BAY/DELTA FISH RESOURCES

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Department of Water Resources
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During Phase I of its proceedings in 1986, the State Water Resources Control Board received information on what was known about the status of and factors affecting biological resources in the San Francisco Bay and Sacramento-San Joaquin Delta. A substantial amount of additional information gathered and analyzed over the last 6 years provides a better understanding of the condition of these resources and the degree to which they are affected by various factors.

We know Bay/Delta fish resources have changed dramatically over the last few decades. Abundances of striped bass, naturally spawning salmon, Delta smelt, and some other species have been lower in recent years than they were 20 or 30 years ago. Populations of at least some of these species appear to have been on the increase over the last year or two. For example, in 1991 the Department of Fish and Game estimated the striped bass population to be over one million adults — the largest population since 1976. Between 1988 and 1991, the adult abundance index for Delta smelt progressively increased from the lowest value recorded since measurements began in 1967 to the eighth highest.

The abundance and kinds of food organisms available for Bay/Delta fish have also changed. Some species introduced over the last few years appear to be significantly altering the food chain in some parts of the estuary.

It is clear that State Water Project operations adversely affect some of these resources. The Department of Water Resources has been working with the fish and wildlife agencies to better identify and quantify the adverse effects and, to the extent feasible, avoid them or reduce their severity. We are also attempting to offset adverse effects we cannot avoid.

It is also clear that factors other than the State Water Project affect the Delta's biological resources in a number of complex ways. These factors include:

- Long- and short-term changes in climatic conditions;
- Other water storage operations and diversions, both in and upstream of the Delta;
- Pollutants in municipal, industrial, and agricultural waste water discharges;
- Introductions of new species;

- Quantity and quality of habitat for anadromous fish in upstream tributaries; and
- Legal and illegal fishing.

All these factors affect fish habitat in the Delta, the number of anadromous fish entering the Delta to use that habitat, or both. The Department of Water Resources is attempting to reduce adverse effects of some of these other factors to offset effects of the State Water Project.

The relative degree to which State Water Project operations and other factors affect population abundance of individual species and the Delta's biological resources overall is not clear. How these factors will interact in the future is even more uncertain.

This presentation is divided into four sections. The first describes effects of the State Water Project on Bay/Delta fish and other biological resources of particular concern. It also discusses uncertainties associated with quantifying such effects and why DWR estimates of the magnitude of these impacts may differ from those of other parties to these hearings. The second section discusses other factors that affect the biological resources of the Bay/Delta and what is known about the nature and magnitude of the effects of these factors. The third section describes DWR actions to reduce or offset the adverse effects of the State Water Project and other factors. The final section summarizes the main points.

PROJECT-RELATED IMPACTS

The State Water Project has the potential to affect Bay/Delta fish and wildlife through operations of the Oroville complex, Clifton Court Forebay, Skinner Fish Facility, and Banks Pumping Plant. This section discusses these effects in general and effects on several species of particular concern.

Types of Impacts

The most apparent effect of the State Water Project is caused by entrainment of fish at Banks Pumping Plant. The Department of Water Resources constructed and operates the Skinner Fish Facility to capture fish before they are drawn into the pumps and return them to the Delta. Nevertheless, substantial numbers of fish may be eaten by striped bass, white catfish, and other predatory fish as they cross Clifton Court Forebay; others pass through the fish screen; and still more die during handling and trucking in the salvage process. Some fish "lost" in the forebay could also be taking up residence there.

Although we know fish are lost at Banks Pumping Plant, it is difficult to estimate the magnitude of such losses. Losses must be back-calculated from the number of fish salvaged and the estimated percentages lost due to trucking and handling, passage through the screen, and passage through the forebay. So far, experiments to determine forebay losses have been performed on just two species, striped bass and Chinook salmon. We have no estimates of forebay losses for other species, although for mitigation calculations we have agreed to temporarily assume the loss rate of steelhead crossing the forebay is the same as that of salmon.

