994). Splittail were collected only at central Delta sites 930, 931, and 934 between March 23 and June 5, 1993.

Table 10 shows estimated entrainment of splittail larvae in 1992 and 1993 for both the Central Valley Project and the State Water Project. No larvae were collected near the CVP intake in 1993; therefore, no entrainment was estimated.

Table 10
ESTIMATED ENTRAINMENT OF SPLITTAIL LARVAE, 1992-1993
(Thousands of Fish)

Year	CVP	SWP	Total
1992	109	0	109
1993	0	194	194
Total	109	194	303

Contra Costa Canal

The Contra Costa Canal, owned by USBR and operated by Contra Costa Water District, has an unscreened intake at Rock Slough that draws 50 to 250 cubic feet of water per second from Rock Slough. Its operations have been addressed in the September 9, 1993, biological opinion (FWS 1993b), Appendix A of which addresses Sacramento splittail. Losses of larvae would be expected whether the intake were screened or not.

Although no loss estimates are available for juvenile or adult splittail, one splittail was collected in DFG sampling for the Contra Costa Canal intake entrainment study. This fish was caught with a sieve net during overnight sampling on March 21-22, 1994. More information on this study is available in the similar section for delta smelt (Chapter 5).

Department of Water Resources egg and larval monitoring, which began in Rock Slough in 1992, caught no larval splittail between February 12 and July 15, 1992, and on only 2 days between February 16 and July 15, 1993 (Spaar 1993, DWR unpublished data). Catch densities in 1993 were:

April 10	0.0086 larvae/m^3 = 0.007/TAF
June 5	0.0118 larvae/m^3 = 0.0096/TAF

Entrainment of splittail larvae in 1993 was estimated to be about 11,000. Entrainment was estimated using the same methodology as for the CVP and SWP intakes (Spaar 1988). A discussion of how larval entrainment is estimated is included in the North Bay Aqueduct section of Chapter 5.

Monthly entrainment of splittail larvae per acre-foot at the Contra Costa Canal was estimated from densities measured in Rock Slough and compared with monthly entrainment at the SWP and CVP for 1992 and at the SWP, CVP, and North Bay Aqueduct for 1993 (Figure 121). Estimates shown in Figure 121 may not be representative of actual entrainment because larval distribution in front of the diversions is influenced by tides. For example, larvae collected near the diversions are more likely to be entrained during a flood tide than an ebb tide. No splittail were estimated to have been entrained in 1992 at the Contra Costa Canal or SWP. At the CVP, entrainment occurred only in April, at 4.80 larvae per acre-foot. The North Bay Aqueduct was not sampled in 1992, so entrainment was not estimated. For 1993, splittail larvae were entrained in April (10.59 larvae/acre-foot) and June (14.58 larvae/acre-foot). No larval entrainment was estimated to have occurred in February, March, May, or July. The entrainment density was lower at the Contra Costa Canal than at the State Water Project in June.

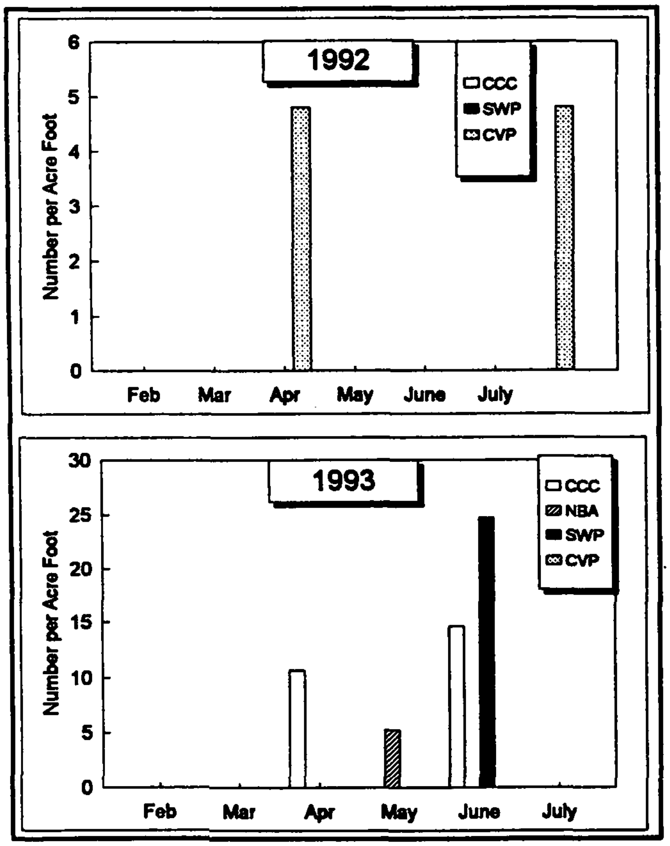


Figure 121
NUMBER OF SPLITTAIL ENTRAINED PER ACRE-FOOT FOR CONTRA COSTA CANAL, NORTH BAY AQUEDUCT, STATE WATER PROJECT, AND CENTRAL VALLEY PROJECT

Delta Cross Channel

Effects of the Delta Cross Channel gates on splittail are not known. As described for delta smelt, gate closure could interfere with spawning success of splittail by delaying any fish migrating from the central Delta to the Sacramento River. Also, Cross Channel operation could alter entrainment at the SWP and CVP by altering Delta hydrology. Transport modeling studies suggest that the relative impacts depend on the relative distribution of spawning between the Sacramento and San Joaquin rivers. However, analyses presented earlier in this chapter indicate entrainment does not have a detectable effect on splittail abundance.

Effects of the State Water Project

Possible effects on splittail of State Water Project facilities, including Banks Pumping Plant, North Bay Aqueduct, Suisun Marsh Salinity Control Gates, and South Delta Barriers, are reviewed below.

Banks Pumping Plant

Entrainment at Banks Pumping Plant is the most obvious effect of the State Water Project on splittail. However, there is insufficient information on predation rates in Clifton Court Forebay and screen efficiencies at Skinner Fish Facility to quantify actual loss of juvenile and adults. Although salvage levels at Skinner Fish Facility vary due to seasonal or annual changes in predation and exports or screening efficiency, salvage provides the best available index of loss rates between years.

Monthly salvage levels of different age classes of splittail at Skinner Fish Facility are summarized in Figure 122. Chapter 5 includes a discussion of the salvage database. At least limited entrainment apparently occurs throughout the year, with peak levels in February-August. These data were examined to determine the effect of SWP operations on different life stages of splittail and what environmental parameters influence splittail salvage.

Figure 123 is a comparison between salvage levels during the months of peak young-of-the-year abundance, total Delta outflow, and SWP exports. There is no statistically significant relationship between

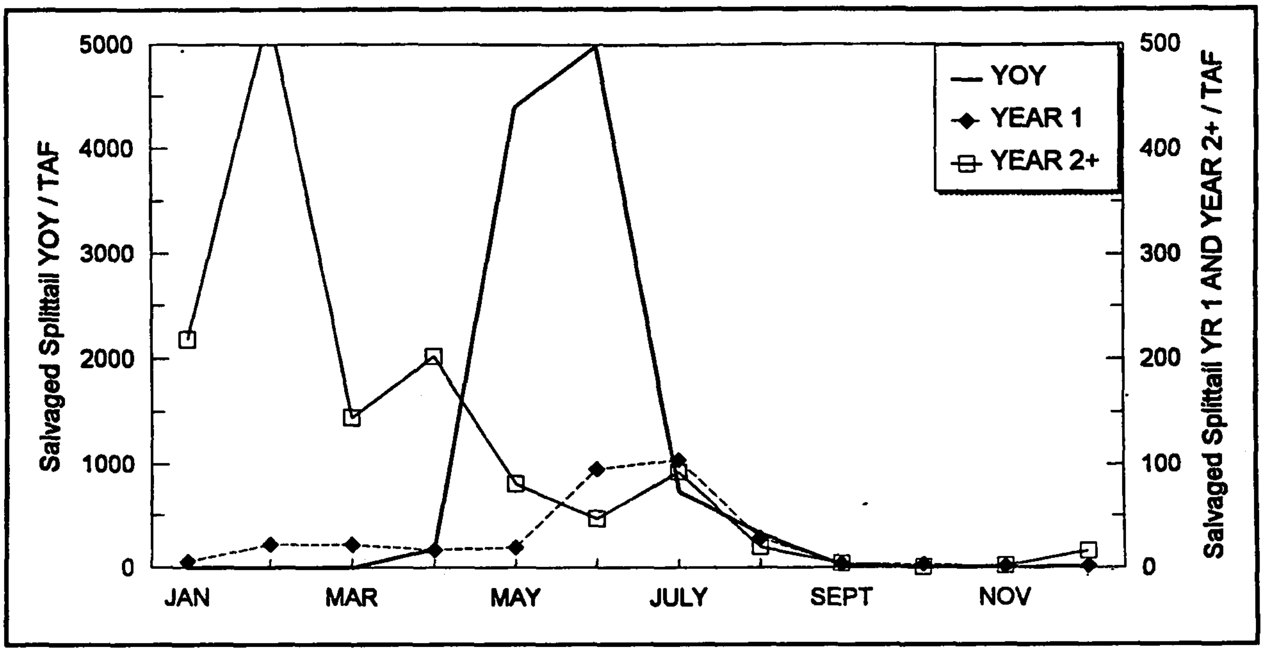


Figure 122
MONTHLY AVERAGE ESTIMATED SPLITTAIL SALVAGED PER ACRE-FOOT EXPORTED BY THE STATE WATER PROJECT, 1980-1991

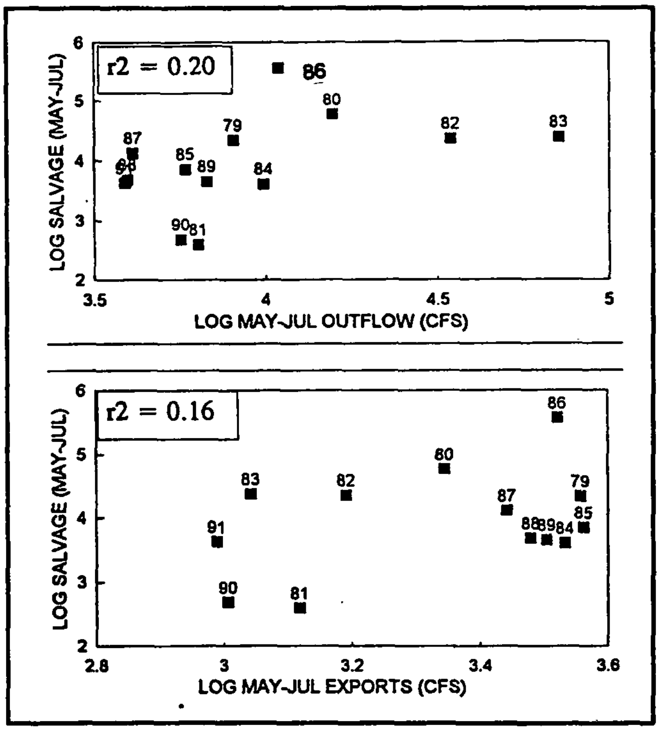


Figure 123
RELATIONSHIP BETWEEN AVERAGE SWP SALVAGE, AVERAGE TOTAL DELTA OUTFLOW, AND AVERAGE SWP EXPORTS, MAY-JULY 1979-1991

salvage and either outflow or exports, but salvage appears to be generally higher in wetter years.

Possible differences in salvage between wet and dry years were tested using the Mann-Whitney U-test. Total SWP salvage of young-of-the-year for 1979-1991 was grouped into "dry" (critical-below normal) or "wet" (above normal-wet) years. Differences between the two groups were significant at the $p<0.01$ level, with salvage greater in wet years. The best explanation is that salvage levels directly reflect trends in young-of-the-year abundance; recruitment is higher in wetter years, increasing the number of young splittail observed at the SWP. This conclusion is supported by the direct relationship between salvage at the export facilities and the midwater trawl index (Figure 119).

Entrainment indices similar to those described for the CVP were developed as a means to correct the salvage data for year-class strength. Figure 124 provides no evidence to support the Fish and Wildlife Service (1994) hypothesis that relative impacts to the splittail population are greater during dry years. Moreover, the relatively low entrainment indices in most years since 1987 are consistent with results for the CVP. As a result, it cannot be concluded that entrainment-related losses are responsible for the recent decline of juvenile splittail abundance.

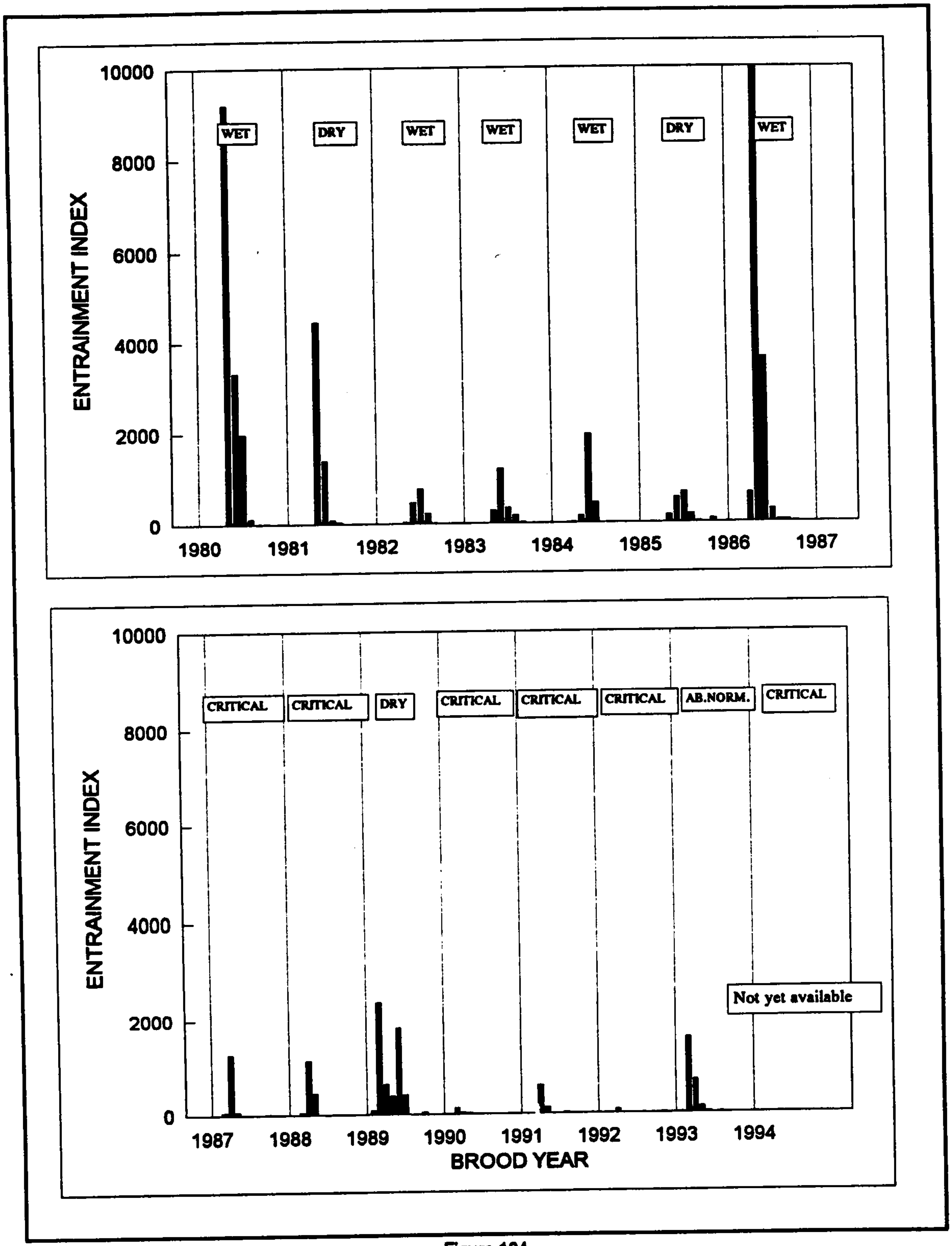


Figure 124
MONTHLY SPLITTAIL ENTRAINMENT INDICES AT SKINNER FISH FACILITY FOR 1980-1993 BROOD YEARS, SEPARATED USING SALVAGE AND SIZE-FREQUENCY DATA

Information on entrainment of splittail larvae at Banks Pumping Plant is available from the DWR Egg and Larval Entrainment Study for 1992 and 1993 (Figure 121, Table 10). More information on larval splittail near the SWP intake can be found in the discussion for the Central Valley Project.

No splittail larvae were collected near the SWP intake in 1992, but they were collected in Old River upstream and near the CVP intake (sites 93, 96) and in Grant Line Canal (sites 94, 98) (Spaar 1993). In 1993, splittail larvae were collected near the SWP intake on June 15 (DWR 1994). The 1993 entrainment of splittail was estimated at about 195,000 larvae (less than 21 mm long).

North Bay Aqueduct

The fisheries surveys described in the North Bay Aqueduct section for delta smelt would potentially also provide information on splittail in Barker, Lindsey, and Cache sloughs. Pre-project surveys from 1986 to 1988 indicate splittail comprised only 0.61% of the total catch and ranged from 80 to 119 mm FL (Kano 1989). Relative abundance of splittail less than 100 mm was higher during winter (February; 0.00071 splittail/cubic meter or 0.00058/TAF) and summer (July; 0.00066 splittail/cubic meter or 0.00054/TAF) than during fall (October; 0.00007 splittail/cubic meter or 0.000057/TAF). Average size of these fish was 86.8 mm FL. Post-project surveys from 1988 to 1990 indicate splittail comprised 0.06% of the total catch (1 fish at 257 mm FL) (Kano 1990b). The catch pattern of these surveys indicate splittail were collected primarily during the period following the high outflow of spring 1986; that is, July and October 1986 and February 1987. From 1987 to 1991, splittail were caught only in February 1989 (1 fish, 257 mm FL) and 1991 (1 fish, 101 mm FL). Similarly, DFG triannual monitoring from 1975 to 1979 caught only one splittail, in February 1976, at 330 mm FL (DFG unpublished data). Purse seine sampling in spring 1993 did not collect any splittail (Lindberg 1993).

Larval fish surveys from 1986 to 1991 identified cyprinid species to the family level only. Identification to species began in 1993. Egg and larval monitoring between February 16 and July 13, 1993, collected splittail larvae in Barker Slough on only two occasions: March 23 (0.0077 larvae/cubic meter or 0.0062/TAF) and May 20 (0.0084 larvae/cubic meter or 0.0068/TAF) (DWR unpublished data).

Monthly entrainment of splittail larvae per acre-foot at the Barker Slough intake was compared with monthly entrainment at the SWP, CVP, and Contra Costa Canal intakes for 1993 (Figure 121). At the North Bay Aqueduct, splittail larvae were entrained in May only, at 5.20 per acre-foot, which is lower than monthly entrainment density for the other sites when larvae were entrained. No larval entrainment was estimated to have occurred in February-April or June-July.

Suisun Marsh Salinity Control Gates

A monitoring program has been underway since 1987 to determine whether operation of the Suisun Marsh Salinity Control Gates had a significant effect on fisheries. The studies were designed to address concerns by the Environmental Protection Agency, National Marine Fisheries Service, and Fish and Wildlife Service that the gates might attract predators, resulting in increased loss of juvenile striped bass and migrating juvenile salmon, or could delay the upstream migration of adult salmon.

Monitoring data for splittail was described in Chapter 7. As demonstrated by Figure 104, there is no detectable difference in splittail density before and after construction of the gates in 1989. Splittail remain the second most abundant fish species captured in DFG gill-net studies in Montezuma Slough, indicating that the gates have not had a significant effect on splittail.

South Delta Barriers

As with delta smelt, the South Delta Temporary Barriers Project could alter splittail salvage rates through changes in circulation patterns and losses to SWP and CVP diversions. DWR (1993) reports that from 1979 to 1991, the median number (based on monthly values) of splittail salvaged between April and November was 1,160 for the SWP and 2,383 for the CVP. In 1992, the median number salvaged between April and September was 20 for the SWP and 51 for the CVP. Although part of the decrease can be attributed to overall decline in splittail abundance, these numbers do suggest salvage of splittail did not increase while the barriers were in place.

The Temporary Barriers Project could also impact splittail through changes in larval transport and recruitment patterns (DWR 1993). Overall, egg and larval survey results suggest few splittail larvae occur in the project area, even though suitable spawning habitat is available. However, larval abundance in the central Delta was also low during 1992. Thus, it is plausible that larvae caught in the southern Delta hatch from eggs spawned in the region. Yet, because of the timing of barrier placement, it is likely that the barriers had little effect on larval survivorship or recruitment in the project area.

During 1992, DFG collected two splittail in monthly hoop-netting and electrofishing surveys upstream and downstream of the barriers (DWR 1993). Both fish were caught during April in Old River about 5 km southeast of the Old River near Tracy barrier. Although these data show some splittail were impounded behind the barriers, the low catch suggests population effects were minimal.

Effects of PG&E Power Plants

Adult and juvenile Sacramento splittail are commonly found near PG&E's Pittsburg and Contra Costa power plants (PG&E 1992a). Survey results at these facilities are summarized in Chapter 7. Splittail appear to be attracted to thermal discharge, as indicated by higher abundance within the Pittsburg Power Plant thermal plumes than in nearby waters (Gritz 1971).