Even estimates of forebay losses for bass and salmon are not precise, because experiments were not conducted over all the seasons, they used hatchery fish rather than wild fish, and they examined a relatively narrow size range of fish. The Department of Water Resources and Department of Fish and Game have agreed to use these estimates of forebay losses to calculate mitigation obligations until better information becomes available. We have also agreed that DWR's mitigation obligation will be recalculated retroactively when these new predation loss estimates become available. We believe actual losses are probably lower in winter when the predator population in the forebay is lower (Kano 1990) and when cooler water temperatures probably reduce the metabolic and consumption rates of those predators that remain. The loss rate is probably also lower when the prey are larger than those used in the experiments. Moreover, estimates of screening efficiencies at Skinner Fish Facility are based on studies in the late 1960s and, therefore, do not reflect increased efficiencies resulting from subsequent design and operational improvements. overdue

State Water Project operations also affect fish by altering the magnitude and direction of flow in Delta channels. Delta hydrodynamics are affected by such SWP operations as changing the amount of water released from Lake Oroville, by changing the amount of water diverted at Banks Pumping Plant, and by the USBR's operation of the Delta Cross Channel gates.

When flow from upstream areas is insufficient to meet Delta exports and Delta agricultural diversions, water is pulled from downstream areas, which causes a reversal of the direction of flow in some Delta channels. Reverse flows are most common in southern and western Delta channels during summer and fall, when Delta inflow tends to be lowest. However, this can occur in any month if Delta inflows are low enough and diversions are high enough. Reverse flows may carry young fish into the central or southern Delta, where habitat may not be as good or where they may be more susceptible to entrainment at local agricultural, municipal, and industrial diversions and SWP and CVP exports.

The magnitude of reverse flows in the lower San Joaquin River can be reduced through operation of the Delta Cross Channel, which allows water to be diverted from the Sacramento River into the central Delta to meet water project export and in-Delta diversion needs. However, the Cross Channel is not screened, and there is evidence the central Delta may not be as hospitable an environment as the Sacramento River for fall-run Chinook salmon.

Delta outflow is the calculated amount of fresh water that flows past Chipps Island into Suisun Bay. Outflow depends on inflow to the Delta, State Water Project, Central Valley Project, and Contra Costa Canal exports from the Delta, and depletions of channel water within the Delta. Freshwater outflow from the Delta creates a hydraulic barrier that reduces the movement of salt from the ocean and determines the location of the entrapment zone. Changes to exports and upstream reservoir operation may alter outflow and shift the location of the entrapment zone. The significance of the entrapment zone and its location are discussed later in this presentation.

Changes in Delta outflow may affect other estuarine and anadromous organisms by altering the time it takes them to move up or downstream. A reduction in transport time may adversely affect Delta species that spawn upstream and depend on currents to carry their eggs and larvae to downstream nursery areas.

Impacts on Striped Bass

California striped bass spend most of their life in the Bay/Delta and along the coast within a few miles of the Golden Gate Bridge. Adult bass move into the Delta and upstream spawning areas in the spring. Spawning is regulated to a large extent by water temperature, but it may also be regulated by salinity.

Primary spawning areas are the Sacramento River from Isleton to Butte City and the San Joaquin River and its sloughs from Venice Island to Antioch. Spawning peaks in May and June but may occur as early as April. Fertilized eggs produced from mass spawning are transported downstream by currents. Eggs hatch within a few days and larvae survive off their yolk sacs for 7 or 8 days before they begin to feed on zooplankton. By July, juvenile bass tend to be concentrated in rearing areas in the Delta and Suisun Bay. Most of the young bass remain in the upper estuary (San Pablo Bay through the Delta) during their first two years. About half the population reaches the minimum legal catchable size (18 inches) when they are three years old, although most do not reproduce and contribute strongly to the population until they are four.

Banks Pumping Plant Impacts

Most entrainment of striped bass eggs and larvae at the Banks Pumping Plant is during May, June, and July. In most years, the number of young bass entrained appears to decrease rapidly from September to December, although there are some exceptions. For example, entrainment was high in winter and early spring during the 1976-77 drought.

Losses at Banks Pumping Plant occur due to passage of eggs or larvae (less than 20 mm long) through the fish screens, predation and other prescreening losses in Clifton Court Forebay, and handling and hauling of salvaged bass.

Prescreening losses include those young bass lost to predators while moving across Clifton Court Forebay as well as any bass that take up residence in the forebay. Predation has been primarily attributed to subadult striped bass, but white catfish, channel catfish, and other species are potential predators as well (Kano 1990). For calculating mitigation, prescreening loss of young-of-the-year striped bass has been estimated for July and August and assumed to be the same for other months (Collins, DFG, pers comm).