Data on splittail entrainment at PG&E's facilities are limited to surveys during 1978 and 1979 (PG&E 1981a, 1981b). In general, splittail entrainment appears much lower than for other species. Results from April 1978 to April 1979 show that 123,000 splittail were entrained at Contra Costa Power Plant (PG&E 1981a, 1981b). However, it is possible that not all of these individuals are lost, because the diverted water is returned to the estuary. It is unknown whether the facilities pose a significant threat to splittail.

Effects of Agricultural Diversions

A detailed discussion of agricultural diversions was presented in Chapter 5. Limited information is available on splittail from 1992 and 1993 sampling for the Delta Agricultural Diversion Evaluation. No life stages of splittail have been collected from any of the diversion sites, but larval splittail are present in adjacent channels at two sites (Spaar, in press; DWR unpublished data; Griffin 1993).

No larval splittail were collected in 1992 or 1993 from the diversion sites. However, larvae were collected from the adjacent channel in both years at two sites — Twitchell Island and Naglee Burk. In 1992, one larvae (7.6 mm TL) was caught off the Twitchell Island site (San Joaquin River) on April 16. Downstream of the Naglee Burk site (Old River), larvae were caught on April 4 (1 larvae, 6.8 mm TL) and April 8 (2 larvae, 7.0 and 7.1 mm TL). In 1993, splittail larvae were again only collected in the channel adjacent to these two sites. Splittail larvae were caught consistently from March 23 to April 10 off the Twitchell Island site (total of 5 larvae, ~8 mm TL). One larvae was caught on April 6 downstream of the Naglee Burk site.

No juvenile or adult splittail were collected from the diversion sampled at Naglee Burk in 1992 and 1993, or at Twitchell Island, Bacon Island, Bouldin Island, or McMullin Tract in 1993. None were collected using a tow-net sled in adjacent channels in 1992 and 1993 or by otter or midwater trawl in August and September 1993 (Spaar, in press; DWR unpublished data).

Although there is no direct evidence of entrainment, splittail are probably most vulnerable to diversions in February-June, during their larval and early juvenile stages. Swimming ability is weakest in the larval stage for most fish species. The Delta irrigation season is usually from late March or early April through September (see discussion in Chapter 5).

Effects of Predation and Competition

Splittail abundance trends may also be affected by a number of native and introduced fish and invertebrate species. The exceptionally large number of introduced species are of particular concern as they have extensively modified the ecosystem. Possible effects through predation and competition are described below.

Of the numerous predators in the region, most such as catfish, striped bass, and sunfish were well established in the estuary before low recruitment levels of splittail occurred during the past 7 years. Several of these species (*eg*, striped bass) also declined in abundance over the same period as splittail young-of-the-year abundance and are, therefore, unlikely to be responsible for recent trends, although they do contribute to splittail mortality. Although recent water transparency increases in the estuary could have enhanced predation, analyses indicate that this variable is not correlated with splittail abundance.

If predation has a major effect on splittail recruitment, the most probable explanation is that a recently introduced species is responsible. The species most likely to have the greatest effect are inland silverside (introduced in 1975) and the yellowfin and chameleon gobies (introduced in the late 1950s).

Predation studies using large field enclosures stocked with larval striped bass demonstrate that inland silversides are highly predaceous (Bennett *et al* 1993). Silverside abundance appears to have increased dramatically in the early 1980s and continued to increase over the latter part of the decade when splittail young-of-the-year indices were low. The relationship between splittail and inland silverside abundance was examined using data from the midwater trawl. Annual catch-per-unit-effort for each species was calculated as the average of the monthly catch for September-December during 1980-1990, when silverside became highly abundant. Regression analyses indicate no significant relationship in CPUE for the two species (r^2=0.19). Given the complexity of predator/prey interactions, it is nonetheless possible that silverside may negatively impact splittail.

Chameleon goby was relatively rare in the midwater trawl catch until 1988, the year after a decline in splittail young-of-the-year abundance was noted at the beginning of the 6-year drought. There are insufficient data points to determine whether the abundance of these species may be associated. Recent data from UC-Davis also suggest that species classified as chameleon goby actually represent two distinct species (P. Moyle, pers comm). By contrast, yellowfin goby have been a common species in the midwater trawl throughout the period of record. However, a comparison of CPUE between yellowfin goby and splittail in the midwater trawl for 1980-1990 suggests their abundance trends are not related (r^2=0.09). This finding does not rule out interactions between these two species.

Several introduced fish species could also compete with splittail for food. In the Bay/Delta system, low food abundance and changing composition suggest that food could be limiting at juvenile or adult stages (Moyle *et al* 1992). Inland silverside is a successful competitor with native species in a number of other locations (Li *et al* 1976). This exotic species forms dense schools in shoal areas, where splittail are more abundant. Yellowfin and chameleon goby are potentially important competitors with splittail, because all appear to be benthic feeders. Nonetheless, the analyses described above provide no evidence that splittail abundance is related to trends in goby and inland silverside.

The introduction of the Asian clam, *Potamocorbula amurensis*, is perhaps the most significant biological change in the estuary over the past decade. Recent evidence suggests that *Potamocorbula* is responsible in part for a decline in phytoplankton abundance in the estuary (Alpine and Cloern 1992) and may directly compete with fish by consuming *Eurytemora affinis* nauplii (Kimmerer, in press), an important zooplankton food source. Studies from 1993 also indicate that high Delta outflow did not significantly reduce the range of the clam (Lehman 1993) and may, therefore, be an ongoing problem for resident biota. However, *Potamocorbula* does not account for lower abundance of young splittail in 1987, a year before the clam was well established.

Effects of Food Abundance

Distribution and habitat use of splittail larvae are not well understood, and their feeding habits have not been studied. Studies are needed that would identify habitat requirements, food selection, and feeding behavior to determine the interactions of splittail and available food sources and the effects on survival and growth of the species throughout its range. These studies would help develop an understanding of the influence of ecological changes to its habitat on year-class strength, survival, and population stability of splittail.

Effects of food abundance on adults and juveniles are discussed below, followed by a discussion of food abundance trends.

Effects of Food Abundance on Juveniles and Adults

Splittail are predominantly benthic foragers with a limited range of prey types, and they feed opportunistically on the benthic food items available within local habitats.

Feeding studies document juvenile and adult splittail as opportunistic benthic foragers. Caywood (1974) analyzed stomach contents of splittail from Miller Park on the Sacramento River in 1973 and 1974 and found the most frequent items included detritus and algae (73 to 81%), earthworms (*Lumbricus* spp.) (40 to 64%) and dipterans (up to 46%). Relative abundance of food organisms was dominated by oligochaetes, cladocerans, and dipterans. Dominant food organisms in splittail stomachs taken near Antioch in the fall of 1973 and analyzed by Caywood (1974) included copepods (86% relative frequency) and dipterans, although in October stomachs were gorged with detritus and algae. Juvenile splittail (143 mm mean FL) sampled from Big Break in April 1974 had detritus, clams (*Corbicula manilensis*), amphipods (*Corophium* spp.), and copepods as the dominant food items (Caywood 1974).

These findings were similar to results of feeding studies by Daniels and Moyle (1983). Stomach contents of splittail from Suisun Marsh consisted predominantly of detritus in both percent frequency of occurrence (74%) and percent volume (57%). A smaller portion of the stomach contents (41% by volume) consisted of animal matter, dominated by crustaceans (35% by volume). Opossum shrimp (*Neomysis mercedis*) were the dominant crustacean food item (37% frequency; 59% volume less detritus) both daily and seasonally. Unlike Caywood's results, oligochaetes were not a dominant food item for splittail in the marsh. Other minor prey items included mollusks, insects, and fish.

Feeding and food selection studies conducted by Herbold (1987) suggest that splittail specifically select *Neomysis* as their main prey item in Suisun Marsh. Fullness indices data indicate that condition factors of splittail are linked to *Neomysis* abundance. Herbold found that as *Neomysis* densities decline there is concomitant increase in the incident of detritus in stomach contents. Splittail did not switch to alternate and more prevalent food items as was observed for other native resident marsh species. It is hypothesized that declines in splittail abundance may be associated with the observed declines in *Neomysis* abundance (B. Herbold, EPA, pers comm, May 5, 1994). However, the historical range of splittail extends far beyond the estuarine habitat of *Neomysis*, so it is questionable whether the shrimp is a required food source. One possibility is that *Neomysis* is indeed the most suitable food within the marsh, but other resources are available in upstream areas.

Effects of Changes in Food Abundance

The effects of changes in Delta phytoplankton and zooplankton species composition and biomass on fish is largely unknown. This is particularly true for larval splittail since information on food selection is limited. The reduction in phytoplankton levels and shift in zooplankton species composition was discussed in Chapter 5. Perhaps of greatest concern is a reduction in abundance of *Neomysis*, identified as a major food source for splittail in previous studies. This information is reviewed below.

Herbold (1987) evaluated feeding habits and food selection of native resident fish species in Suisun Marsh, which included juvenile and adult splittail, comparing prey item abundances and stomach contents. Splittail utilized *Neomysis* almost exclusively as the main food source through the marsh.

Neomysis achieves its greatest abundance at low salinities of about 2-3 mS/cm (1-2 ppt) (Kimmerer 1992; Knutson and Orsi 1983). Mysid shrimp distribution is similar to *Eurytemora affinis*, an estuarine copepod, but the shrimp are more abundant in fresh water. Heubach (1969) found that rates of reproduction of mysids were highest from fresh water to a salinity of 3.6 ppt. Both of these species are commonly associated with the entrapment zone and are considered euryhaline, although mysids generally occur nearer the upstream extent of the entrapment zone (Obrebski *et al* 1992; Kimmerer 1992).

Neomysis abundance and distribution were described using abundance anomaly values to examine long-term trends in the estuary (Obrebski *et al* 1992; Kimmerer 1992) (Chapter 5). The use of anomalies is described in detail by Obrebski *et al* (1992). This type of analysis removed the effects of specific conductance and season, which cause short-term and localized variations in phytoplankton and zooplankton abundance. Anomalies are the difference in pigment measurements[1] for a sampling station and date and the mean pigment value for the specific conductance class (Table 2 in Obrebski *et al* 1992) and month.

Obrebski *et al* (1992) and Kimmerer (1992) examined abundance trends of *Neomysis* in the estuary using Department of Fish and Game zooplankton monitoring data from 1972 to 1987. Abundance of *Neomysis* was higher between 1972 and 1976 than after 1976. This pattern was observed for several species of freshwater zooplankton (Obrebski *et al* 1992). For the period analyzed, the lowest abundance of *Neomysis* was in 1977 and 1988 (Figure 41 in Kimmerer 1992). Obrebski *et al* were able to show that declines in *Neomysis* abundance were seasonal and most significant in the fall both within the entrapment zone and regionally across the Delta (Tables 3 and 5 in Obrebski *et al* 1992). Kimmerer (1992, Figures 44 and 45) found that entrapment zone position also had an effect on mysid abundance. Mysid abundance was lower when the entrapment zone was upstream, but the pattern was influenced by season and correlated with temperature in some cases. Over all seasons, *Neomysis* abundance was highest when entrapment zone position was less than 92 km upstream (Sherman Island) of the Golden Gate Bridge.

The decline in mysid shrimp abundance has continued through 1993, based on abundance anomaly (Figure 125). Record low abundance was documented in 1990 and 1992. The decline coincides with 6 years of drought. Trends in abundance for splittail and *Neomysis* were evaluated for potential associations. Regression analyses of *Neomysis* abundance anomaly on fall midwater trawl data (r2=0.02) and log of fall midwater trawl data (r2=0.04) showed no correlations. These regression coefficients do not support the hypothesis that splittail abundance is associated with Neomysis abundance. Effects of the long-term drought on estuary conditions and other environmental variables may be responsible for the declines in abundance of either splittail or *Neomysis*.

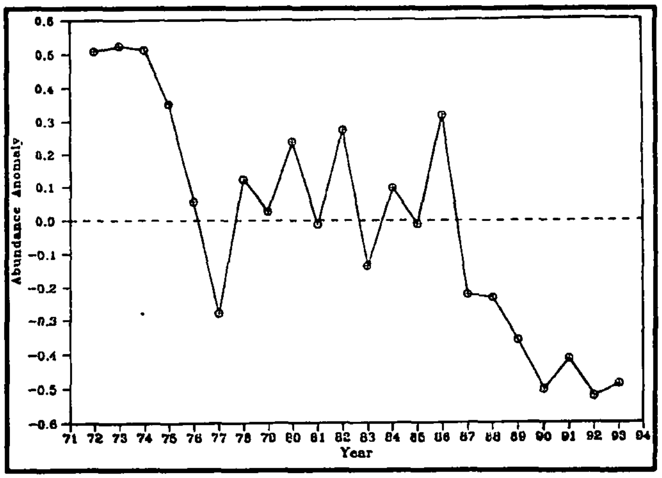


Figure 125

NEOMYSIS ANOMALIES, BY YEAR

Source: Department of Fish and Game

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[1] Pigment is an indicator of phytoplankton levels.

Effects of Recreational Harvest

Splittail are not harvested commercially, but comprise at least a small recreational fishery. Harvest of splittail was first evaluated by Caywood (1974), who noted a recreational fishery near Sacramento, at the port of Stockton, and at the Mokelumne-Cosumnes River confluence. Angler surveys were also conducted by PG&E in 1974 to evaluate the fishery for a number of species near Contra Costa and Pittsburg power plants. Splittail averaged 1.8% of the total catch by anglers from late June through October 1974 near Pittsburg Power Plant. In some cases, splittail averaged up to 14% of the total catch. Time of day had a significant effect on catch ($P<0.01$) (PG&E 1975a). Near Contra Costa Power Plant, splittail comprised 1% of the catch (PG&E 1975b).

The present status of the recreational fishery is not known. However, Moyle *et al* (1993) report that splittail are sometimes used as bait for striped bass. Although recreational harvest could reduce the number of spawners, there is no evidence to suggest that this factor has a major effect on splittail abundance.

Effects of Spawning Stock Size and Year-Class Strength

Like delta smelt and other species, splittail abundance could be limited by the number of spawners in the population. If the spawning population is reduced by a fishery or environmental factors, recruitment may become poor. However, application of stock-recruitment theory to splittail is complicated by the fact that abundance data for adults are relatively crude, with no definite separation between age classes. As demonstrated by Daniels and Moyle (1983), fecundity increases with age, length, and weight, indicating that knowledge of the relative contribution of different age classes is necessary to evaluate recruitment patterns.

In the absence of detailed size and age data, analyses were performed with the assumption that the number of year 2+ fish in the population was an adequate measure of the spawning stock. Spawning stock size and year class strength were examined using annual salvage and Delta Outflow/Bay study abundance indices, described in Chapter 7. Abundance indices were analyzed for SWP (1979-1993), CVP (1980-1993), Delta Outflow/Bay Study otter and midwater trawl indices (1980-1992), and Suisun Marsh survey (1979-1992) using linear regression and log transformation techniques.

As shown in Figure 126, there is no significant relationship between the number of year 2+ fish and young-of-the-year recruitment reflected in the SWP ($r^2=0.065$, $p>0.05$) and CVP ($r^2=0.01$, $p>0.05$) log-transformed data. The r^2 values were even lower for untransformed data for the SWP ($r^2=0.01$) and CVP ($r^2<0.01$). As a specific example of why stock size does not appear to be a critical factor, large numbers of young splittail were produced in 1983, despite apparently low levels of adults. By contrast, recruitment was poor in 1988, when there appeared to be a relatively strong spawning population.

Analyses of the other studies' data are consistent with these results. There was no significant relationship for the Delta Outflow/Bay Study midwater (log transformed $r^2=0.001$, untransformed

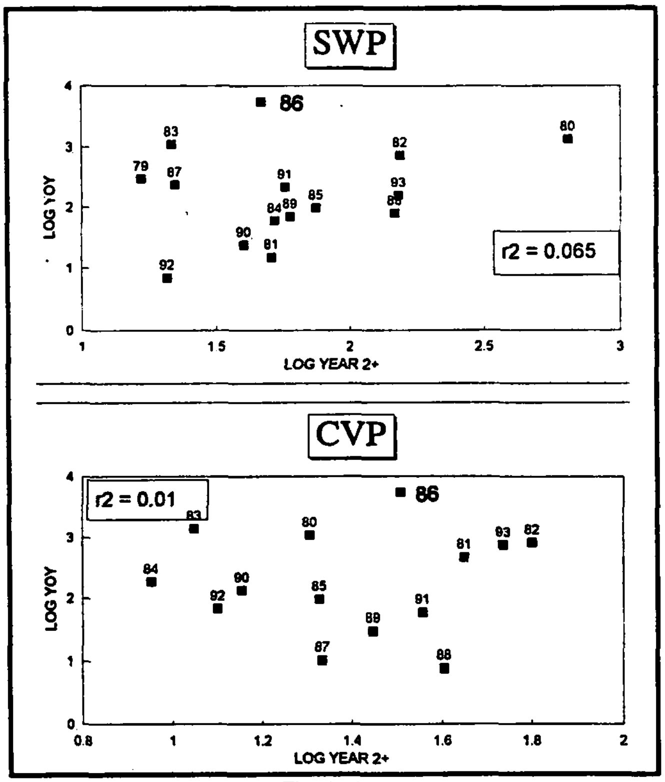

Figure 126
STOCK-RECRUITMENT RELATIONSHIP FOR SWP AND CVP SPLITTAIL SALVAGE ABUNDANCE INDICES

data $r^2=0.067$, $p>0.05$) or otter trawl (log transformed $r^2=0.001$, untransformed data $r^2=0.057$, $p>0.05$). Similarly, the Suisun Marsh indices showed no significant relationship (log transformed $r^2=0.22$, untransformed $r^2=0.06$).

The stock-recruitment relationship was also examined using an alternative approach with the fall midwater trawl dataset. The fall midwater trawl captures primarily young-of-the-year splittail, and, in the absence of data on adult catches, it was assumed that the annual abundance indices represented young-of-the-year exclusively.

To simplify the analysis, the following assumptions were made:

- Adults reproduced at age 2.
- All fish died after spawning at age 5.
- Age-specific mortality rates were constant among years.

The third assumption allowed the use of the abundance index for young-of-the-year in a given year as an index of subsequent adult abundances. For a given year, the young-of-the-year abundance index from 2 years prior was used as the abundance index for age class 2 adults. Likewise, the abundance of adults in age classes 3, 4, and 5 were taken as equal to the young-of-the-year abundances from 3, 4, and 5 years before.

Daniels and Moyle (1983) provide mean standard lengths for Sacramento splittail at 1, 2, 3, 4, and 5 years old and also a regression equation for calculating splittail fecundity based on standard length. The following procedure was used to develop a measure of the relative reproductive contribution of each age class:

- Fecundity was calculated for adult age classes (2-5 years).
- Age-specific fecundities were divided by the maximum fecundity (5 years old) to give the relative fecundity of each age class.
- Adult abundance indices for each age class were multiplied by the corresponding age-specific relative fecundity to yield the relative reproductive contribution of each age class.

Data were log transformed because the abundance indices did not conform to a normal distribution. Log transformation normalized the dataset. (Kolmorgorov-Smirnov statistic = 0.5136, $p>0.05$). For each analysis, several data transformations (reciprocal, reciprocal square root, reciprocal of the fourth root, natural log, fourth root, and square root) were applied to the independent variable to identify the best fit regression equation. The young-of-the-year abundance indices were regressed on several combinations of adult age class, as follows:

- YOY abundance index in a given year versus the abundance index of 2-year-old adults.
- YOY abundance index in a given year versus the average abundance index of 2- and 3-year-old adults.
- YOY abundance index in a given year versus the average abundance index of 2-, 3-, and 4-year-old adults.
- YOY abundance index in a given year versus the average abundance index of 2-, 3-, 4-, and 5-year-old adults.

In addition to these regressions, the weighted abundance indices of the 2-, 3-, 4-, and 5-year age classes were averaged and a regression analysis performed on the young-of-the-year abundance index in a given year and the weighted average of the 2-, 3-, 4-, and 5-year age classes.

The annual young-of-the-year abundance indices were not significantly related ($p< 0.05$) to any combination of adult abundance indices (Table 11). No significant relationship was found between the annual abundance indices and the average of the 2-, 3-, 4-, and 5-year classes weighted according to reproductive contribution.

Table 11
RESULTS OF REGRESSION ANALYSES OF YOUNG-OF-THE-YEAR ABUNDANCE INDICES FOR SACRAMENTO SPLITTAIL AND AVERAGE ABUNDANCE INDICES OF COMBINATIONS OF ADULT AGE CLASSES

Adult Age Classes	r^2	p-value
2-year-olds only	0.02	0.55
Average of 2- and 3-year-olds	0.13	0.10
Average of 2-, 3-, and 4-year-olds	0.13	0.10
Average of 2-, 3-, 4-, and 5-year-olds	0.08	0.22
Weighted average of 2-, 3-, 4-, and 5-year-olds	0.05	0.36

The salvage and midwater trawl results suggest that environmental factors — not the number of adults — control splittail recruitment. However, regression analyses indicate that recruitment affects the number of spawners. Figure 127 shows that there are significant relationships ($p<0.01$) between the number of young-of-the-year and year 1 abundance one year later and young-of-the-year and year 2+ abundance two years later at the SWP. The relationships are not statistically significant for the CVP, but do show a similar trend; high young-of-the-year indices result in higher levels of year 1 splittail. The same general trend is also evident in the Delta Outflow/Bay and Suisun Marsh studies (Figure 128). All except the young-of-the-year/year 1 relationship for the otter trawl are statistically significant at the $p<0.05$ level.

Additional data are not available to directly confirm this trend for years prior to 1979, but the low levels of year 2+ observed at the SWP in 1979 (Figure 127) are consistent with the extremely low midwater trawl indices in 1976 and 1977 (Figure 84, page 120). Similarly, improved levels of year 2+ in 1980 seem compatible with the markedly higher midwater trawl indices in 1978.

Given an association between young-of-the-year indices and the number of adults subsequently observed in the population, it is possible that poor recruitment during the recent 6-year drought will lead to a reduced spawning stock. Nonetheless, the lack of a stock recruitment relationship for this species indicates that a reduction in the number of spawners is not responsible for low levels of young-of-the-year, at least through 1992. If recruitment patterns during the past three decades are indeed representative of the resilience of this species, young-of-the-year production should rebound quickly when environmental conditions improve.

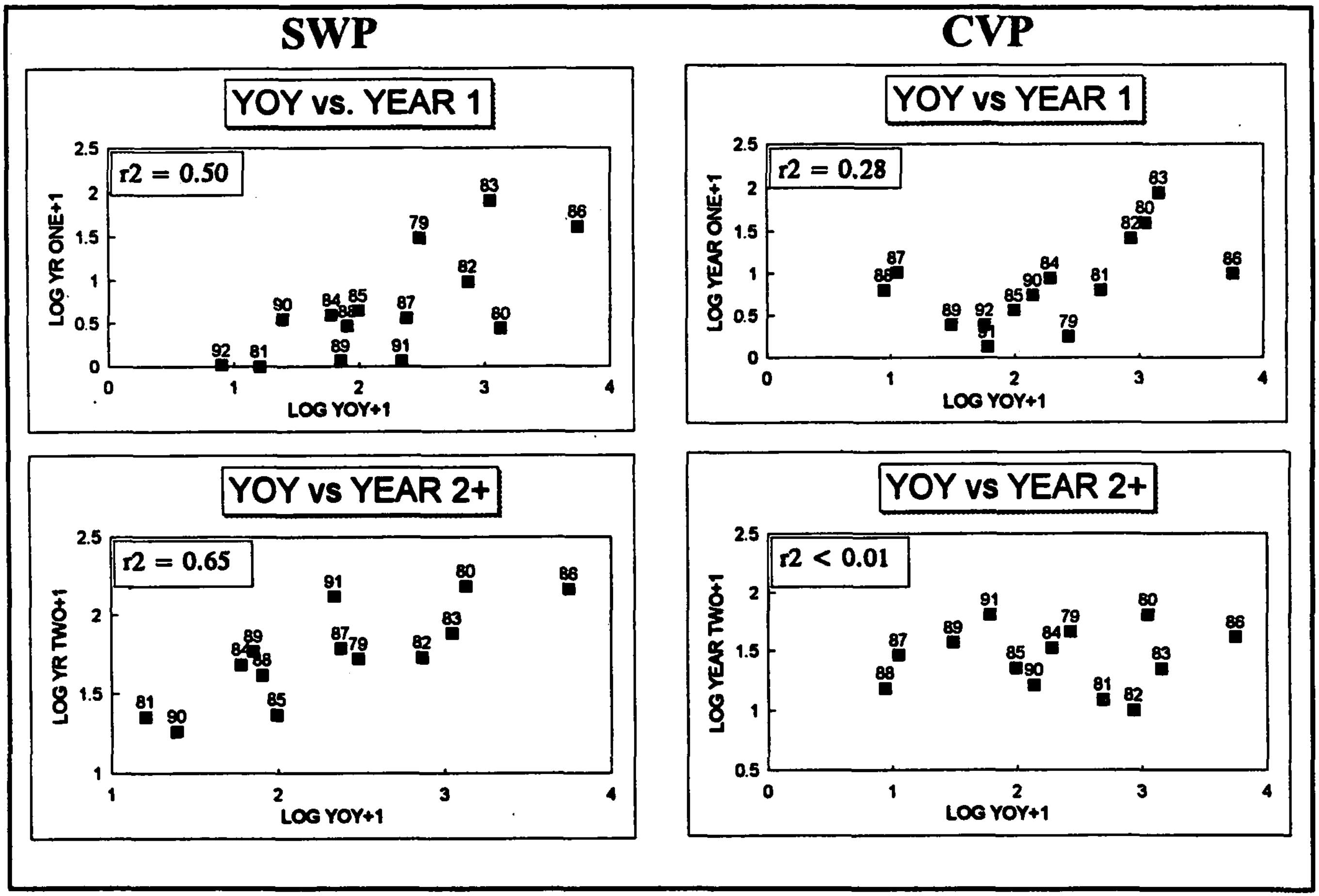

Figure 127

RELATIONSHIPS BETWEEN YEAR 1 AND PREVIOUS-YEAR YOUNG-OF-THE-YEAR AND YEAR 2+ AND YOUNG-OF-THE-YEAR TWO YEARS EARLIER FOR SWP AND CVP ANNUAL SALVAGE ABUNDANCE INDICES

One possible explanation is that increased floodplain inundation or high outflow is necessary to create strong year classes.

Effects of Water Quality

Few water quality parameters have the potential to affect the abundance and distribution of Sacramento splittail over its entire range. A general discussion of some of the major water quality parameters was provided in Chapter 5. Water transparency and specific conductance (salinity) are the most likely factors that could affect splittail at the population level. Water temperature, pH, and dissolved oxygen have not changed on a scale large enough to affect splittail. Factors such as silica, nitrate, and phosphate are not believed to directly affect this species.

This following sections discuss the potential for water transparency and specific conductance to affect the splittail population. The results should be interpreted with caution, because the correlation analyses shown do not necessarily demonstrate cause-and-effect relationships.

Water Transparency

Water transparency is directly dependent on the concentration of suspended organic and inorganic particles. Major factors influencing transparency include sediment transport from streamflow and seasonal blooms of phytoplankton.

Secchi depth readings show that water transparency has been variable throughout the upper estuary, but there has been an increasing trend in most regions (Chapter 5). Studies with other species

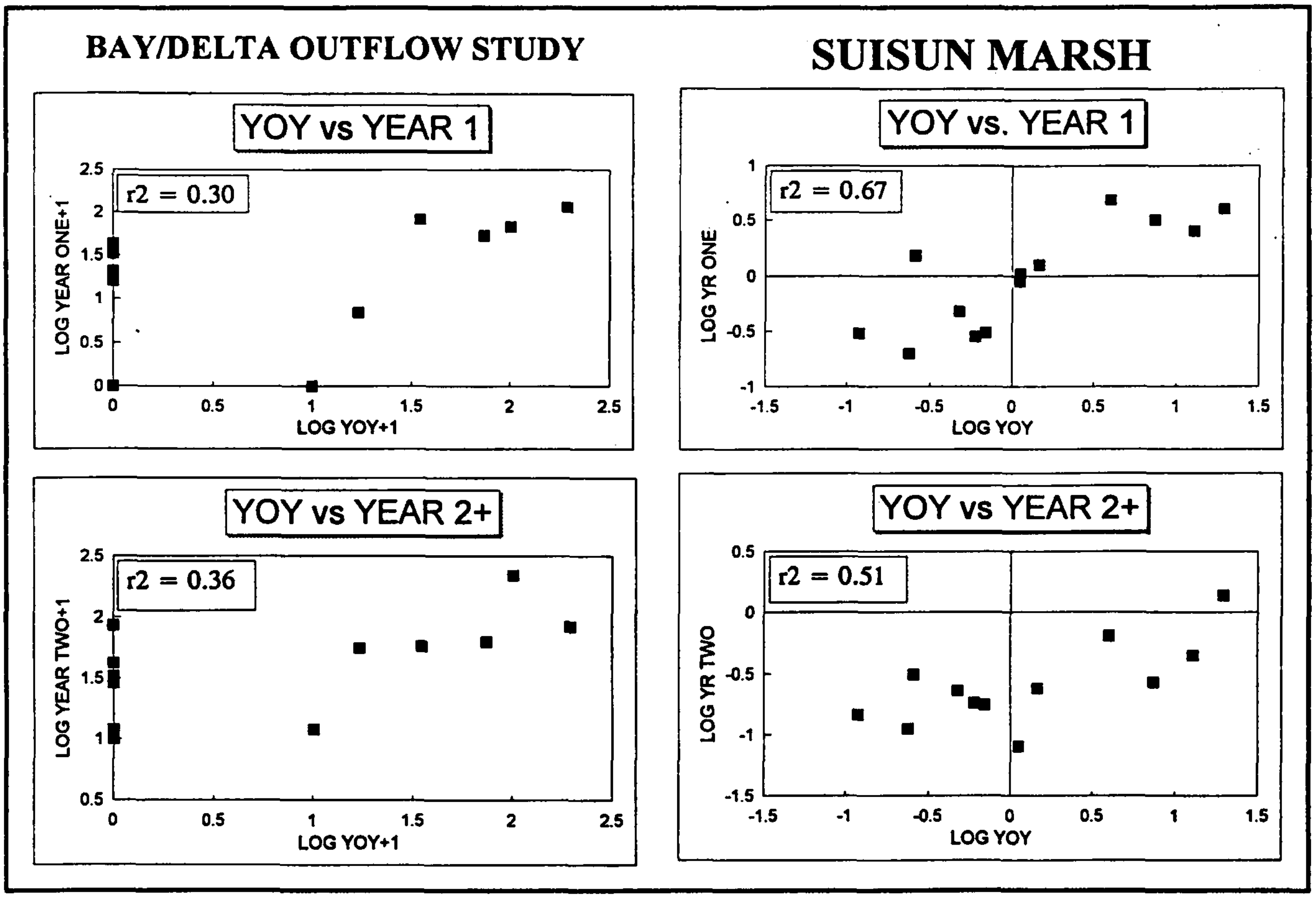

Figure 128

RELATIONSHIPS BETWEEN YEAR 1 AND PREVIOUS-YEAR YOUNG-OF-THE-YEAR AND YEAR 2+ AND YOUNG-OF-THE-YEAR TWO YEARS EARLIER FOR OUTFLOW/BAY STUDY OTTER TRAWL AND SUISUN MARSH ANNUAL ABUNDANCE INDICES

(Ligon *et al* in press) indicate that such increases could increase the susceptibility of splittail to predation.

The relationship between splittail abundance and water transparency was evaluated using an approach similar to that described for delta smelt. Results are summarized in Table 12. In general, water transparency was not significantly correlated with splittail abundance. The only exceptions are the northern Delta in spring and Suisun Bay in fall. However, the lack of a consistent trend between seasons and regions indicates these relationships may be spurious.

Table 12
RESULTS OF CORRELATION ANALYSES,
SPLITTAIL MIDWATER TRAWL ABUNDANCE AND
MEAN SEASONAL ESTIMATES OF
SECCHI DISC DEPTH FOR
FIVE REGIONS IN THE UPPER ESTUARY

Constituent values are mean seasonal mean seasonal Secchi disc depth anomalies (variation due to specific conductance removed).
All results are for 1971 to 1991.

	Correlation Coeffocients			
Region	Winter	Spring	Summer	Fall
Southern Delta	-0.30	-0.04	-0.10	-0.25
Central Delta	-0.27	0.07	-0.08	-0.19
Northern Delta	-0.37	-0.49*	0.09	-0.07
Western Delta	-0.25	0.23	0.25	0.01
Suisun Bay	-0.22	-0.20	-0.15	-0.39*

* P<0.05

Specific Conductance

The Fish and Wildlife Service (1994) identified salinity increases in the Suisun Bay/Grizzly Bay region as a possible factor influencing splittail abundance. The major factor controlling specific conductance in the estuary is sea water intrusion. In the southern Delta, agricultural drain water may also alter specific conductance independent of salt water movement.

Specific conductance directly affects the distribution of splittail, although the optimum salinity range for different life stages is not known. In Suisun Bay, splittail of all sizes are most consistently found in shallow water at salinities less than 2-3 ppt (Meng 1993). However, splittail appear to tolerate higher levels, as catches are often greatest in summer when salinities are 6-10 ppt.

Salinity tolerance of splittail was examined in further detail using data from the Delta Outflow/Bay study for 1980-1992. Catch data from the midwater and otter trawl surveys were separated into young-of-the-year, year 1, and year 2+ using methods described in Chapter 7. Samples were then grouped based on either average salinity (midwater trawl) or bottom salinity (otter trawl) for two periods: January-July and August-December. The catch data have not been adjusted to account for sampling effort or area. Moreover, it is difficult to use the data to differentiate between active preferences and tolerance of environmental conditions. For example, splittail may choose to remain in suboptimal salinities if other habitat conditions (*eg*, food abundance) are positive.[1] The results are summarized in Figures 129 and 130.

The highest catches of all age classes occurred at 0 ppt, which is consistent with observations by Meng (1993). In general, older age classes of fish are more common at a broader range of salinities but show no detectable change in distribution between the two halves of the year. In contrast, it appears that young-of-the-year splittail become more abundant at higher salinities in the second half of the year. While midwater and otter trawl catches of young-of-the-year occurred up to 10-13 ppt throughout the year, there were more observations above 0 ppt during August-December. It is unclear whether this seasonal shift represents an active migration of young-of-the-year to higher salinity water or whether higher salinity water intrudes into splittail habitat as outflow decreases in late summer and early fall. If the latter hypothesis is correct, large numbers of young-of-the-year may be observed at low salinities in winter and spring because they are carried downstream to Suisun Bay and beyond by high flows.

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[1] Salinity challenge studies underway at the University of California, Davis, may help to address this issue.

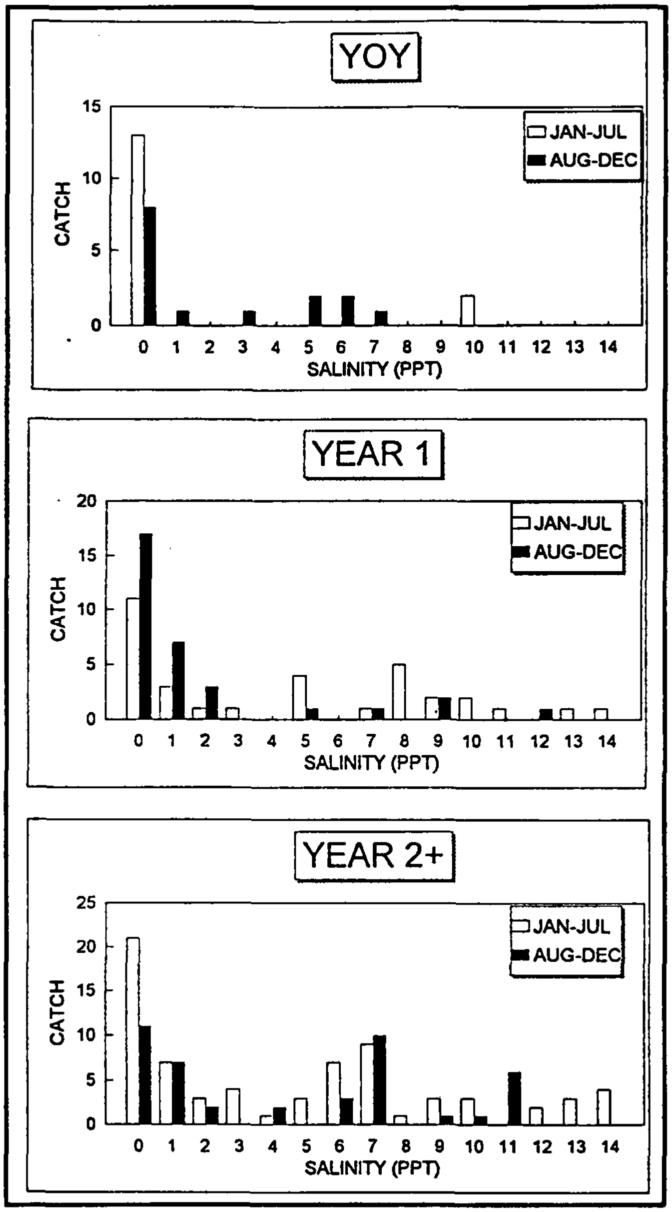

Figure 129

SPLITTAIL CATCH VERSUS BOTTOM SALINITY FROM THE DELTA OUTFLOW/BAY STUDY OTTER TRAWL, 1980-1992

The three age classes were separated using length-frequency data.

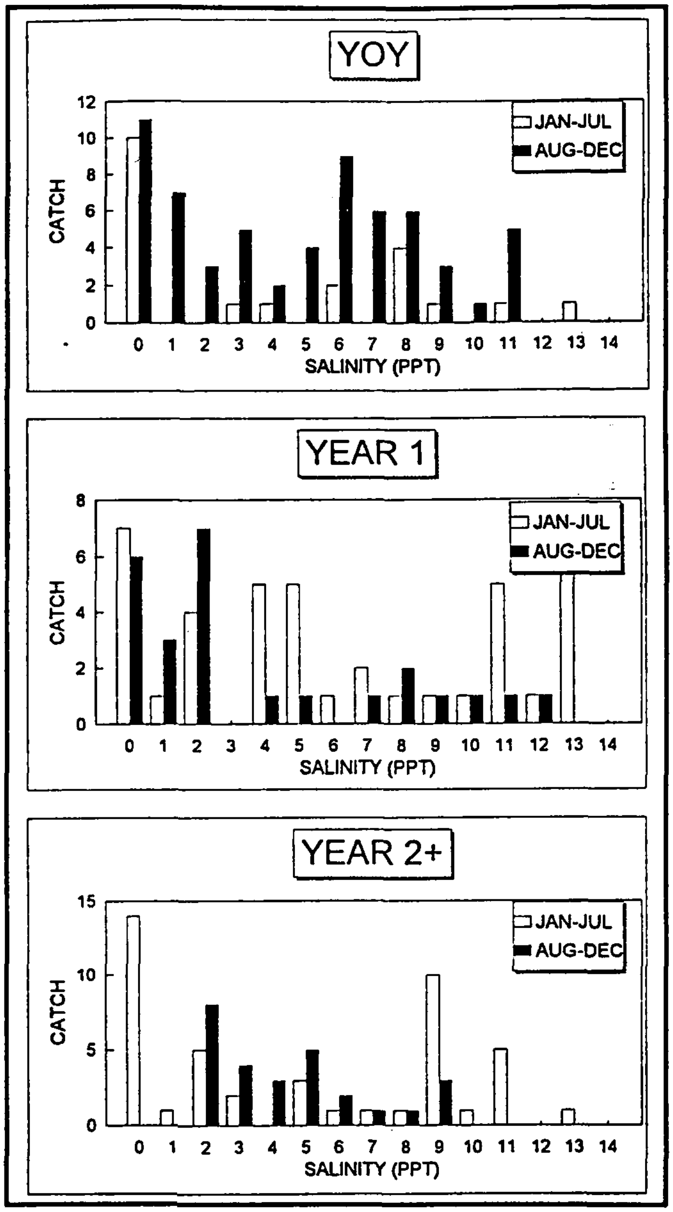

Figure 130

SPLITTAIL CATCH VERSUS BOTTOM SALINITY FROM THE DELTA OUTFLOW/BAY STUDY MIDWATER TRAWL, 1980-1992

The three age classes were separated using length-frequency data.

Because the highest catches of all life stages of splittail were observed at low salinities, this variable may account for trends in abundance. This was examined by correlating mean seasonal specific conductance values with splittail midwater trawl abundance on a regional basis for 1971-1991. Development of the water quality database was described in Chapter 5.

As shown in Table 13, splittail abundance was negatively correlated with specific conductance in all regions of the upper estuary in a variety of seasons. The highest correlation coefficients were generally found during summer and fall, when specific conductance values tend to be highest. However, these relationships are not necessarily cause and effect. A number of variables co-vary with salinity and may have a more direct effect on splittail abundance. As an example, inundation of potential floodplain spawning habitat occurs during wetter years, when salinities are lowest.

Table 13
RESULTS OF CORRELATION ANALYSES,
SPLITTAIL MIDWATER TRAWL ABUNDANCE AND
MEAN SEASONAL ESTIMATES OF
SPECIFIC CONDUCTANCE FOR
FIVE REGIONS IN THE UPPER ESTUARY

Values are mean seasonal mean seasonal specific conductance.
All results are for 1971 to 1991.

	Correlation Coeffocients			
Region	Winter	Spring	Summer	Fall
Southern Delta	-0.50*	-0.64*	-0.74***	-0.62***
Central Delta	-0.32	-0.30	-0.44*	-0.36
Northern Delta	-0.31	-0.29	-0.26	-0.29
Western Delta	-0.32	-0.35	-0.42*	-0.39*
Suisun Bay	-0.49*	-0.58**	-0.60***	-0.53**

* P<0.05
** P<0.01
*** P<0.005

Effects of Contaminants

Toxic contaminants, discussed in detail in Chapter 5, may affect splittail populations. Possible pollutants include heavy metals, pesticides, herbicides, and polycyclic aromatic hydrocarbons. No toxicity studies have been conducted to determine the sensitivity of splittail to these compounds. Contaminants in the sediments are potentially the greatest threat to splittail because they are frequently in shallow water near the bottom, although contaminants in the water column are also a concern. Evidence suggests that toxins in sediments may have significant effects on the biota of the benthic environment, even at low levels (Elder 1988). Splittail reside in the shoals, where there is a greater risk of exposure to urban and agricultural runoff. Toxicity may be reduced in channel areas where greater dilution and flushing occur.

The fact that most of the surveys for juveniles showed an increase in abundance in 1991 is of possible significance. Rice field discharge practices were changed this year, leading to a reduction in herbicide levels in water discharged into areas known to contain splittail. In 1991, Bennett *et al* (1994) noted a major reduction in liver deformities, a characteristic of toxic exposure, in young striped bass.