Screen losses appear to depend primarily on bass size and water velocity. During the period May 15 through November 30, the fish facilities are operated to provide optimum velocities to protect striped bass. Additional losses occur as a result of handling and trucking salvaged bass. Mortality appears to be highest for the smallest fish.

Striped bass losses since 1986 have been calculated according to a method agreed upon by Water Resources and Fish and Game in the Two-Agency Fish Agreement (Phase I DWR-560. Losses of eggs and larvae at Banks Pumping Plant are estimated by multiplying densities at the entrance to Clifton Court Forebay between April and July by the volume of water pumped. The loss of larger juvenile bass is back-calculated from salvage and mortality rates as described earlier. Bass losses are usually standardized to reflect the equivalent number of yearling bass they would have produced. Figure 1 shows that most of the losses occur from May through July and are due to the assumed predation rate. It also shows that the percentage of losses due to predation drops through the fall and winter as the bass grow and become less susceptible to predation.

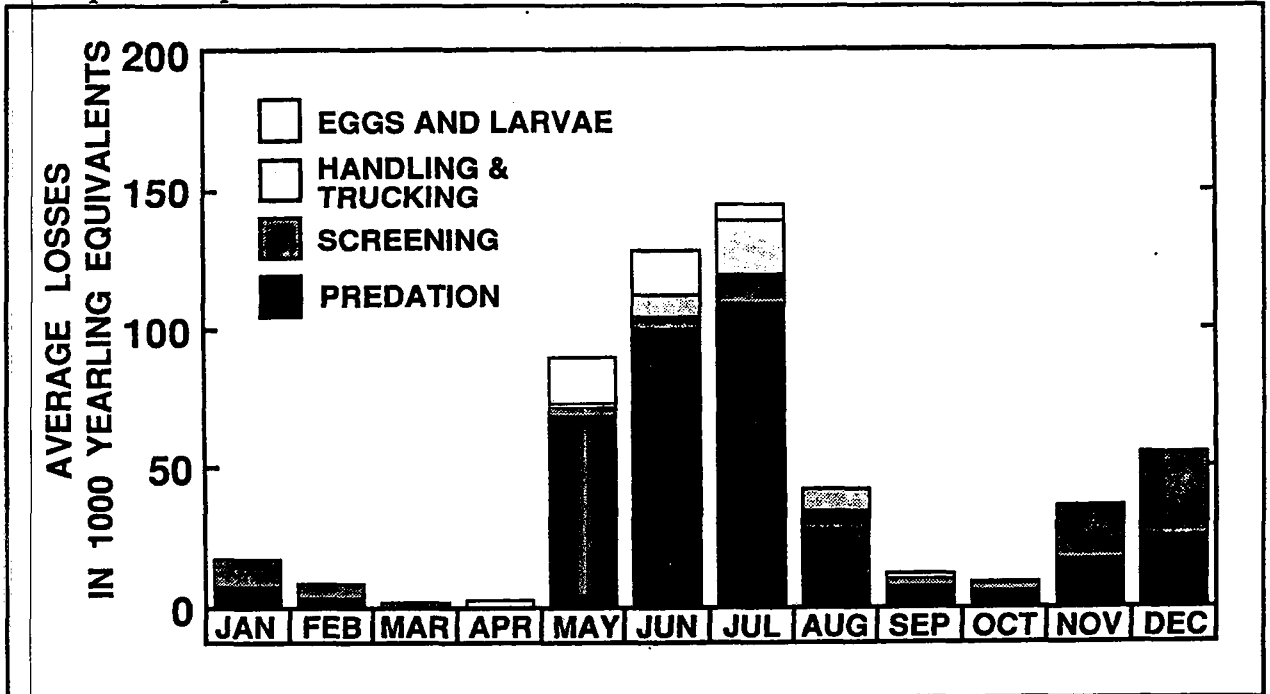


Figure 1
ESTIMATED STRIPED BASS LOSSES DUE TO SWP PUMPING, 1980-1987
Predation assumes a size-dependent, 0-100 percent predation rate in Clifton Court Forebay.

As mentioned earlier, this method of calculating losses may overestimate the actual number of bass lost, particularly in winter. Predation rates used in the Two-Agency Fish Agreement were based on summer studies. During winter there are fewer predators in the forebay (Kano 1990), so predation should be less. Moreover, since the water is colder, predators that remain in the forebay should have a lower metabolic rate and, therefore, should consume fewer young bass than in summer.

Losses from 1986 to 1990 using assumptions of the Two-Agency Fish Agreement are summarized in Table 1. (Table 1 also presents information on the number of fish replaced for mitigation, discussed later in this presentation.) An estimated 3.9 million yearling equivalents were lost during the 5-year period. This would be the equivalent of about 429,000 legal-size bass, assuming the survival rate is similar to that of hatchery-reared yearlings (11 percent). The average impact to the total number of legal size bass would, therefore, be the equivalent of about 86,000 adults per year.

Table 1
ESTIMATED LOSSES OF STRIPED BASS AT BANKS PUMPING PLANT, MITIGATION OBLIGATION, AND REPLACEMENT, 1986-1991

	Striped Bass in Yearling Equivalents			
	Annual Losses			
Year	<20 mm	>20 mm	Mitigation Obligation*	Number Replaced
1986	35,315	944,061	544,429	0
1987	41,726	954,958	683,712	0
1988	59,625	874,055	854,041	345,292
1989	56,306	579,003	796,240	406,458
1990	7,717	401,291	790,811	1,235,787
1991	NA	NA	NA	** 1,765,801
Total	200,689	3,753,368	3,669,233	3,753,338
Credit			+84,105	

* The Two-Agency Fish Agreement defines the mitigation obligation as the average of annual losses over the previous 5 years.
**More than 800,000 yearlings were stocked in 1991 using funds from the $15 million account established by the Two-Agency Fish Agreement. These fish are in addition to those credited to offset annual losses at Banks Pumping Plant.

Delta Cross Channel Diversions

The Central Valley Project's Delta Cross Channel, completed in 1951, has two 60-foot gates at the Sacramento River to enhance transfer of water south into the central Delta. U.S. Fish and Wildlife Service studies indicate survival of fall-run salmon smolts may be lower in the central Delta than in the mainstem Sacramento River (Kjelsen *et al* 1991). There is also concern that striped bass eggs and larvae diverted into the central Delta may be more susceptible to entrainment by SWP and CVP export pumps and local agricultural diversions.

Possible effects of Delta Cross Channel diversion on the entrainment of bass longer than 20 millimeters at Banks Pumping Plant were examined by Wendt (1987; Phase I DWR-606). He found a strong correlation between the number of bass salvaged at Skinner Fish Facility in the summer and the total amount of SWP and CVP exports, flow in the lower San Joaquin River, striped bass young-of-the-year index, and average size of the bass. He did not find the amount of flow through the Delta Cross Channel to be a significant factor. This finding was confirmed by a similar DWR staff analysis in 1990, which included more recent data. Although hydrodynamic modeling suggests Cross Channel diversions could affect the number of smaller bass entrained, such bass account for only about 5 percent of the average annual yearling equivalents lost at Banks Pumping Plant (Table 1). Thus, it does not appear that Delta Cross Channel operation has a significant effect on the number of yearling equivalent striped bass entrained at Banks Pumping Plant. This result is not surprising in that modeling and hydrodynamic studies have indicated that flow through the Cross Channel is independent of pumping from the southern Delta.

Delta Outflow Issues

Another major concern is that the State Water Project may have a negative impact on striped bass by changing Delta outflow. The Department of Fish and Game has found a positive correlation between Delta outflow and production of young and adult striped bass. One possible explanation for this relationship is that reduced outflow may increase the time it takes for eggs and larvae to reach important rearing areas in Suisun Bay and the western Delta, and away from the influence of agricultural and project diversions. Another is that higher outflow could act to dilute toxins within the system. A third hypothesis is that reducing outflow may shift the position of the entrapment zone to upstream areas having less suitable nursery habitat for young striped bass. The entrapment zone hypothesis is discussed in more detail later in this presentation.

Reverse Flows

It has long been hypothesized that reverse flows may have a negative impact on young striped bass and their food supply. Reverse flows could impact striped bass by drawing young fish to the export pumps from spawning and nursery areas in the central and western Delta. The change in flow pattern could also adversely affect bass habitat or food supply in the lower San Joaquin River, although these effects have yet to be demonstrated.