Chapter 9

CVP/SWP OPERATION SIMULATIONS

The Bureau of Reclamation's PROSIM model was used to simulate CVP/SWP operations for purposes of examining the effects of criteria contained in the February 12, 1993, National Marine Fisheries Service biological opinion on system responses thought to be of significance to the environment of the delta smelt. The purpose was to demonstrate and quantify the significant differences created, especially in Delta conditions, due to operations required of the CVP and SWP in compliance with the NMFS criteria. The most significant of these criteria, the minimum QWEST criterion, results in increased Delta outflow and decreased CVP and SWP export pumping, especially during February, March, and April, three months during which the projects are required by the FWS 1994 biological opinion to provide transport and habitat flows to benefit delta smelt.

The NMFS criteria have been implemented for only two years: 1993 and 1994. These criteria were not in place during the late 1970s through 1992, cited by FWS as a period of decline for delta smelt. The 1994 FWS biological opinion regards CVP and SWP operations, as carried out during that period, as a factor in the decline of the delta smelt. FWS relied on this linkage in its determination that CVP and SWP operations would jeopardize the delta smelt. An examination of the differences in CVP and SWP operations caused by the NMFS criteria suggests:

- Transport and habitat flows are provided for a significantly greater number of days, especially in February, March, and April.
- Project operations are so different than those of the late 1970s to 1992 that a determination of how or when the CVP and SWP could be jeopardizing delta smelt should consider only current operations (including NMFS) criteria.
- Certain elements of the NMFS criteria also protect delta smelt and could be accepted as sufficient protection to avoid a dual set of criteria, which would increase the likelihood of management conflicts between the needs of winter-run Chinook and delta smelt.

PROSIM version 5.31 was used for two studies encompassing 70-year sequences of CVP and SWP operations. The studies considered operations with:

- Decision 1485 Only (Pre-NMFS) — RUN531E
- Decision 1485 Plus NMFS (Post-NMFS) — RUN531F

Detailed documentation of the PROSIM model, the input data, modeling assumptions and criteria, and results of the two studies are available from the Bureau of Reclamation. This chapter briefly describes aspects of the PROSIM model most significant to these two studies.

Hydrologic Data

Both studies use historical hydrologic data for the Central Valley for 1922 to 1991. These data are superimposed on a forecasted 1995 level of development. The PROSIM hydrologic database is the same as Water Resources' DWRSIM database (with some exceptions), but it is organized into the format required for PROSIM. Hydrologic inputs of the eastside streams and San Joaquin River are supplied as a time series of "pre-operated" inflows to the Delta, derived from DWRSIM analyses.

Demands

For both the pre-NMFS and post-NMFS studies, 1995 level demands were assumed for the CVP. In most cases this was the same as full contractual water supply. North-of-Delta demands may be reduced depending on hydrologic conditions in the Sacramento Valley. In summary, 1995-level annual CVP demands were:

	Million Acre-Feet
North of Delta (maximum)	3.089
South of Delta (including Cross Valley)	3.535
Total	6.624

Specifically, CVP demands include Refuge Water at Level II, including 143.3 TAF in the Sacramento Valley, and 201.3 TAF in the San Joaquin Valley, with only 50 TAF assumed used for Grasslands. No interim water supplies are assumed. Cross Valley Canal demand is 128 TAF (wheeled by DWR).

SWP export demands are based on annual entitlement requests, assumed to be 3.685 MAF, with the monthly delivery pattern taken from a DWRSIM input set.

Assumptions and Criteria Common to Both Studies

The following assumptions and criteria were used for both PROSIM studies.

- Decision 1485 outflow and water quality standards met jointly by CVP and SWP.
- Coordinated Operation Agreement determines sharing of responsibility for in-basin uses and use of unstored flow for export.
- Decision 1485 replacement pumping for CVP at Banks Pumping Plant of up to 194 TAF in July, August, and September.
- Annual Trinity River release from Lewiston Dam of 340 TAF (per May 1991 decision by Secretary of the Interior).
- Minimum flow of 3,500-4,000 cfs at navigation control point (Wilkins Slough) on Sacramento River.
- Minimum flows at Keswick of 3,250-6,000 cfs, but not less than described by USBR/DFG 1960 agreement, and clarified by October 1981 letter from USBR to DFG. During November-March, a ramp-down limit of 20% per month applies to releases from Keswick Dam if they are less than 6,000 cfs.
- Minimum flows on the American River from SWRCB Decision 893 but higher amounts in October-February, based on Folsom storage. November-March ramp-down limit of 20% per month imposed on release to American River. March-May minimum release depends on forecasted inflow and storage. June-September minimum is fixed in May.
- No assumption regarding management and dedication of the 800,000 acre-feet under CVPIA.
- Banks pumping limited to a maximum of 7,300 cfs from mid-December to mid-March. This limitation is a monthly average used for model purposes only. The actual pumping rate may be as much as 10,600 cfs based on compliance with the Corps of Engineers' operating criteria letter.

Assumptions and Criteria for Post-NMFS Study

To the extent they could be addressed by a monthly computer model, the February 12, 1993, NMFS biological opinion's Reasonable and Prudent Alternative operations for protection of winter-run Chinook salmon were adopted for use in the post-NMFS study. These were:

- Minimum of 1.9 MAF Shasta storage on September 30. Exceptions taken for 8 critical runoff years (out of 70 study years).
- Minimum Keswick flow of 3,250 cfs in October-March. Ramp-down limits imposed for decreases below 6,000 cfs.
- Reservoir storage objectives, releases, and water allocations are modified to help meet the upper Sacramento River temperature criteria as specified in the biological opinion. (No temperature analysis was performed on this study, but it was checked for reasonable conformance with similar studies.)
- Delta Cross Channel gates closed in February-April.
- QWEST must be >0 in February through April and >-2000 cfs in November-January. Delta export pumping reduced if necessary to meet the QWEST index.
- Effect of NMFS Incidental Take criteria is not modeled. The 1% seasonal take limit at CVP and SWP export pumps has constrained operations in both 1993 and 1994, resulting in periods of reduced pumping to avoid entrainment.

Limitations of PROSIM in Simulating NMFS Criteria

Some of the NMFS criteria are expressed such that a translation to the monthly time steps used by the PROSIM model has been used to approximate their effect. This was done with the QWEST criteria, where the 14-day running averages required by the biological opinion are translated as monthly minimum requirements for use by PROSIM. In most cases this will result in underestimating the effect of QWEST, because meeting the 14-day average requirement on an ongoing basis will usually result in a monthly average higher than the minimum requirement, especially when inflows to the Delta are changing.

The upper Sacramento River temperature criteria are expressed as mean daily requirements in the NMFS biological opinion. As with the QWEST criteria, meeting temperatures on a daily basis will usually result in a monthly average somewhat lower than the requirement. Again, PROSIM results may then be an underestimate of the amounts of storage and release required to meet the actual criteria.

Some elements of the NMFS criteria are not modeled at all by PROSIM. Conditional closures of the Delta Cross Channel gates (for presence of winter-run) from October 1 to January 31 are not modeled. The requirement for basing CVP water allocations on a conservative (at least 90% probability of exceedence) forecast is not modeled. Finally, the effect of the NMFS criterion limiting incidental take to 1% of the estimated number of juvenile out-migrants is not modeled. During 1992 (under an earlier biological opinion), 1993, and 1994 CVP and SWP Delta exports have been limited at times to avoid excessive incidental take. Since no take limits are modeled by PROSIM, this may amount to a further underestimate of the effects of the NMFS criteria.

Results

Results of the PROSIM studies comparing the pre-NMFS and post-NMFS criteria are presented in Figures 131 through 136 and Tables 14 through 19. Although effects vary in magnitude depending on hydrologic conditions, the NMFS 1993 criteria will result in:

- Reduced Delta export.
- Increased flow in the lower San Joaquin River (QWEST).
- Increased Delta outflow.
- Location of X2 farther downstream.
- Generally higher CVP reservoir storage.
- Generally lower CVP and SWP water delivery.
- Modified streamflows, particularly in the upper Sacramento River, where temperature criteria affect the timing and amounts of release.

The major effects of the NMFS criteria are highlighted in Figures 137 through 142 by presenting the pre-NMFS and post-NMFS results for each year of the 70-year studies, arranged from wettest to driest (according to the Sacramento River Index for each water year). A "difference bar" is plotted on Figures 137-142 to draw attention to the magnitude of differences between pre-NMFS and post-NMFS modeled results through the range of hydrologic conditions represented. In many cases, differences caused by the NMFS criteria are most prominently manifested in the drier half of the water years. For reference, Table 20 shows the Sacramento River Index and water year type chronologically for 1922-1991. Table 21 shows the same information, but arranged by year type from wettest to driest.

Conclusions

- The NMFS criteria significantly decrease CVP/SWP export pumping in February, March, and April. This effect is very prominent in below-normal, dry, and critical years.
- The increased Delta outflows and estimated downstream movement of X2 resulting from the NMFS criteria, especially in February, March, and April, more frequently meet the objectives of FWS Reasonable and Prudent Alternative 1 for delta smelt transport and habitat. This effect is most prominent in below-normal, dry, and critical years.
- The NMFS criteria have changed CVP and SWP operations so significantly that only recent operations (1993 and 1994) and the proposed operations (including NMFS criteria) should be considered in determining whether future operations could jeopardize delta smelt.
- The NMFS criteria also protect delta smelt; if they were accepted as sufficiently protective, the need for dual criteria would be avoided, in turn reducing potential management conflicts between winter-run Chinook and the delta smelt.
- The NMFS criteria generally require accumulation of greater amounts of storage (for upper Sacramento temperature control), especially during below-normal, dry, and critical years. This would pose a potential management conflict with transport and habitat flow requirements if those had to be met by releases from upstream reservoirs.
- Because of the modeling limitations, these PROSIM studies underestimate the magnitude of the effects of the NMFS criteria. Experience and intuition suggest that in many of the water years simulated, the real effects on export, Delta outflow, and even storage and releases could be significantly greater than PROSIM portrays.

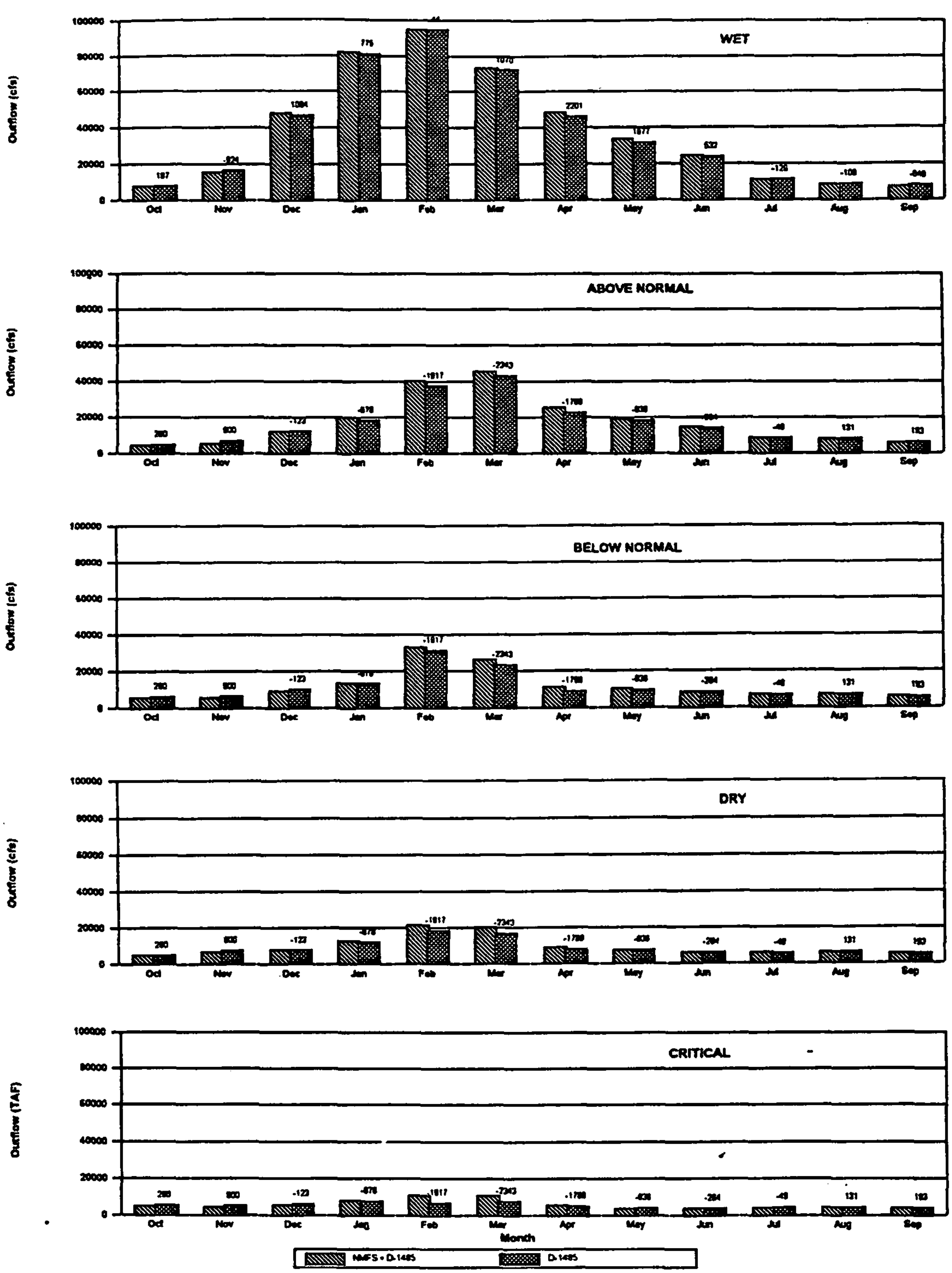

Figure 131
TOTAL DELTA OUTFLOW FOR FIVE WATER-YEAR TYPES
Based on a 70-Year Simulation