The possible role of reverse flows in drawing young striped bass to the export pumps is supported by the statistical evaluation by Wendt (1987). That study indicated there was a significant inverse relationship between flow in the lower San Joaquin River and the number of young bass salvaged at Banks Pumping Plant in June and July.

Impacts on Salmon

Four races of Chinook salmon pass through the Delta: fall-run, winter-run, spring-run, and late-fall-run. Although, fall-run salmon presently constitute about 80 percent of the total population passing through this estuary, impacts to winter-run salmon are important because that race has been classified as an endangered species by the California Fish and Game Commission and as a threatened species by the National Marine Fisheries Service.

Adult Chinook salmon migrate through the Delta to spawn in mainstem rivers and upstream tributaries. Following emergence, salmon fry generally rear in upstream areas for a few months before migrating downstream, but some rear upstream until the following year and leave the rivers as yearlings. Outmigrating juvenile salmon undergo a physiological change to the smolt stage, which allows them to survive in salt water. Time of smolt outmigration depends on the race, weather, and water temperature. Smolts entrained at Skinner Fish Facility are generally 50 to 125 millimeters long.

Banks Pumping Plant Losses

Salvage records from Skinner Fish Facility indicate salmon fry and smolts are entrained year-round, but peak levels generally occur in late winter and spring, when the most abundant salmon race, fall-run, passes through the Delta. In addition to seasonal factors, evidence suggests entrainment of young salmon into Clifton Court Forebay may be influenced by a variety of other parameters. Chinook salmon fry and smolts are probably entrained at higher rates when the radial gates are open during twilight and at night. Recent Department of Fish and Game hydroacoustic studies suggest more fish may be entrained when the radial gates are open at the beginning of the flood tide, when head differences and velocities are low (Collins, DFG, pers comm). Department of Water Resources operators try to avoid operating the gates in this fashion.

Predation has been cited as the major reason for State Water Project losses based on the large number of predatory striped bass in the forebay and experimental releases of hatchery-raised salmon. Salmon losses may be affected by transit time across the forebay, salmon size, metabolic needs of predators, water velocities across the fish screens, and handling and trucking of salvaged salmon.

Clifton Court Forebay loss estimates for the Two-Agency Fish Agreement are based on the assumption that 75 percent of entrained fish will be lost crossing the forebay. This figure is based on three estimates of losses that ranged from 63 to 88 percent using experimental releases of hatchery fish. Water Resources and Fish and Game have agreed to use the average of 75 percent for mitigation purposes until better information is available. Other factors used in calculating losses are screen efficiencies and trucking and handling mortality.

Accurate estimation of winter-run Chinook salmon losses is particularly difficult. Department of Fish and Game's winter-run classification system appears to consistently overestimate the number of larger winter-run migrating through the Delta (Brown and Greene 1992). Even if fish arriving at Skinner Fish Facility could be accurately identified as winter-run, it is likely the loss experiments on smaller, fall-run hatchery fish overestimate forebay predation rate. (We will discuss this issue in more depth in Exhibit WRINT DWR-31.)

Table 2 summarizes annual losses of salmon from 1986 to 1990 calculated using the Two-Agency Fish Agreement method. An estimated 6.7 million smolt equivalents were lost during that period. Although most of these losses occur in late winter and spring, when large numbers of fall-run salmon are passing through the Delta, losses may occur in all seasons because of the life history pattern of each salmon race. Figure 2 shows the average monthly distribution of salmon losses for water years 1980 through 1987 and the relative amount of losses caused by predation, screening, and trucking and handling.

Table 2
ESTIMATED LOSSES OF CHINOOK SALMON AT BANKS PUMPING PLANT, MITIGATION OBLIGATION, AND REPLACEMENT, 1986-1991

	Chinook Salmon in Smolt Equivalents			
	Annual Losses		Mitigation	Number
Year	YOY	Yearlings	Obligation*	Replaced
1986	1,147,249	2,300,866	1,973,164	0
1987	528,544	713,791	1,536,872	0
1988	409,103	747,953	1,609,586	78,125
1989	373,717	246,641	1,486,018	15,625
1990	90,098	188,228	1,349,238	15,625
1991	NA	NA	NA	79,573
Total	2,548,711	4,197,479	7,954,878	188,948
Credit			-7,765,930	

*The Two-Agency Fish Agreement defines the mitigation obligation as the average of annual losses over the previous 5 years.