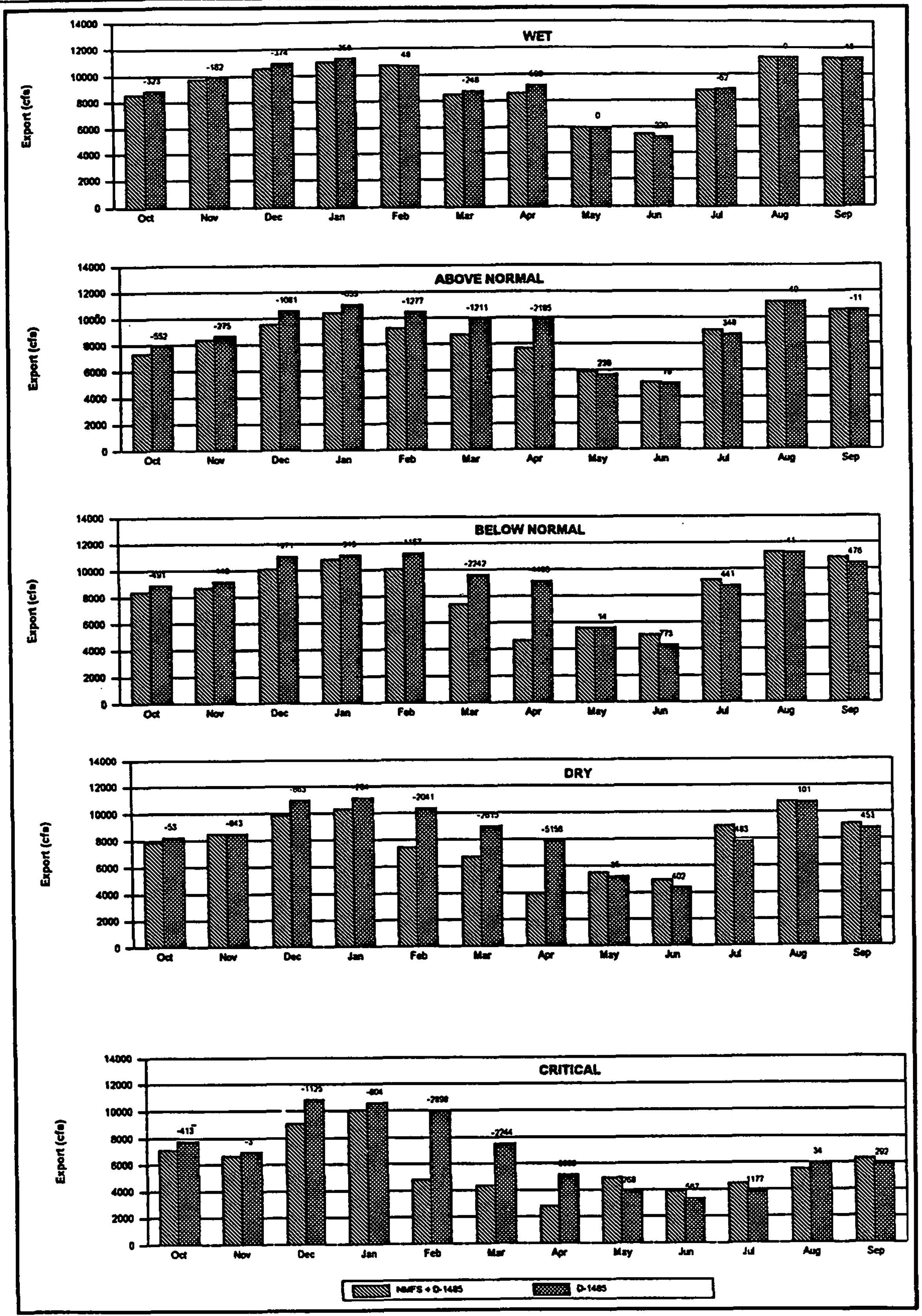

Figure 132

COMBINED BANKS AND TRACY PUMPING PLANT EXPORTS FOR FIVE WATER-YEAR TYPES

Based on a 70-Year Simulation

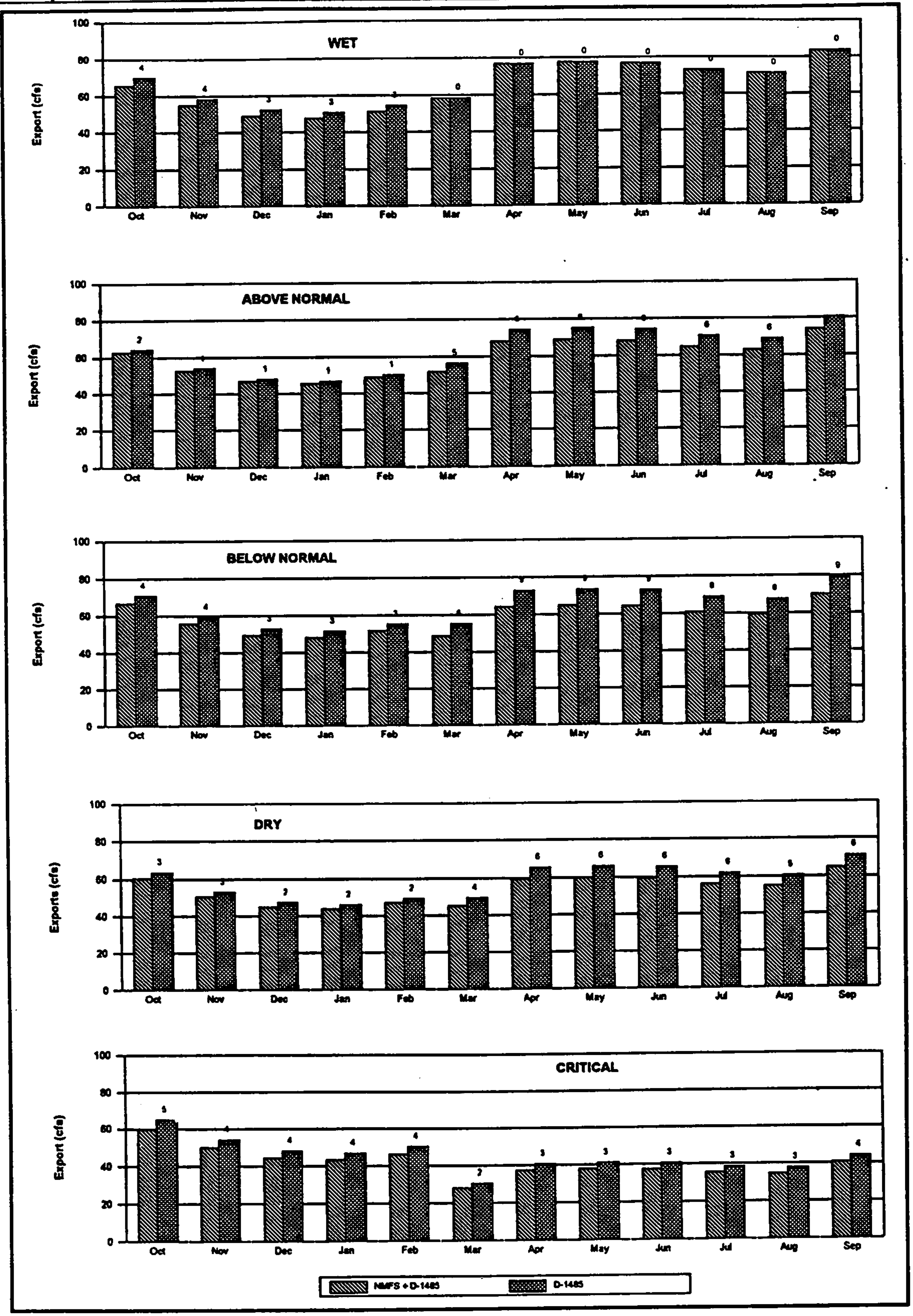

Figure 133
ESTIMATED NORTH BAY AQUEDUCT DIVERSIONS FOR FIVE WATER-YEAR TYPES

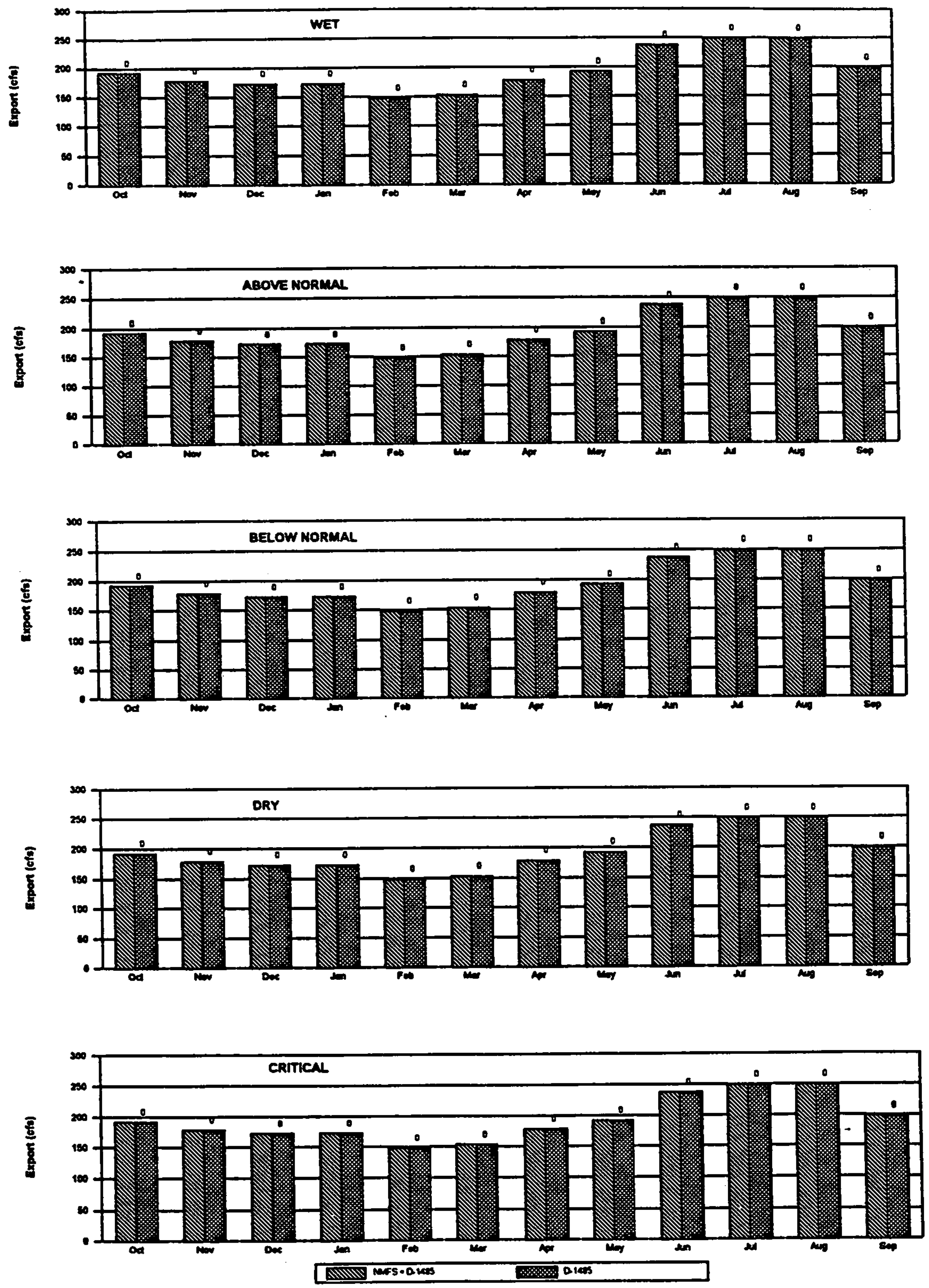

Figure 134
ESTIMATED CONTRA COSTA CANAL DIVERSIONS FOR FIVE WATER-YEAR TYPES

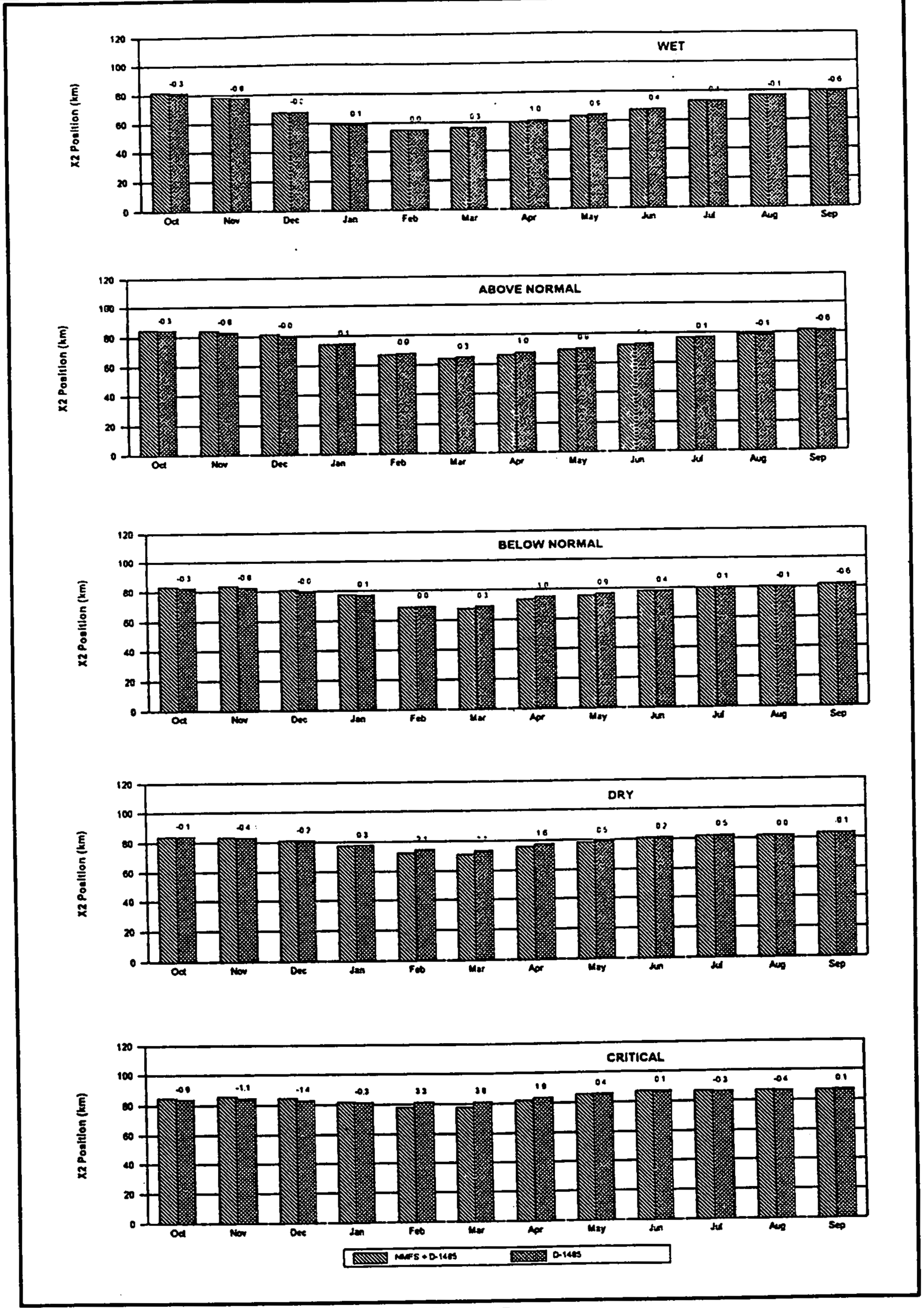

Figure 135
AVERAGE MONTHLY X2 POSITION
Based on a 70-Year Simulation

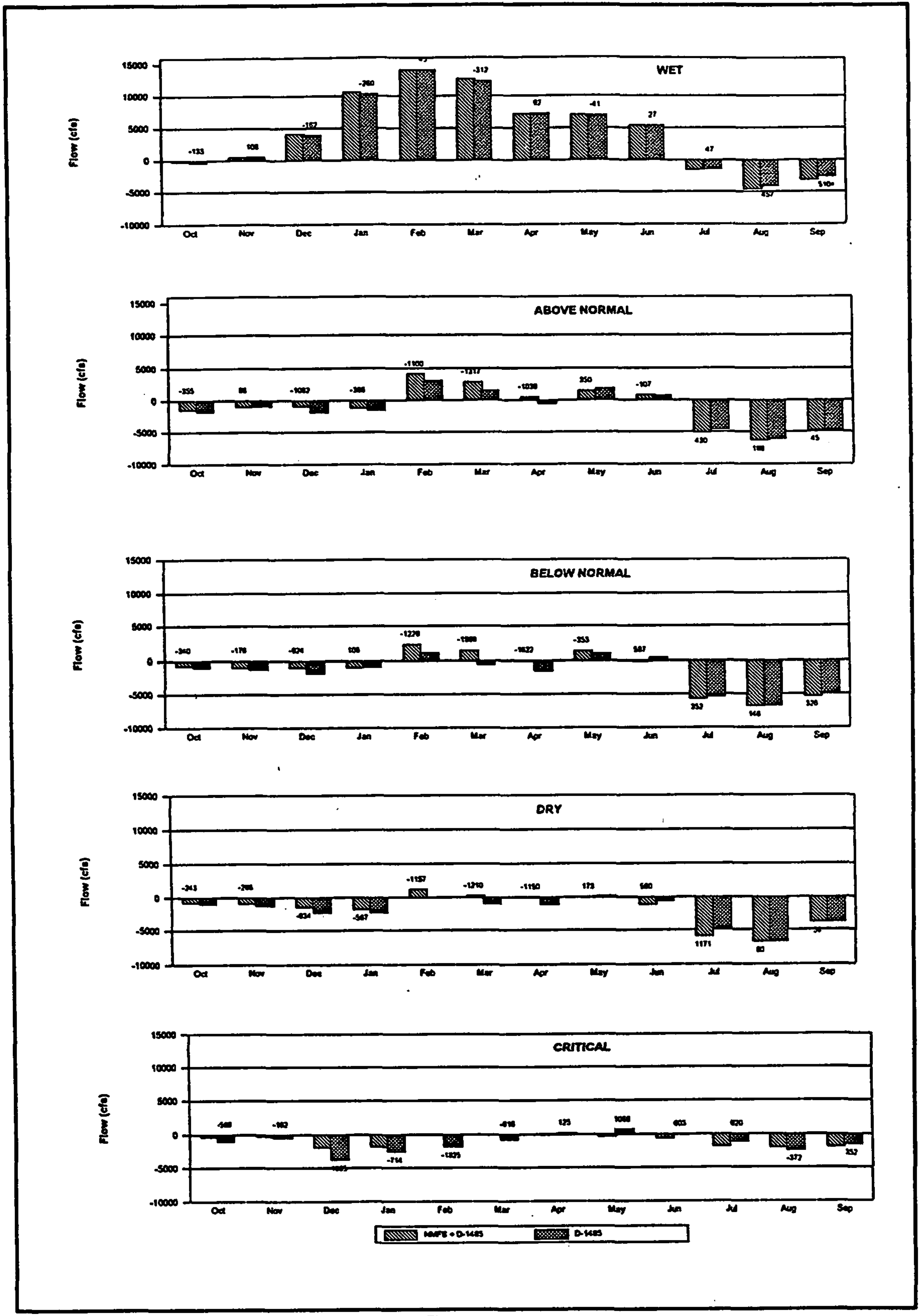

Figure 136
QWEST FLOWS FOR FIVE WATER-YEAR TYPES
Based on a 70-Year Simulation

Table 14
AVERAGE CHANGE IN DELTA OUTFLOW RESULTING FROM NMFS CRITERIA

Results of PROSIM Simulations, July 1994
(In 1,000 Acre-Feet)

Water Year Type	Number of Years	February	March	April	Water Year Total	February to April Total
Wet	25	– 5	79	121	310	195
Above Normal	9	93	82	201	436	376
Below Normal	13	105	204	137	446	446
Dry	11	174	174	46	378	394
Critical	12	228	199	44	429	471
1922-1991	70	96	138	109	383	343

Table 15
AVERAGE CHANGE IN SWP AND CVP RESULTING FROM NMFS CRITERIA

Results of PROSIM Simulations, July 1994
(In 1,000 Acre-Feet)

Water Year Type	Number of Years	February	March	April	Water Year Total	February to April Total
Wet	25	+ 2	– 15	– 35	–108	– 49
Above Normal	9	– 67	– 80	–145	–341	–293
Below Normal	13	– 88	–119	–247	–504	–454
Dry	11	–177	–167	–242	–597	–585
Critical	12	–278	–190	–147	–614	–615
1922-1991	70	–100	– 97	–140	–375	–337

Table 16
AVERAGE NUMBER OF DAYS (FEBRUARY-JUNE) X2 IS DOWNSTREAM OF CHIPPS ISLAND WITH AND WITHOUT NMFS CRITERIA

Results of PROSIM Simulations, July 1994

Water Year Type	Number of Years	Pre-NMFS	Post-NMFS	Change
Wet	25	143	144	+ 1
Above Normal	9	110	117	+ 7
Below Normal	13	57	78	+21
Dry	11	32	49	+17
Critical	12	3	5	+ 2

Table 17
AVERAGE NUMBER OF DAYS (FEBRUARY-JUNE) X2 IS DOWNSTREAM OF THE CONFLUENCE WITH AND WITHOUT NMFS CRITERIA

Results of PROSIM Simulations, July 1994

Water Year Type	Number of Years	Pre-NMFS	Post-NMFS	Change
Wet	25	150	150	—
Above Normal	9	147	150	+ 3
Below Normal	13	148	148	—
Dry	11	115	128	+13
Critical	12	30	54	+24

Table 18
CHANGE IN END-OF-YEAR STORAGE AT SHASTA, FOLSOM, AND CLAIR ENGLE RESERVOIRS RESULTING FROM NMFS CRITERIA

Results of PROSIM Simulations, July 1994
(In 1,000 Acre-Feet)

Water Year Type	Number of Years	Pre-NMFS	Post-NMFS	Change
Wet	25	5576	5570	– 6
Above Normal	9	4574	4530	– 44
Below Normal	13	4193	4299	+106
Dry	11	4019	4152	+133
Critical	12	2469	2951	+482
1922-1991	70	4413	4528	+115

Table 19
CHANGE IN COMBINED CVP/SWP ANNUAL WATER DELIVERY RESULTING FROM NMFS CRITERIA

Results of PROSIM Simulations, July 1994
(In 1,000 Acre-Feet)

Water Year Type	Number of Years	Pre-NMFS	Post-NMFS	Change
Wet	25	9644	9604	– 40
Above Normal	9	9501	9074	–427
Below Normal	13	9271	8768	–503
Dry	11	9005	8313	–691
Critical	12	6786	6185	–601
1922-1991	70	8966	8592	–374

Table 20
SACRAMENTO RIVER INDEX, 1922-1991

Water Year	Year Type	Sacramento River Index	Water Year	Year Type	Sacramento River Index
1922	AN	18.0	1957	BN	14.9
1923	BN	13.2	1958	W	29.7
1924	C	5.7	1959	D	12.0
1925	AN	16.0	1960	BN	13.1
1926	D	11.8	1961	D	12.0
1927	W	23.8	1962	BN	15.1
1928	AN	16.8	1963	W	23.0
1929	C	8.4	1964	D	10.9
1930	BN/D	13.5	1965	W	25.7
1931	C	6.1	1966	BN	12.9
1932	BN/D	13.1	1967	W	24.1
1933	C	8.9	1968	BN	13.6
1934	C	8.6	1969	W	27.0
1935	AN	16.6	1970	W	24.1
1936	AN	17.3	1971	W	22.6
1937	BN	13.3	1972	BN	13.4
1938	W	31.8	1973	W	20.0
1939	C	8.2	1974	W	32.5
1940	W/AN	22.4	1975	AN	19.2
1941	W	27.1	1976	C	8.1
1942	W	25.2	1977	C	5.1
1943	W	21.1	1978	W	23.9
1944	D	10.4	1979	D	12.4
1945	BN	15.1	1980	W	22.3
1946	AN	17.6	1981	D	11.1
1947	D	10.4	1982	W	33.3
1948	AN	15.8	1983	W	37.7
1949	D	12.0	1984	W	22.4
1950	BN	14.4	1985	D	11.0
1951	W	22.9	1986	W	25.7
1952	W	28.6	1987	C	9.2
1953	W	20.1	1988	C	9.2
1954	AN	17.4	1989	BN/D	14.8
1955	D	11.0	1990	C	9.2
1956	W	29.9	1991	C	8.4

W Wet
AN Above Normal
BN Below Normal
D Dry
C Critical

Table 21
SACRAMENTO RIVER INDEX, 1922-1991, RANKED FROM WET TO DRY

Water Year	Year Type	Sacramento River Index	Water Year	Year Type	Sacramento River Index
1983	W	37.7	1945	BN	15.1
1982	W	33.3	1957	BN	14.9
1974	W	32.5	1989	BN/D	14.8
1938	W	31.8	1950	BN	14.4
1956	W	29.9	1968	BN	13.6
1958	W	29.7	1930	BN/D	13.5
1952	W	28.6	1972	BN	13.4
1941	W	27.1	1937	BN	13.3
1969	W	27.0	1923	BN	13.2
1986	W	25.7	1932	BN/D	13.1
1965	W	25.7	1960	BN	13.1
1942	W	25.2	1966	BN	12.9
1967	W	24.1	1979	D	12.4
1970	W	24.1	1961	D	12.0
1978	W	23.9	1949	D	12.0
1927	W	23.8	1959	D	12.0
1963	W	23.0	1926	D	11.8
1951	W	22.9	1981	D	11.1
1971	W	22.6	1955	D	11.0
1940	W/AN	22.4	1985	D	11.0
1984	W	22.4	1964	D	10.9
1980	W	22.3	1944	D	10.4
1943	W	21.1	1947	D	10.4
1953	W	20.1	1988	C	9.2
1973	W	20.0	1990	C	9.2
1975	AN	19.2	1987	C	9.2
1922	AN	18.0	1933	C	8.9
1946	AN	17.6	1934	C	8.6
1954	AN	17.4	1929	C	8.4
1936	AN	17.3	1991	C	8.4
1928	AN	16.8	1939	C	8.2
1935	AN	16.6	1976	C	8.1
1925	AN	16.0	1931	C	6.1
1948	AN	15.8	1924	C	5.7
1962	BN	15.1	1977	C	5.1

W Wet
AN Above Normal
BN Below Normal
D Dry
C Critical

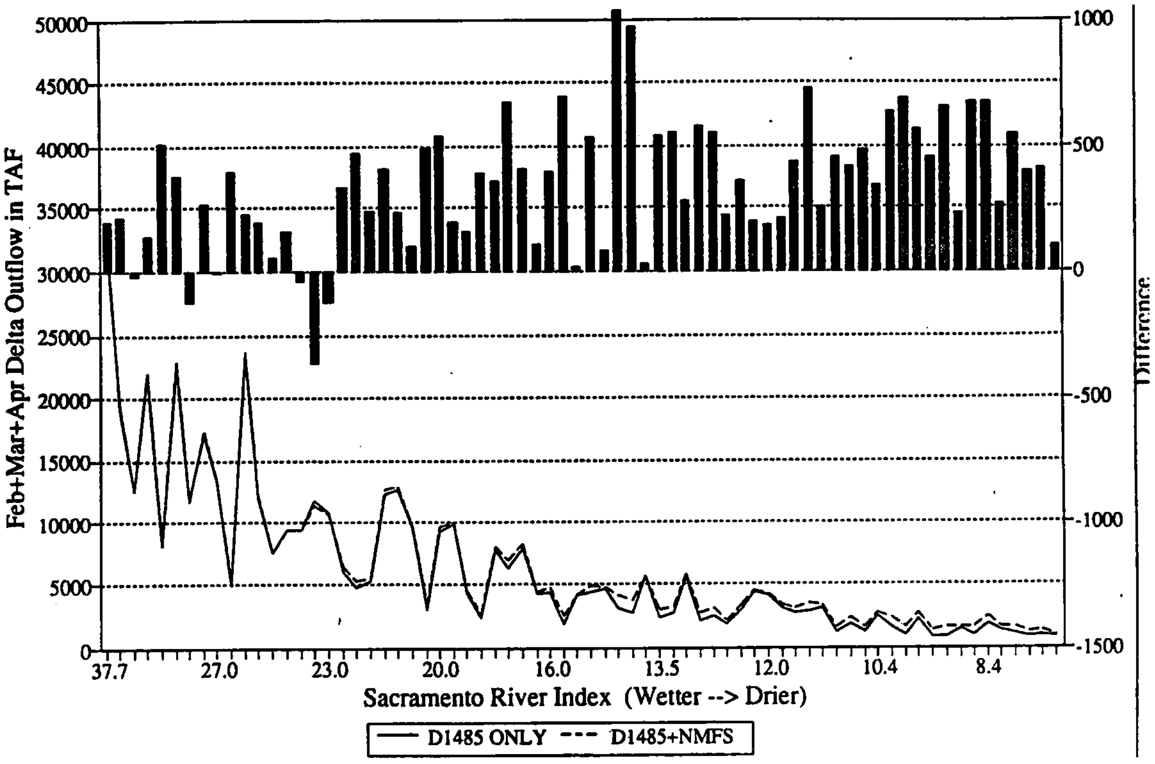

Figure 137
CHANGE IN FEBRUARY-APRIL OUTFLOW FOR A RANGE OF WATER YEARS

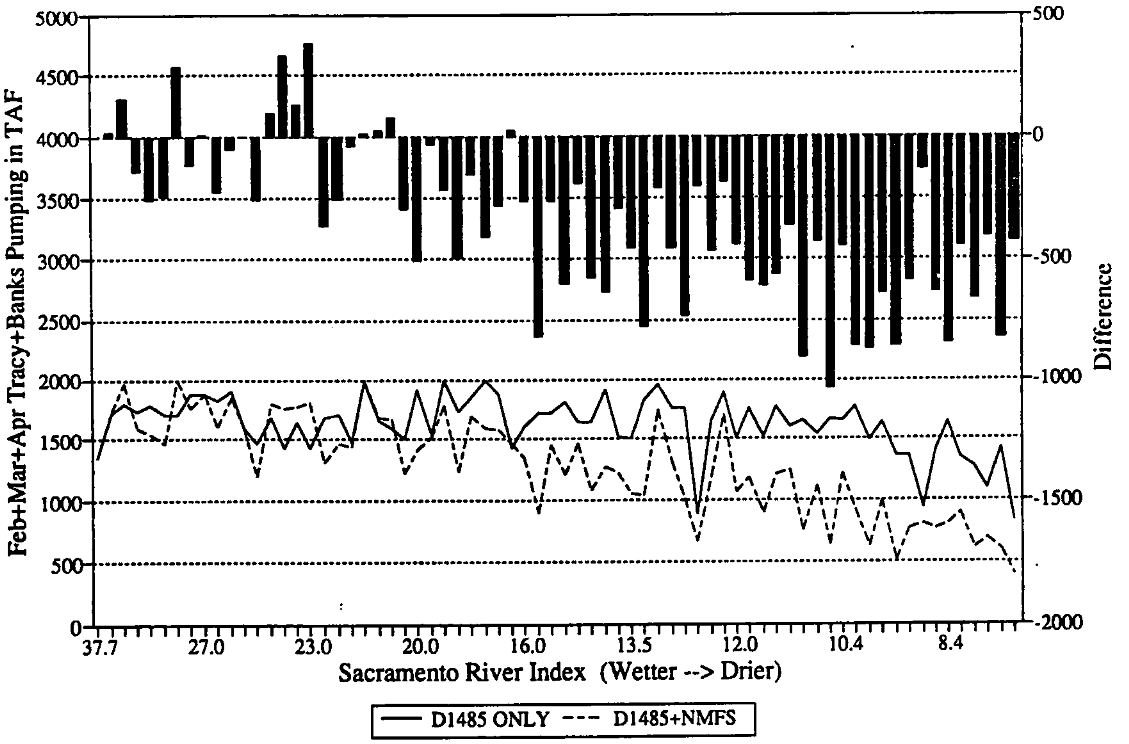

Figure 138
CHANGE IN FEBRUARY-APRIL BANKS AND TRACY PUMPING FOR A RANGE OF WATER YEARS

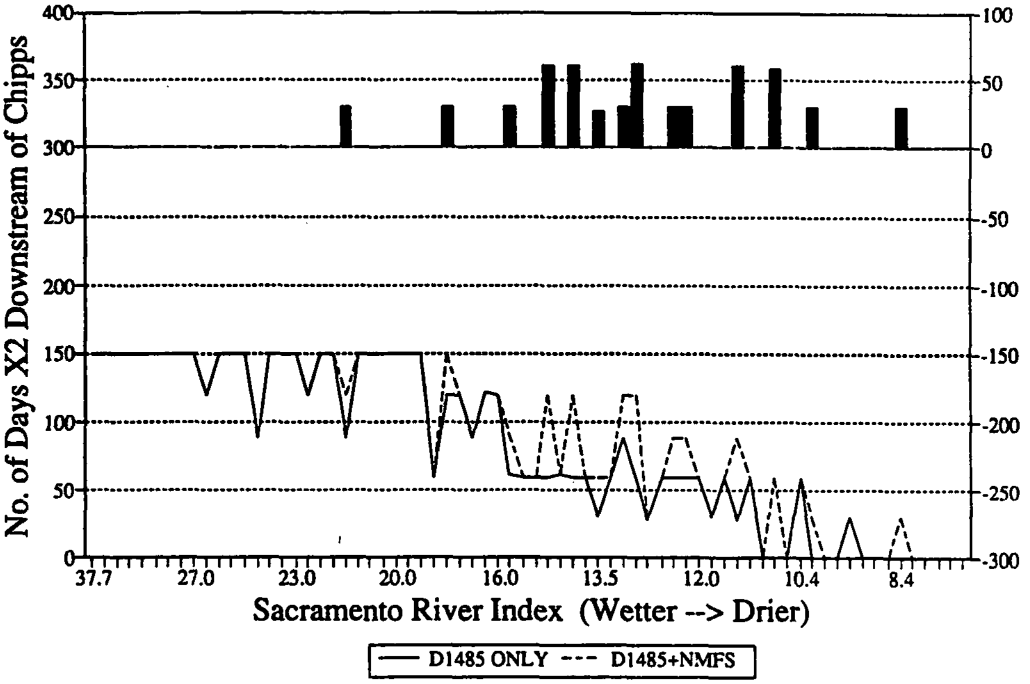

Figure 139
CHANGE IN THE NUMBER OF DAYS X2 IS DOWNSTREAM OF CHIPPS ISLAND FOR A RANGE OF WATER YEARS

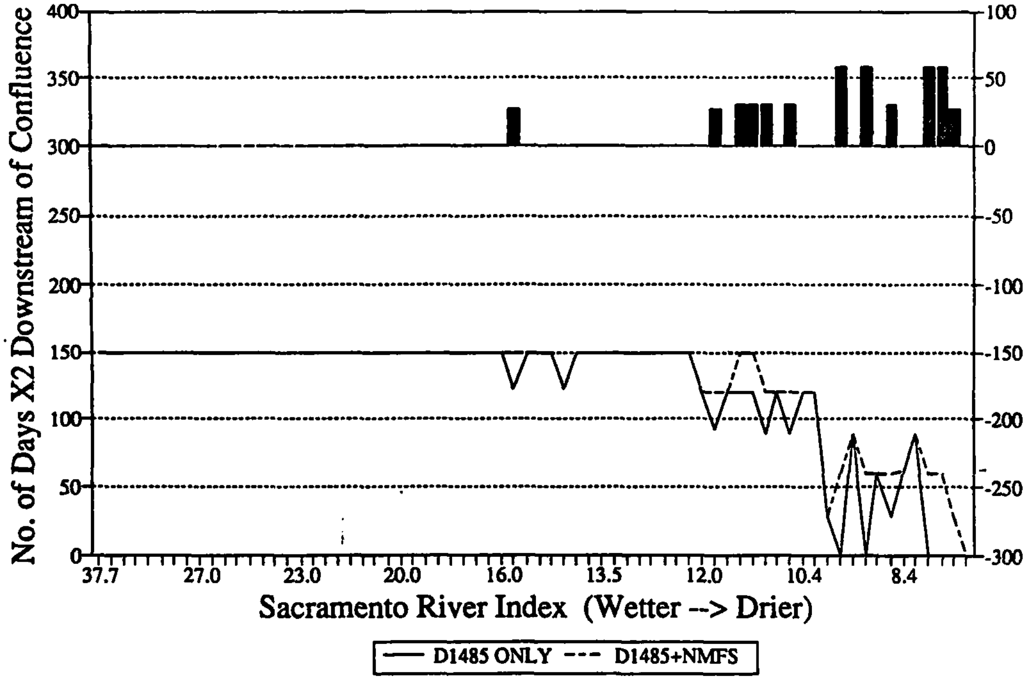

Figure 140
CHANGE IN THE NUMBER OF DAYS X2 IS DOWNSTREAM OF THE CONFLUENCE FOR A RANGE OF WATER YEARS

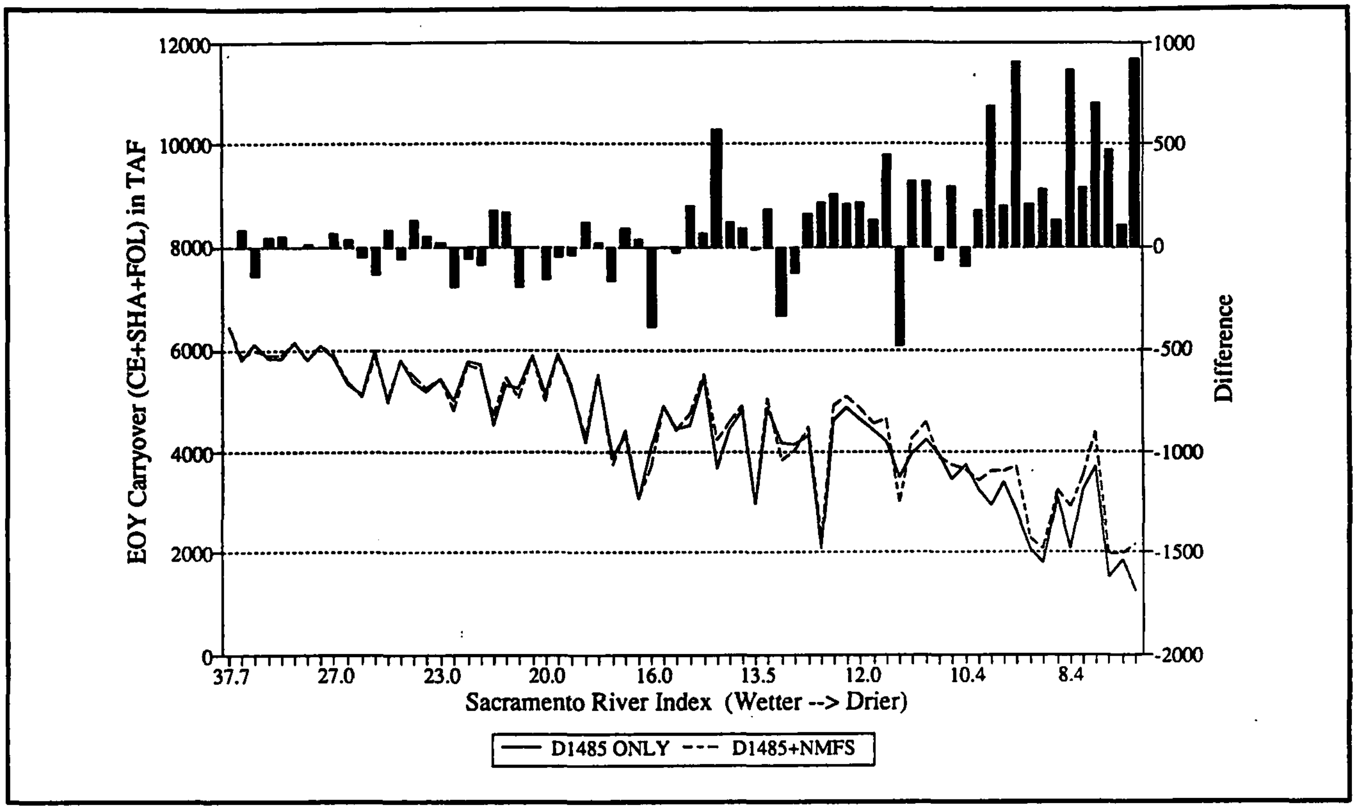

Figure 141
CHANGE IN END-OF-YEAR CARRYOVER STORAGE (CLAIR ENGLE, SHASTA, FOLSOM) FOR A RANGE OF WATER YEARS

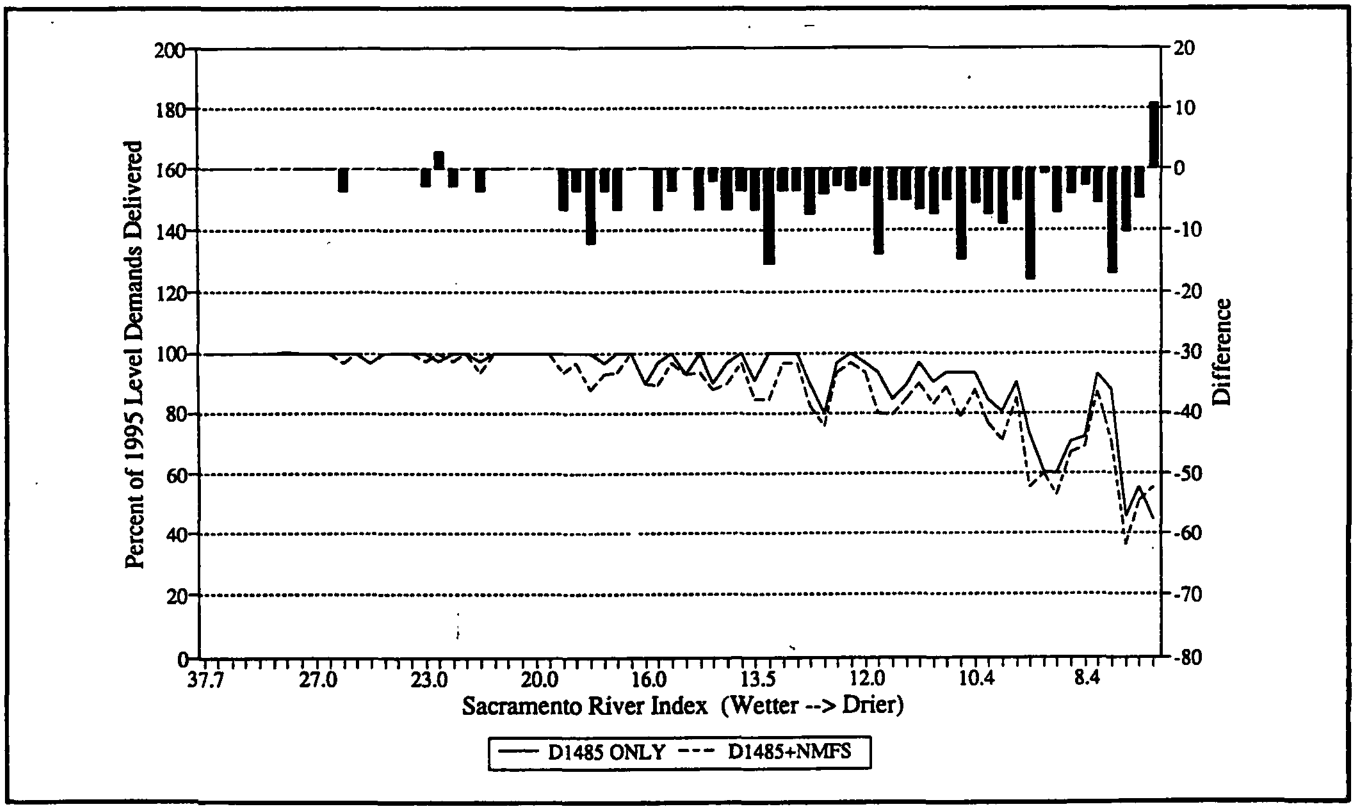

Figure 142
CHANGE IN PERCENT OF 1995-LEVEL DEMAND DELIVERED FOR A RANGE OF WATER YEARS

Chapter 10

ANALYSIS OF CVP AND SWP IMPACTS

Results of modeling studies to assess project impacts for different water year types are summarized in Chapter 9. The accompanying figures show the range of potential Delta hydrodynamic conditions and pumping levels during the mid-1990s with operation of existing Central Valley Project and State Water Project facilities. There are numerous uncertainties about project operations in the future. Important questions also remain about factors influencing the abundance of splittail and delta smelt. This discussion is an analysis of the best available information on project operations and biology. Conclusions may be revised after further evaluation.

Expected impacts on delta smelt and Sacramento splittail, based on current modeling capabilities and assumptions, are described in this chapter.

Tracy Pumping Plant and Banks Pumping Plant

Simulated combined future exports for Tracy Pumping Plant and Banks Pumping Plant (Figures 132 and 138) show that winter-run criteria will substantially limit exports in February-April, particularly in dry years. Entrainment and associated losses of delta smelt and splittail would not occur if these facilities had not been constructed. Specific impacts for the two species are described below.

Delta Smelt

The magnitude and timing of losses at the SWP and CVP appear to result from complex interactions of several factors, including flow, delta smelt distribution, and cohort abundance. The most likely mechanism for flow and distribution effects is that in low outflow years the delta smelt population shifts to upstream areas, where entrainment risks are greater. The impact of losses following entrainment is expected to be greater when year-class strength is weak. Year-class strength appears to depend at least partly on the number of adult spawners the previous year. Rationale for this hypothesis is described below.

A shift in population distribution has been established by Stevens *et al* (1990). The cause of the distribution shift appears to be increased salinity in Suisun Bay and the western Delta during drier years, discussed in Chapter 5 under "Water Quality".

Actual levels of entrainment and associated losses at the CVP and SWP Delta facilities are not known because information is lacking about screening efficiencies and predation rates. Without this information, salvage at the export facilities provides only an index of the relative timing and magnitude of entrainment and losses.

The major evidence for increased losses during drought years is the significant relationship between spring salvage of juvenile delta smelt at Skinner Fish Facility and total outflow during periods of peak abundance. Salvage levels appear to increase most dramatically when average outflow drops to below 10,000 cfs when juveniles are abundant (Figure 51, Chapter 5). Entrainment indices also show that salvage is relatively higher in dry years at Tracy Fish Facility.

The higher risk of entrainment and, presumably, associated losses in the interior Delta is consistent with DWR Particle Tracking Model studies (Chapter 5), which indicate the export pumps have a "zone of influence" in the interior Delta from which a large percentage of modeled particles were entrained. If the distribution of delta smelt is shifted into this area, entrainment losses are likely to increase.

Although flows in the western Delta were also significantly correlated with SWP salvage, particle tracking studies suggest reverse flows are *not* a good indicator of entrainment. Model studies showed particles in the interior of the Delta were carried to the export pumps despite high positive QWEST values. QWEST and actual western Delta flow are not equivalent, but often show similar trends. The association between western Delta flow and salvage may, therefore, be due to the correlation between western Delta flow and Delta outflow or other factors, rather than to a direct cause-and-effect relationship. The relationship between inflow and SWP salvage may be due to a similar reason. As evidence that outflow is a better indicator of entrainment and associated losses, this variable had a higher r^2 value with salvage than either western Delta flow or Delta inflow. Although export levels could change the area affected by pumping, exports were not found to be correlated to salvage levels, even when drought years are isolated. Hence, although future exports will continue to be higher in wetter years when outflow is high, statistical evidence suggests impacts will be *lower* in wetter years than in drier years.

While outflow appears to be a major hydrologic variable associated with SWP entrainment and loss, impacts to the smelt population also depend on year-class strength. If year-class is weak, the relative impacts of entrainment-related losses to the delta smelt population are expected to be worse. SWP and CVP entrainment indices developed to incorporate cohort abundance generally follow the same trend as the salvage/outflow relationship. Impacts for 1979 to 1993 were usually lower in wet years and high in most drought years.

Apparently timing and distribution of flow also affect salvage levels. For example, spring high salvage levels (and presumably loss rates) occurred in 1984, when major outflow events were confined primarily to the early part of the water year.

Based on these observations, it is not surprising that no simple relationship has been found between delta smelt abundance indices and exports. Direct losses may have little effect on abundance indices except in dry years when cohort strength is weak. However, no statistically rigorous relationship could be shown between salvage, which represents the best indicator of entrainment, and delta smelt abundance.

These uncertainties make it difficult to identify population level impacts for the simulated exports and outflow levels. It is likely, however, that project impacts will be lower than in the 1980s, because winter run criteria result in reduced exports and increased Delta outflow in the critical winter and early spring months.

Splittail

The evidence suggests that entrainment at export facilities does not have a significant effect on abundance. Unlike delta smelt, splittail do not show increased entrainment in dry years. Salvage results indicate that loss rates at the two facilities depend directly on the number of splittail in the system. Therefore, higher entrainment is associated with wet years, when splittail are abundant because of favorable environmental conditions.

Although there is no evidence that loss at the SWP and CVP affects splittail abundance, changes in operation could result in changes in entrainment rates. Operation of the project under National Marine Fisheries Service criteria is expected to result in lower impacts to adult splittail than operation under Decision 1485 because of reduced exports from October to April, the months when most year 2+ are observed. Increased loss of young-of-the-year might occur in May to July because of higher exports under NMFS. These changes are not expected to have a net major effect on the splittail population.

North Bay Aqueduct

Expected future exports for the North Bay Aqueduct are presented in Figure 133. Specific impacts for the two species are described below.

Delta Smelt

There are no direct entrainment data on larval delta smelt, although tests are being planned for 1995. Based on sampling in Barker Slough, it is safe to assume that larvae are entrained. Effectiveness of the North Bay Aqueduct fish screen on smaller juveniles and pre-juveniles is unknown.

The calculated density estimates for larval delta smelt in Barker and Lindsey sloughs are in the same order of magnitude as those near the Tracy and Banks pumping plants and the intake to the Contra Costa Canal. However, the annual estimates of delta smelt larvae entrained are in the thousands for the North Bay Aqueduct and orders of magnitude larger for Tracy/Banks.