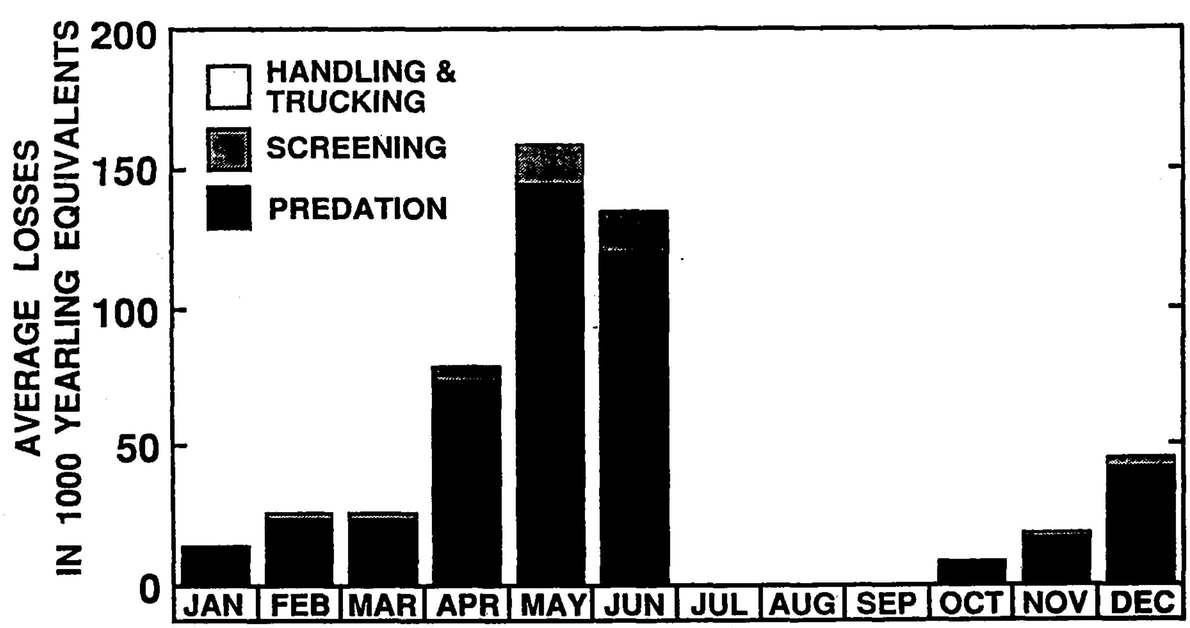


Figure 2
ESTIMATED CHINOOK SALMON LOSSES DUE TO SWP PUMPING, 1980-1987

Predation assumes a 75 percent predation rate in Clifton Court Forebay.

Delta Cross Channel Diversions

Survival of smolts as they migrate downstream from Sacramento to Chipps Island has been intensively studied by the Fish and Wildlife Service as part of the Interagency Ecological Studies Program (Kjelsen *et al* 1991). Hatchery-reared smolts have been released at key locations in the Delta to examine the effect of different conditions on losses. The studies showed fall-run smolt survival through the Delta was correlated with the amount of water diverted via the Delta Cross Channel, water temperature in the Sacramento River at Freeport, and total SWP and CVP diversions. Conditions in the central Delta (*eg,* agricultural diversions) may be less suitable for young salmon, resulting in higher mortality rates.

Outflow and Reverse Flow

There has been some concern that survival of young salmon may be affected by reverse flows and/or outflow. There is also concern that reverse flows may confuse adults migrating through the Delta to upstream spawning areas.

There is no evidence to support either hypothesis. Fish and Wildlife Service studies (Kjelsen *et al* 1991) found no relationship between reverse flows in the western Delta (at Jersey Point) and the survival of Sacramento fall-run smolts migrating through the Delta. Although Delta outflow was found to be significantly correlated with smolt survival, the authors indicated it was probably due to water temperature, which was closely correlated with flow (wet years tend to be cooler).

Smolt survival may not be clearly linked to reverse flows and total outflow because salinity, water temperature, tidal flow, or related factors could be more important stimuli for outmigration than flow. Another consideration is that reverse flows tend to occur more frequently in summer and fall — after the period of peak outmigration.