Additional water from the North Bay Aqueduct will likely be used to augment flows in the western Suisun Marsh to meet Decision 1485 salinity standards.

Water for Suisun Marsh may be needed as early as September and continue through May in dry and critically dry years. DWR and USBR estimate that 30 to 50 cfs would be needed in about 1 of 15 years; however, water would have been needed for Suisun Marsh during most of the years during the recent drought. January through May coincides with the delta smelt spawning period, during which a pumping restriction to protect delta smelt larvae was in effect during 1993 and 1994. With a 65 cfs pumping restriction and water needed for Suisun Marsh, there will not be adequate capacity remaining for North Bay Aqueduct water users. This potential conflict needs to be resolved in future biological opinions.

Prospect Island is being purchased by the Federal Government to be enhanced for fish and wildlife habitat. Prospect Island will include shallow-water habitat specifically designed to enhance delta smelt and Sacramento splittail populations. If this project is successful, it will result in an increased population of delta smelt and Sacramento splittail in the North Bay Aqueduct area.

A recently created "flooded island" area at the junction of Cache and Shag sloughs is even closer than Prospect Island to the North Bay Aqueduct intake. Water Resources is monitoring this area, which may be affecting delta smelt populations near the intake.

Splittail

Egg and larval monitoring in Barker Slough indicates that relatively few splittail are entrained in the North Bay Aqueduct. Assessment of long-term impacts on splittail requires additional monitoring.

Egg and larval monitoring for Sacramento splittail in Barker Slough began in 1993. Data prior to that did not separate splittail from other cyprinid species. In 1993, a total of seven splittail were caught in Barker and Lindsey sloughs. Data for 1994 are not yet available.

There have been no splittail entrainment studies at the North Bay Aqueduct, so entrainment can only be estimated. Effectiveness of the NBA fish screens at preventing entrainment of splittail juveniles and adults is unknown. Calculated density of larval splittail in Barker and Lindsey sloughs is about the same as for delta smelt. However, the sampling history is much shorter, leaving some question about seasonal and year-to-year variability in the data.

Contra Costa Canal

Simulated future exports for Contra Costa Canal are presented in Figure 134. Specific impacts for delta smelt and Sacramento splittail are described below. Incidental take of the two species in Contra Costa Canal is covered under the September 9, 1993, biological opinion.

Delta Smelt

Based on salvage results from Skinner and Tracy fish facilities, delta smelt are expected to be more vulnerable to Delta diversions during drought years, when their distribution shifts closer to the diversion. Entrainment data for Contra Costa Canal are limited to egg and larval monitoring in 1992 to 1994.

A transport modeling simulation for the proposed Los Vaqueros Project based on specific hydrology, smelt abundance, and distribution suggests losses could occur (Jones and Stokes 1992). The degree to which model results represent the variability in smelt abundance and distribution under actual conditions is not known. The model assumed larval and juvenile smelt to be distributed and entrained in proportion to the net water movement in Delta channels. Larvae were assumed to be present in February through June. Losses estimated by the simulation are probably greater than would actually occur because peak occurrence of larvae may be more restricted than is assumed in that analysis.

As an example of possible differences, the model assumed uniform density of smelt at the intake, but smelt usually show a patchy distribution. Impacts of entrainment could be over- or under-estimated, depending on actual smelt densities at the intake.

Splittail

As for delta smelt, entrainment data are limited to egg and larval monitoring in 1992 to 1994. These results indicate that entrainment was higher in 1993, a wet year, than either of the two dry years sampled. This is consistent with salvage trends at Skinner and Tracy fish facilities: favorable environmental conditions in wet years lead to increased abundance and a proportional increase in entrainment. If the same mechanism applies to Contra Costa Canal, the variation in export levels is not likely to have a net effect on splittail populations.

Suisun Marsh Salinity Control Facilities

Delta Smelt

Monitoring indicates the Suisun Marsh Salinity Control Gates have had minimal adverse impacts on delta smelt, and there is no evidence that continued operation of the gates would create additional impacts.

The Roaring River Diversion does entrain delta smelt, although addition of a fish screen appears to have significantly reduced those impacts. Entrainment is expected to continue at low levels when delta smelt are present in Suisun Marsh. However, delta smelt have become increasingly rare in the marsh since 1981, so entrainment may be infrequent until the population recovers.

Splittail

Monitoring indicates no detectable change in the level of adult splittail since construction of the gates. Therefore, there is no evidence that continued operation of the gates would create additional impacts.

Delta Outflow

Average total Delta outflow from the simulation is presented in Figures 131 and 136 for each water year type. Figures 135, 139, and 140 show predicted average monthly position of X2 (an indicator of entrapment zone location). In general, increased outflow and downstream movement of X2 are expected to result from the NMFS criteria, especially in February-April. Impacts of project-related flow changes on direct loss are described earlier in this chapter. Altered flow patterns in the estuary could have other impacts on delta smelt and splittail, including changes in entrainment rates at agricultural or industrial diversions.

Delta Smelt

Upstream reservoir storage and project exports reduce outflow in winter and spring, contributing to an incremental upstream shift in delta smelt distribution. However, these impacts are somewhat mitigated by NMFS criteria, which result in higher outflow levels than would occur under Decision 1485 alone. Also, releases from CVP and SWP reservoirs maintain summer and fall outflow higher than it would be without the projects.

Particle tracking studies suggest entrainment by agricultural diversions may be high if delta smelt are forced to move into the interior Delta. Changes in outflow could also move delta smelt populations closer to or farther from the influences of PG&E diversions near the confluence of the Sacramento and San Joaquin rivers. Changes in outflow due to project operation could also alter delta smelt losses at agricultural diversions. The net effect of outflow changes on losses from entrainment and impingement at PG&E facilities would be either beneficial or detrimental, depending on the water year.

Project-related changes in outflow may also affect the position of the entrapment zone. Exact impacts to delta smelt are difficult to specify because of statistical limitations in the relationships developed for delta smelt. At present, these relationships account for less than 25% of the variability in delta smelt abundance. The incremental value of specific levels of outflow (and X2 position) cannot yet be accurately identified. Nonetheless, delta smelt abundance is generally reduced whenever X2 is located upstream of Chipps Island. Abundance is highly variable when X2 is downstream of this point, but increases in at least some of the years. Therefore, it appears that project-related changes to entrapment zone position could reduce *long-term* average delta smelt abundance. Modeling studies indicate that these impacts are mitigated in part by NMFS criteria, which generally result in the entrapment zone being farther downstream in February-April than under Decision 1485 alone. X2 position is fairly similar for the rest of the spring and summer.

Splittail

The significant relationship between abundance and outflow suggests that project-related changes in outflow could affect splittail recruitment. However, there is some evidence that strong recruitment also depends on uncontrolled outflow events that inundate floodplain spawning and rearing habitat. Because diversions generally have little effect on the occurrence of these events, the appearance of strong year classes may be largely independent of project operations.

Similar relationships were found between abundance and X2 or specific conductance position, yet there is some concern that this may be due to covariation with other factors such as outflow or floodplain inundation. The range of splittail extends far beyond the entrapment zone: from the tributaries of the upper Sacramento River in the north to the lower Tuolumne River in the south. Moreover, monitoring indicates that abundance of adult splittail has remained stable in its lower range, where salinity should have the greatest effect. The major exception to this is Suisun Marsh, where abundance has remained relatively low since 1981. Moreover, abundance of young-of-the-year splittail appears to have decreased in this region during the 6-year drought. If X2 position is indeed an important factor regulating splittail recruitment, the outflow levels shown for NMFS operations would have lower impacts to splittail than operating under Decision 1485 alone.

Reverse Flow

Results from the model PROSIM, summarized in Figure 136, indicate QWEST is generally positive in wet years, but net reverse flows are more frequent in August and September. In other water year types, net reverse flows are frequently strongest from July to September and range from -2000 to +2000 cfs the rest of the year. The general trend is that QWEST levels are higher under Decision 1485 and NMFS than under Decision 1485 alone during October-April. In other months, Decision 1485 and NMFS QWEST levels are usually similar to or lower than under Decision 1485 alone. The export facilities contribute to net reverse flows that would not occur without SWP and CVP pumping in the Delta.

Delta Smelt

Although there has been some concern that net reverse flow may be detrimental to delta smelt (Moyle *et al* 1992), no association has been found between QWEST and abundance indices. Moreover, modeling studies show that particles, and presumably young fish, in areas west of Antioch are only slightly affected by net reverse flows (QWEST = -2000 cfs). Model results also suggest QWEST is a poor indicator of entrainment of particles at SWP, CVP, and agricultural diversions because entrainment occurs in the interior delta even at high positive QWEST values. While these results should be interpreted with caution because smelt do not behave like neutrally-buoyant particles, they at least indicate the major processes. Therefore, the QWEST levels are not expected to create impacts in addition to those identified for Delta outflow.

Splittail

The inverse relationship between abundance and the number of days of reverse flow (QWEST) during spawning season indicates that this factor could affect the splittail population. It is more likely, however, that the relationship is a result of covariation with either outflow or floodplain inundation. Moreover, no similar relationship was found between juvenile or adult salvage and QWEST. If reverse flow is, in fact, an important parameter, the QWEST levels shown under NMFS criteria would have benefits to splittail compared to Decision 1485.

Delta Cross Channel Gates

Under the NMFS criteria, the Delta Cross Channel gates would be closed in February through April. Possible effects are discussed below.

Delta Smelt

Closing the Delta Cross Channel gates from February 1 to April 30 could create a barrier to some adult delta smelt migrating upstream to spawn. It is not known whether the Cross Channel, with the radial gates closed, would provide acceptable spawning habitat similar to a dead-end slough (Radtke 1966) or whether operation would interfere with spawning success by delaying migration.

Operation of the Delta Cross Channel changes flow patterns and may result in increased or decreased vulnerability of larval delta smelt to entrainment by CVP, SWP, agricultural, and industrial diversions. Modeling studies using tracers suggest closing the Cross Channel could reduce entrainment and subsequent loss of larval fish spawned in the Sacramento River but adversely impact fish spawned in the lower San Joaquin River system. Given these conflicting results and uncertainties about the degree to which tracers simulate larvae, the overall impact of Delta Cross Channel operation is not known. Impacts are likely related to annual distribution of spawning between the two river systems.

Splittail

Closure of the Delta Cross Channel in winter and spring could create a barrier for adult splittail on their spawning migration. Although operation of the gates could also affect entrainment rates of young splittail, the overall impacts may be minor because losses at diversions do not have a detectable effect on abundance.

Chapter 11

CUMULATIVE EFFECTS

Cumulative effects are those impacts resulting from future State and other non-Federal actions that are not subject to consultation requirements established in Section 10 of the Endangered Species Act. These actions may affect listed species occurring or reasonably certain to occur in the action area. Future Federal actions are subject to the consultation requirements established in Section 7 of the Endangered Species Act and, therefore, are not considered cumulative to the proposed action. The cumulative effects mentioned below have been discussed in preceding chapters and are summarized here.

Cumulative effects on delta smelt and splittail include any diversion of water that may entrain adults or larvae or that decrease outflows incrementally and cause a shift in the preferred habitat to less than optimal areas. Another component of decreased outflows is salt water intrusion, which may allow competing organisms, such as the Asian clam, to extend their ranges and increase their populations. These organisms compete with delta smelt for food. Numerous water diversions for agriculture, duck clubs, power plants, and municipal/ industrial uses upstream of the Delta, in the Delta, and in Suisun Bay contribute to these cumulative effects.

Other cumulative effects are predation, limited food, disease, and parasites. Cumulative effects can also include chemical contamination from point and non-point discharges that may adversely affect survival rates and reproductive success. Pesticides, herbicides, and selenium have all been suggested as potential sources of delta smelt mortality.

Although these cumulative effects operate together with the effects of the proposed action to influence the status of delta smelt and splittail, the relative importance of these factors to delta smelt and splittail abundance is not clear. Any program or proposal to reduce the threat of jeopardy or to help recover populations of the two species may need to address all these factors to assure effectiveness.

Chapter 12

ANALYSIS OF 1994 REASONABLE AND PRUDENT ALTERNATIVES

The 1994 delta smelt summer townet index of 13.0 is near the average for the period of record and the highest index observed since 1980. For a dry year, the smelt were fairly widely distributed with specimens collected from Grizzly and Honker Bays, in Suisun Bay near Carquinez Strait, and in the lower Sacramento River. The reasonable and prudent alternatives and the take provisions, in conjunction with the NMFS requirements for winter–run Chinook may have contributed to better survival of larval and juvenile smelt, as evidenced by the moderate tow–net index. Whether these actions result in an increased adult abundance index and adequate adult distribution remains to be seen.

Fish and Wildlife Service minimum criteria for transporting delta smelt downstream in a critical water year were exceeded in 1994 due in part to a brief wet period in February and in part to the NMFS February 12, 1993, biological opinion criteria for protection of winter–run Chinook salmon. Delta outflow exceeded 12,000 cfs for 34 days during February and March; the critical year requirement was 18 days between February 1 and June 30. The X2 isohaline was located downstream of Collinsville on April 1, and thereafter Delta outflow exceeded 6,800 cfs for 43 days between April 1 and May 19; critical year requirement was 40 days between April 1 and June 30. However, delta smelt did not migrate west until June, after outflow had dropped to about 4,000 cfs. Therefore, while RPA No. 1 may have moved some smelt out of the Delta during the February through May period and the 6,800 cfs flows may have been helpful in maintaining the smelt in a downstream location, monitoring indicates the majority of the fish migrated in June and were probably responding to some cue other than flow. This illustrates the limited extent of our knowledge of delta smelt biology.

There are some questions about the potential effects on Delta hydrodynamics if the Delta Cross Channel gates are closed during the February through April transport period. The gates were closed from January 7 to May 26 for protection of winter–run salmon. Gate closure may inhibit interior Delta circulation promoting a "bathtub" effect which may have been one reason delta smelt did not migrate during the latter part of this period. This and similar questions will be addressed during simulations using the DWR particle tracking model. Modeling scenarios are being developed and preliminary results should be available in fall 1994.

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Appendix A
RECOMMENDATIONS FOR FUTURE STUDIES

Possible Future Studies on Delta Smelt

BASIC BIOLOGY

ABUNDANCE AND DISTRIBUTION TRENDS

- Continue Kodiak trawl surveys to provide information about abundance and distribution trends.
- Perform analysis of percent of index in Suisun Bay versus outflow using most recent data.
- Examine abundance trends using tow-net surveys 1 and 2 as replicates.

FACTORS AFFECTING ABUNDANCE AND DISTRIBUTION

Outflow/Entrapment Zone

- Reexamine DFG's regression analysis to determine if outflow (cfs) is related to abundance. The recent wet year may make the relationship significant.

Reverse Flow

- Additional transport modeling studies based on 1994 distribution.
- Analysis of the effect of possible vertical migration of smelt larvae on transport.

CVP Diversion and Entrainment

Tracy Pumping Plant

- Examine salvage versus outflow relationship.
- Update analysis of entrainment indices using 1994 data.
- Studies to develop screen, trucking, and handling criteria.

Delta Cross Channel/Georgiana Slough

- Analyze acoustical barrier data for Georgiana Slough.

SWP Diversion and Entrainment

Banks Pumping Plant

- Update salvage versus outflow relationship using data after 1991.
- Update analysis of entrainment indices using 1994 data.
- Multiple regression for change in midwater trawl index versus salvage and spring outflow or X2 days in Suisun Bay.
- Studies to develop screen, trucking, and handling criteria.

PG&E Entrainment

- Summarize contents of Habitat Conservation Plan.

Agricultural Diversions

- Continue reports from ongoing studies.

Predation and Competition

- Update abundance trends for yellowfin goby, chameleon goby, inland silverside, and perhaps others.
- Include Bill Bennett's most recent studies on silverside.

Food Abundance

- Update analysis by using most recent data on food resources.

Water Quality

- Studies to examine the hypothesis that water transparency affects abundance.
- Update analysis of Suisun Marsh catch of delta smelt versus average monthly salinity.

Contaminants

- Use histology to determine if there is evidence of toxic effects.

Disease and Parasites

- Report results of studies on Mycobacterium from UC-Davis.

Interbreeding with Wakasagi

- Continue to describe occurrence in delta and possible effects on smelt.

Possible Future Studies on Sacramento Splittail

BASIC BIOLOGY

Reproduction

- Determine how fecundity varies by size and age.

Survival

- Tagging studies to estimate annual survival of different age and sex groups.

ABUNDANCE AND DISTRIBUTION TRENDS

- Perform gill-net surveys to document the distribution and relative abundance of juvenile and adult splittail in Suisun Marsh, Suisun Bay, the Delta, and the lower Sacramento and San Joaquin rivers.
- Use gill-net data to determine if juvenile splittail reside in the Sacramento and San Joaquin rivers in summer.
- Use gill-net data to compare habitat use of juvenile and adult splittail.
- Scale and otolith studies to examine the age composition of the splittail population.
- Anchor tag studies to gather information on population movements.
- Use gill-net data to determine if relationships can be developed between adult abundance and midwater or otter trawl catch.
- Continue developing an annual YOY abundance index using FWS beach seine data.
- Examine data from DFG fyke-net electrofishing, and creel census studies.

FACTORS AFFECTING ABUNDANCE AND DISTRIBUTION

Outflow/Entrapment Zone

- Use results of gill-net studies to determine importance of entrapment zone.
- Determine feasibility of reconfiguring Yolo and Sutter bypasses to provide splittail habitat.
- Use abundance data from surveys other than midwater trawl and tow-net data to examine relationship with outflow.

Reverse Flow

- Use abundance data from surveys other than midwater trawl and tow-net data to examine relationship with reverse flow.

CVP Diversion and Entrainment

Tracy Pumping Plant

- Conduct studies to develop screen, trucking, and handling criteria.

Delta Cross Channel/Georgiana Slough

- Analyze acoustical barrier data for Georgiana Slough.

SWP Diversion and Entrainment

Banks Pumping Plant

- Update salvage versus outflow relationship using data after 1991.
- Update analysis of entrainment indices using 1994 data.
- Multiple regression of salvage levels versus outflow and exports.
- Studies to develop screen, trucking, and handling criteria.

PG&E Entrainment

- Summarize contents of Habitat Conservation Plan.

Agricultural Diversions

- Continue reports from ongoing studies.

Predation and Competition

- Update abundance trends for yellowfin goby, chameleon goby, inland silverside, and perhaps others.

Water Quality

- Determine salinity tolerance of YOY and adult splittail (UC-Davis).
- Use abundance data from surveys other than the midwater trawl to examine relationship with water quality.

Contaminants

- Use histology to determine if there is evidence of toxic effects.
- Determine if there is a statistical relationship between herbicide use and abundance.

Disease and Parasites

- Perform surveys to describe diseases of splittail.

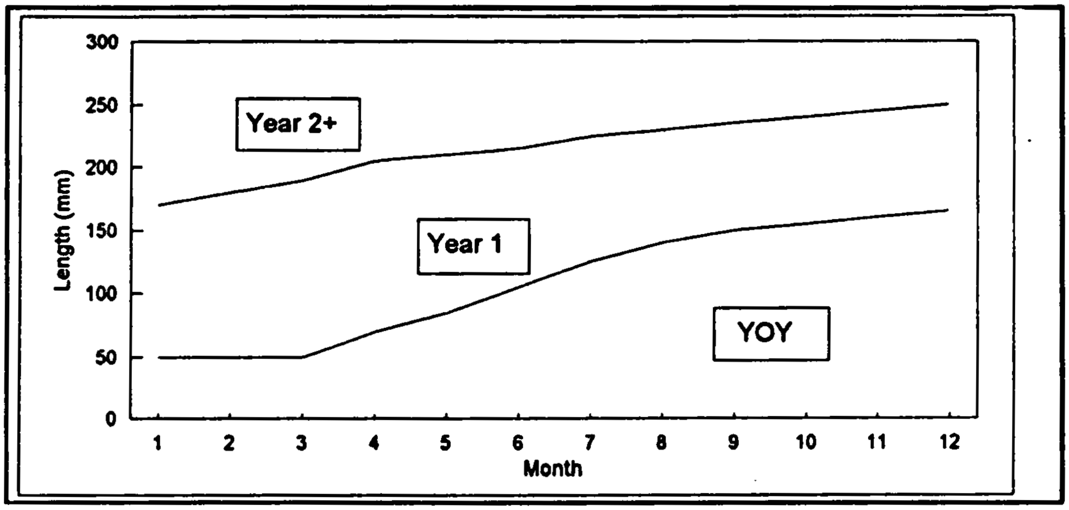
Recreational Harvest

- Determine extent of present fishery.