Impacts on Steelhead Trout

The life cycle of steelhead trout is similar to that of salmon in many respects, although the timing and duration of different stages varies. Steelhead generally migrate upstream to spawn between August and March. A key difference between steelhead and Chinook salmon is that many steelhead trout do not die after spawning, but return to the ocean. Another contrast is that after hatching and emergence, young steelhead remain in upstream areas for long periods, usually two to three years. Thus, they generally migrate through the Delta at a larger size than salmon. Steelhead tend to spend one or two years in the ocean before returning upstream to spawn.

Banks Pumping Plant Losses

The same factors that influence entrainment and loss of Chinook salmon are thought to apply to steelhead. Some young steelhead trout are entrained in Clifton Court Forebay during downstream migration from late-February through June, with a peak in May.

There have been no specific studies on loss rates of steelhead in Clifton Court Forebay. The 75 percent loss rate for Chinook salmon has been assumed for calculating mitigation obligations. Note, however, that this rate was estimated using fall-run salmon smolts (generally less than 100 millimeters), while outmigrating steelhead tend to be larger (130-250 millimeters) (Moyle 1976) and are probably far less susceptible to predation. Using Skinner Fish Facility salvage data and the assumed loss rates, losses of steelhead since 1986 have been estimated to average about 23,000 yearling equivalents. Losses calculated for 1986 through 1990 are shown in Table 3.

Table 3
ESTIMATED LOSSES OF STEELHEAD TROUT AT BANKS PUMPING PLANT, MITIGATION OBLIGATION, AND REPLACEMENT, 1986-1992

	Steelhead Trout as Yearling Equivalents			
	Annual Losses		Mitigation	Number
Year	YOY	Yearlings	Obligation*	Replaced
1986	0	15,663	21,884	0
1987	747	21,266	11,591	0
1988	0	25,080	16,018	0
1989	253	32,571	22,240	0
1990	0	19,187	22,953	53,900
1991	NA	NA	NA	20,450
1992	NA	NA	NA	29,900
Total	1,000	113,767	94,686	104,250 74,350
Credit			+9,564 - 20,336	

*The Two-Agency Fish Agreement defines the mitigation obligation as the average of annual losses over the previous 5 years.

Delta Cross Channel Diversions

No studies have examined survival of steelhead trout diverted through the Delta Cross Channel, but some of the same factors shown to be important for fall-run salmon (Kjelsen *et al* 1991) could also apply to steelhead. There may also be key differences. There is evidence that young steelhead may be less sensitive to water temperature (DFG 1991), one of the primary factors thought to be responsible for salmon smolt mortality in the Delta.

Outflow and Reverse Flow

Delta survival and outmigration of young steelhead may be influenced by reverse flows and/or outflow. However, as with salmon, there is no evidence to support this conclusion. The main factors regulating steelhead smolt migration through the lower Delta could be salinity or other tidal influences, rather than flow. An additional factor is that steelhead are generally larger than fall-run salmon when they migrate through the Delta and may be stronger and more capable of overcoming reverse flows.

There are however very few steelhead around any more

Impacts on Delta Smelt

Delta smelt *(Hypomesus transpacificus)* is proposed for listing as threatened under the federal Endangered Species Act and is treated as a species of special concern by the Department of Fish and Game. This native species is found only in the Sacramento-San Joaquin estuary, usually in Suisun Bay and the Delta.

Historically, upstream limits of Delta smelt extended to Sacramento on the Sacramento River and Mossdale on the San Joaquin River. The lower limit is western Suisun Bay. Although they may be washed into San Pablo Bay during times of high outflows, they do not establish permanent populations there (Moyle *et al* 1992).

Delta smelt inhabit open surface and shoal waters, presumably in schools. During the spawning period, adults move from Suisun Bay or river channels in the lower Delta to spawning areas upstream. Spawning occurs from about February through June at temperatures ranging from 45 to 59 degrees Fahrenheit. Spawning occurs along river margins and adjacent sloughs in the western Delta. The demersal, adhesive eggs descend and attach to hard substrates such as submerged tree branches, roots, gravel, and vegetation (Wang 1986).

Newly hatched larvae are buoyant and drift downstream near the surface. Growth is rapid through the summer. Juveniles reach 40 to 50 millimeters by early August; adults reach 55 to 70 millimeters in seven to nine months (DWR 1992). Most Delta smelt mature, spawn, and die within one year (Wang 1986).