Appendix B

PRELIMINARY LENGTH CRITERIA USED TO SEPARATE YEAR CLASSES OF SACRAMENTO SPLITTAIL

State Water Project / Central Valley Project

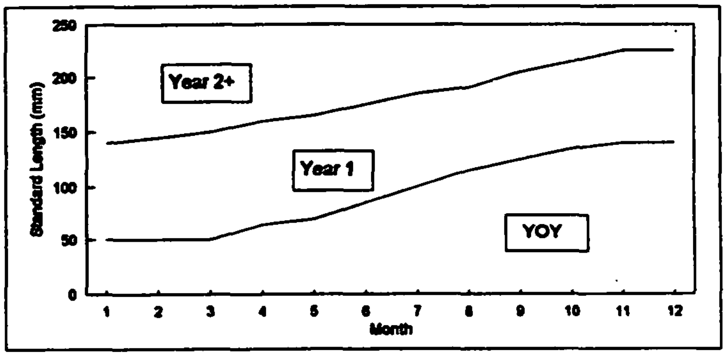


PRELIMINARY LENGTH CRITERIA USED TO SEPARATE YEAR CLASSES OF SPLITTAIL

AGE CLASS	SIZE RANGE	MONTH 1	2	3	4	5	6	7	8	9	10	11	12
YOY	MINIMUM	0	0	0	0	0	0	0	0	0	0	0	0
	MAXIMUM	50	50	50	70	85	105	125	140	150	155	160	165
YEAR 1	MINIMUM	51	51	51	71	86	106	126	141	151	156	161	166
	MAXIMUM	170	180	190	205	210	215	225	230	235	240	245	250
YEAR 2+	MINIMUM	171	181	191	206	211	216	226	231	236	241	246	251
	MAXIMUM	?	?	?	?	?	?	?	?	?	?	?	?

SPLITTAIL LENGTH
(millimeters)

Suisun Marsh



PRELIMINARY LENGTH CRITERIA USED TO SEPARATE YEAR CLASSES OF SPLITTAIL

AGE CLASS	SIZE RANGE	MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
YOY	MINIMUM	0	0	0	0	0	0	0	0	0	0	0	0
	MAXIMUM	50	50	50	65	70	85	100	115	125	135	140	140
YEAR 1	MINIMUM	51	51	51	66	71	86	101	116	126	136	141	141
	MAXIMUM	140	145	150	160	165	175	185	190	205	215	225	225
YEAR 2+	MINIMUM	171	146	151	161	166	176	186	191	236	216	226	226
	MAXIMUM	?	?	?	?	?	?	?	?	?	?	?	?

SPLITTAIL LENGTH

(millimeters)

SIZE RANGE		MONTH											
MIN	MAX	1	2	3	4	5	6	7	8	9	10	11	12
0	20					22	41	1					
20	25				8	30	37	3	1				
25	30				36	130	49	9	3	2			
30	35				60	241	49	6	2	2			
35	40				49	383	113	7	2				
40	45				6	494	165	4	2				
45	50				2	342	206	17	4				
50	55			2	1	172	223	20	3	1			
55	60	1			1	70	186	25	4	3			1
60	65		1	1		18	134	28	6	1			
65	70					6	67	33	7	1			
70	75						61	14	7			YOY	
75	80	YEAR 1			1	1	20	18	7				
80	85			1			11	17	14	1			
85	90			2			16	21	23	3			1
90	95		3	4	1	1	3	14	17	1			1
95	100		3	6			3	16	36	4			
100	105		4	4	2			7	31	3			
105	110	2	5	2	2	1		8	43	2	1		
110	115	1	2	3	2			1	23	8	1		1
115	120		4	4				5	17	6			1
120	125	4	6	8	1	1		3	16	2		1	
125	130	1	12	5	3	1		3	10	2			1
130	135	1	9	9	7	1		3	3	4	1		1
135	140		6	16	3		1			1	1		1
140	145	1	6	19	5	2		1		2			
145	150	2	3	12	8	2		3	2		1		
150	155	2	7	18	8				1	1			
155	160	1	3	14	4	1	1		1				
160	165	1	3	22	7	2		3					
165	170		6	14	4	3	1	5			1		
170	175	2	4	12	4	4	2	4	1	1			
175	180	2	3	9	5	3	2	4	3				
180	185		5	5	3	2	2	3	2	1	1		
185	190	3	5	3	5	4	2	5	8		2		
190	195	2	5	4	5	4	2	6	6		1		
195	200	7	8	4	4	3	3	2	4	2		1	
200	205	6	12	5	2	3	3	7	6	1		2	
205	210	4	7	9	4	4		7	3				1
210	215	6	10	7	5	2		8	7		1		1
215	220	6	16	8	6	2	2	4	3	1			
220	225	6	26	7	13	5	1	4	6				
225	230	18	31	9	6	5	1				1		
230	235	18	33	17	11	8	1	2	2				
235	240	28	52	14	19	7	1	6	4	1			1
240	245	31	51	16	19	4	2	1	2				
245	250	36	56	18	22	7	1	2	3				1
250	255	43	55	8	23	7		4	1	2	1		1
255	260	49	48	13	25	5	3	1	3				
260	265	50	45	17	26	2		3	1	1			
265	270	28	42	18	12	5	1	3	1	2			
270	275	36	38	20	25			2	2			1	
275	280	19	18	25	24			3					2
280	285	23	16	30	23	2		2	2				
285	290	11	23	29	29	2		3	2				2
290	295	9	15	35	44	2							
295	300	10	22	29	48	4		2	2			YEAR 2+	
300	305	8	31	27	33	1			2				
305	310	5	17	24	31	2		2					1
310	315	8	23	24	18	3		3		1			
315	320	7	10	25	23	6							1
320	325	10	15	16	24	2			1				1
325	330	10	11	24	23	2		2					1
330	335	11	13	18	28	2							
335	340	9	11	19	32	3							2
340	345	18	10	18	25	2	1						1
345	350	10	13	18	33	4	1		1			1	3
350	355	9	6	8	25	1	1						
355	360	5	7	9	20			1					1
360	365	10	5	13	13	3							
365	370	5	6	9	8	1		1		1		1	
370	375	1	10	6	14	5		1				1	1
375	380	3	8	6	7								
380	385	4	5	3	10								
385	390	3	8	5	7	3							
390	395	1	4	6	7								
395	400	3	3	2	1	1							
400	400	3	2	11	14	1	1	4	2				1

SPLITTAIL LENGTH FREQUENCY AT THE STATE WATER PROJECT, 1979-1991

		MONTH											
Length Range		1	2	3	4	5	6	7	8	9	10	11	12
20	25					5	2						
25	30				9	12	15						
30	35				2	21	11	1					
35	40					14	22	2					
40	45					11	12	2					
45	50					4	14	3					
50	55						13	6		1			
55	60						6	6	1	2			
60	65						12	7	1				
65	70						6	6	3	1	1		
70	75						4	13	4	2			
75	80						2	4	3	1			
80	85							7	8	4			
85	90							4	12	3			
90	95							2	11	6	5		
95	100	1			1			1	8	2	5	1	1
100	105	1			2				6	7	6	1	1
105	110				2		1		3	7	4	1	1
110	115	2		2	2					4	6	1	
115	120	1		4	3	1				1	3		
120	125			1	4	1				1	1	1	
125	130				4						3		
130	135	1			3	2	2					2	3
135	140	1	1		2	1	1		1				
140	145			1	1	1	3					1	
145	150			2	1	2	1	1					
150	155			1				3					2
155	160			1		1	2	1					
160	165						1		1	1			
165	170										1		
170	175							2		1		1	
175	180							1		6			
180	185			1			1	1	1	4			
185	190							1	1	4	1		
190	195	1	1	1				1	2	4	1		2
195	200	1		2					3	2			
200	205	2				1				7		3	
205	210	1					1		1	1	1	1	
210	215	4	1	1		1	1	1		3		2	
215	220	2	1		2	2	1	1	1	2	2		1
220	225	1		3			4		3	1	1	1	
225	230		1	1		2	1	2	1				
230	235	1	1	1		1	1	1	3				
235	240	2					2	3		2	1		1
240	245	1						1	1	1	2	1	
245	250	1						1	2	1	5	1	
250	255							3		1	1		
255	260		1			1	1	2	2	6		1	
260	265				2		1		1	3	1		
265	270	1	1		1	2	1	1	2	2			1
270	275					2	1	2	1	3		1	1
275	280	1						2					
280	285	1						1	1	1	1		
285	290	1				2	1			2	1		

SPLITTAIL LENGTH FREQUENCY DISTRIBUTION, 1980-1990, ALL GEAR TYPES,
DELTA OUTFLOW / SAN FRANCISCO BAY STUDY

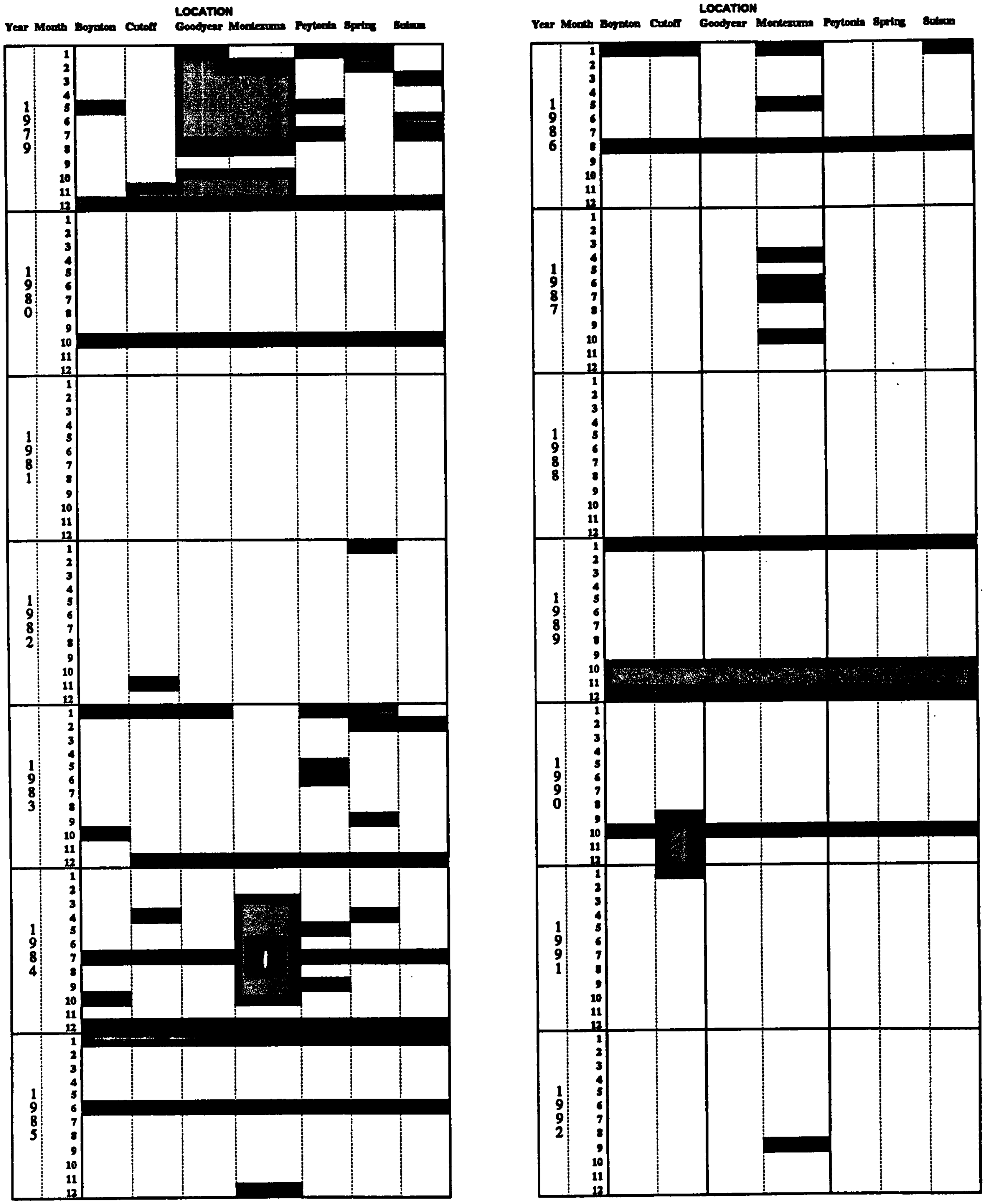
STANDARD LENGTH (mm)		MONTH											
MIN	MAX	1	2	3	4	5	6	7	8	9	10	11	12
0	20												
20	25		3		3	9	12	1			YOY		
25	30		1		3	11	24						
30	35					12	32	3					
35	40					25	35	14	1				
40	45					9	40	24	1				
45	50					8	63	70	1				
50	55				1		90	76	14	3			
55	60	1	YEAR 1				74	99	27	3	2		1
60	65	1	1				43	116	33	21	4	5	1
65	70	1	8	1			9	125	39	51	15	8	3
70	75	10	18	6	2		2	107	49	74	37	13	5
75	80	18	25	6	3	2		93	57	78	44	15	18
80	85	29	36	10	7	1		45	64	77	36	24	34
85	90	33	41	17	17	3	1	23	50	49	27	27	35
90	95	49	67	22	24	4	2	4	42	52	17	25	47
95	100	67	68	39	38	20	1	1	38	31	21	25	56
100	105	62	69	43	62	14	2	2	21	47	17	28	47
105	110	70	84	78	71	28	5	3	4	26	28	25	48
110	115	90	80	71	153	39	9	6	2	14	21	22	44
115	120	51	60	88	239	63	14	6	5	2	9	13	26
120	125	27	25	62	222	94	32	8	4	4	3	13	9
125	130	12	12	37	239	117	32	6	10	4	2	4	11
130	135	6	7	22	165	145	47	18	7	3	1	3	3
135	140	4	4	6	106	130	59	14	10	4	1	3	2
140	145	3	3	3	46	82	97	35	10	4	6	1	5
145	150	5	8	3	20	73	80	53	13	3	2	3	3
150	155	6	15	5	10	39	83	74	30	20	8	4	7
155	160	17	11	4	9	17	60	84	52	32	6	9	10
160	165	24	17	4	13	6	29	91	64	33	9	15	14
165	170	30	16	17	11	11	24	83	72	39	7	17	21
170	175	38	30	21	24	9	8	50	65	46	23	24	20
175	180	40	36	23	24	13	6	30	45	34	11	26	17
180	185	36	20	28	37	13	13	14	29	36	13	25	20
185	190	40	21	28	46	17	15	15	10	18	4	26	16
190	195	29	18	27	40	31	27	10	17	14	4	10	9
195	200	15	12	21	39	35	18	21	16	10	2	6	11
200	205	11	6	13	21	40	28	26	17	9	3	4	8
205	210	7	7	11	23	32	22	15	28	10	1	8	7
210	215	9	3	3	19	18	17	26	28	12	2	6	6
215	220	8	5	3	10	22	15	23	22	10	1	6	9
220	225	7	2	1	12	9	14	16	24	10		3	4
225	230	8	3	5	5	4	6	11	14	18	1	4	5
230	235	8	8	1	2	5	4	10	10	9		4	7
235	240	8	3	1	3	6	6	9	3	9	1	1	6
240	245	2	1		6	2	6	6	9	3	1	2	3
245	250	3	4	3	2	3	6	6	5	3		3	4
250	255	4	2	2	1		3	6	7	3	2	1	4
255	260	5	4	2	4	1	3	4	3	2	1	3	1
260	265	1	1	3	2	2	2	2	4	2	2	4	6
265	270	3	5		3	3	1	5	1	3		3	6
270	275	2	2		YEAR 2+		2	2	2	3	2		10
275	280	5	4	2	5	1	2		1	1		2	3
280	285	1	1		2	4	2			1	3	2	4
285	290	3	4		4	1	1		1	1		2	6
290	295		3	4	1	1	1		4	1		3	2
295	300	1	3	1	1								
300	305	1	1			2	2	1	1			2	
305	310						1		1		1		1
310	315	1		1	1		1	1	2		1		
315	320	1	1			1		1		1		1	
320	325		1			1					1	2	1
325	330		1		1	1					1	1	1
330	335	1							1	1			
335	340												
340	345								1				1
345	350			1									
350	355												
355	360		1										
360	365												
365	370												
370	375												
375	380												
380	385												
385	390												
390	395												
395	400												
400	405												

SPLITTAIL LENGTH FREQUENCY FOR THE SUISUN MARSH SURVEY
1979-1992

Appendix C

MONTHLY DATA GAPS IN THE SUISUN MARSH SURVEY

MONTHLY DATA GAPS IN THE SUISUN MARSH DATABASE.



SCIENTIFIC NAMES OF FISH

American eel	*Anguilla rostrata*
American shad	*Alosa sapidissima*
bay goby	*Lepidogobius lepidus*
bigscale logperch	*Percina macrolepida*
black bullhead	*Ameiurus melas*
black crappie	*Pomoxis nigromaculatus*
blue catfish	*Ictalurus furcatus*
bluegill	*Lepomis macrochirus*
brown bullhead	*Ameiurus nebulosus*
brown trout	*Salmo trutta*
California halibut	*Paralichthys californicus*
California roach	*Hesperoleucus symmertricus*
chameleon goby	*Tridentiger trigonocephalus*
channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
common carp	*Cyprinus carpio*
delta smelt	*Hypomesus transpacificus*
English sole	*Pleuronectes vetulus*
fathead minnow	*Pimephales promelas*
golden shiner	*Notemigonus crysoleucas*
goldfish	*Carassius auratus*
green sturgeon	*Acipenser medirostris*
green sunfish	*Lepomis cyanellus*
hardhead	*Mylopharodon conocephalus*
hitch	*Lavinia exilicauda*
inland silverside	*Menidia beryllina*
jacksmelt	*Atherinopsis californiensis*
largemouth bass	*Micropterus salmoides*
longfin smelt	*Spirinchus thaleichthys*
mosquitofish	*Gambusia affinis*
northern anchovy	*Engraulis mordax*
Pacific herring	*Clupea pallasii*
Pacific lamprey	*Lampetra tridentata*
pink salmon	*Oncorhynchus gorbuscha*
plainfin midshipman	*Porichthys notatus*
prickly sculpin	*Cottus asper*
pumpkin seed	*Lepomis gibbosus*
rainwater killifish	*Lucania parva*
redear sunfish	*Lepomis microlophus*
red shiner	*Cyprinella lutrensis*
riffle sculpin	*Cottus gulosus*
river lamprey	*Lampetra ayresii*
Sacramento blackfish	*Orthodon microlepidotus*
Sacramento perch	*Archoplites interruptus*
Sacramento splittail	*Pogonichthys macrolepidotus*
Sacramento squawfish	*Ptychocheilus grandis*
Sacramento sucker	*Catostomus occidentalis*
shiner surfperch	*Cymatogaster aggregata*
silver salmon	*Oncorhynchus kisutch*
smallmouth bass	*Micropterus dolomieu*
speckled dace	*Rhinichthys osculus*
speckled sanddab	*Citharichthys stigmaeus*
splittail	*Pogonichthys macrolepidotus*
staghorn sculpin	*Leptocottus armatus*
starry flounder	*Platichthys stellatus*
steelhead trout	*Oncorhynchus mykiss*
striped bass	*Morone saxatilis*
striped mullet	*Mugil cephalus*
surf smelt	*Hypomesus pretiosus*
threadfin shad	*Dorosoma petenense*
threespine stickleback	*Gasterosteus aculaetus*
tui chub	*Gila bicolor*
tule perch	*Hysterocarpus traski*
wakasagi	*Hypomesus nipponensis*
warmouth	*Lepomis gulosus*
white catfish	*Ameiurus catus*
white crappie	*Pomoxis annularis*
white croaker	*Genyonemus lineatus*
white sturgeon	*Acipenser transmontanus*
yellow bullhead	*Ameiurus natalis*
yellow perch	*Perca flavescens*
yellowfin goby	*Acanthogobius flavimanus*

COMMON ABBREVIATIONS AND METRIC CONVERSIONS

Area

km^2	square kilometers; to convert to square miles, multiply by 0.3861
m^2	square meters; to convert to square feet, multiply by 10.764

Length

cm	centimeters; to convert to inches, multiply by 0.3937
FL	fork length; length from the most anterior part of a fish to the median caudal fin rays (fork in the tail)
km	kilometers; to convert to miles, multiply by 0.62139
m	meters; to convert to feet, multiply by 3.2808
mm	millimeters; to convert to inches, multiply by 0.03937
SL	standard length; tip of upper jaw of a fish to crease formed when tail is bent sharply upward
TL	total length; length from the most anterior part of a fish to the end of the tail

Volume

AF	acre-foot; equal to 43,560 cubic feet
L	liters; to convert to quarts, multiply by 1.05668; to convert to gallons, multiply by 0.26417
MAF	million acre-feet
mL	milliliters
TAF	thousand acre-feet

Flow

cfs	cubic feet per second; to convert to acre-feet per day, multiply by 1.98
gpm	gallons per minute
mgd	million gallons per day

Velocity

fps	feet per second
m/s	meters per second; to convert to feet per second, multiply by 3.2808

Mass

kg	kilograms; to convert to pounds, multiply by 2.2046

Concentration

mg/L	milligrams per liter; equals parts per million (ppm)
µg/L	micrograms per liter; equals parts per billion (ppb)

Specific Conductance

µS	microsiemens; equivalent to micromhos
µS/cm	microsiemens per centimeter

Temperature

°C	degrees Celsius; to convert to °F, multiply by 1.8 then add 32 degrees
°F	degrees Fahrenheit; to convert to °C, subtract 32 degrees then divide by 1.8

Mathematics and Statistics

df	degrees of freedom
e	base of natural logarithm
E	expected value
log	logarithm
N	sample size
NS	not significant
%	percent
‰	per thousand
P	probability
r	correlation or regression coefficient (simple)
R	correlation or regression coefficient (multiple)
SD	standard deviation
SE	standard error
V	variance

Government

COE	U.S. Army Corps of Engineers
DFG	California Department of Fish and Game
DWR	California Department of Water Resources
EPA	U.S. Environmental Protection Agency
FWS	U.S. Fish and Wildlife Service
NMFS	National Marine Fisheries Service
SWRCB	California State Water Resources Control Board
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey

General

CPUE	catch per unit effort
YOY	young of the year