Delta smelt feed primarily on planktonic copepods throughout their lives. Cladocerans are seasonally important, and opossum shrimp, *Neomysis mercedis*, are of secondary importance. Diet studies from the mid-1970s found the principal copepod eaten was *Eurytemora affinis*, but in samples collected in 1988 the dominant copepod was *Pseudodiaptomous forbesi,* an introduced species first noted in the estuary in 1987 (Moyle *et al* 1992).

Outflow and Reverse Flow

A multiple regression analysis by the Department of Fish and Game found no evidence that Delta smelt abundance is controlled by Delta outflows (Stevens *et al* 1990). Also, as shown in Figure 3, there is a lack of association between the duration of reverse flows and Delta smelt abundance. This indicates reverse flows are not necessarily the mechanism driving the Delta smelt population (Stevens *et al* 1990). However, Moyle *et al* (1992) postulate that diversions from the Delta provide the most likely explanation of declines in Delta smelt abundance by shifting the entrapment zone to river channels, which presumably results in habitat constriction and fish entrainment at the SWP and CVP pumping facilities and agricultural diversions. This theory is not supported by the findings of the Department of Fish and Game (Stevens *et al* 1990).

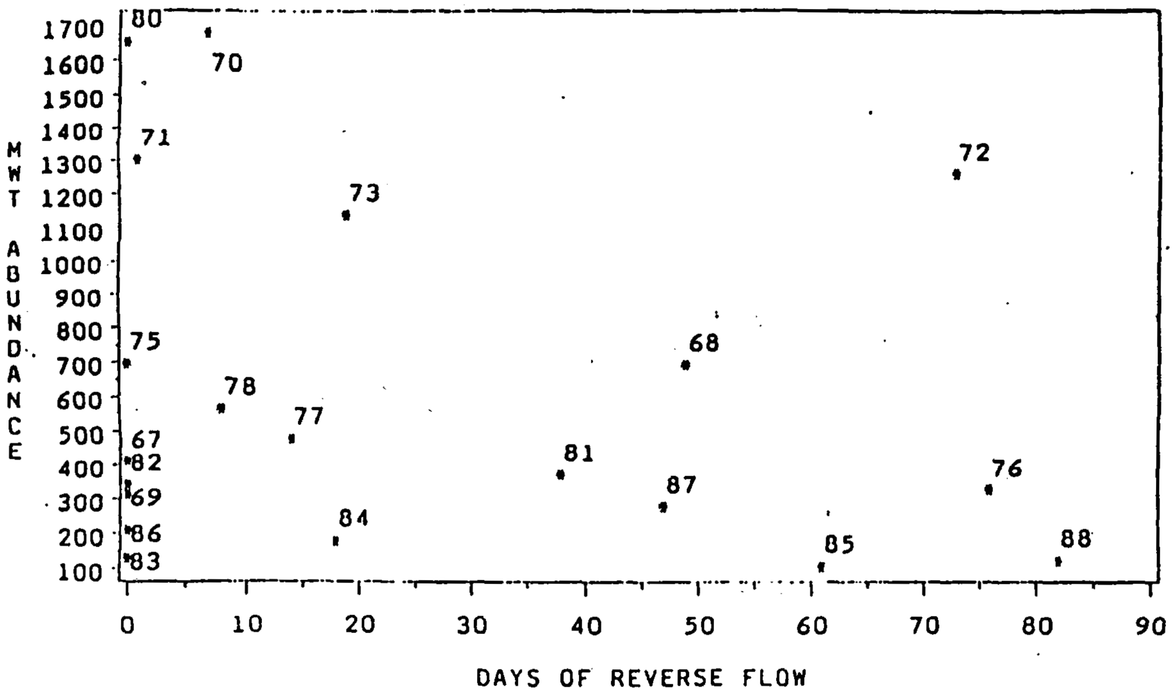


Figure 3
RELATIONSHIP BETWEEN FALL MIDWATER TRAWL INDEX OF DELTA SMELT ABUNDANCE AND THE NUMBER OF DAYS OF REVERSE FLOWS IN THE LOWER SAN JOAQUIN RIVER FROM MARCH THROUGH JUNE

SOURCE: D. Stevens, L. Miller, and B. Bolster. 1990. Report to the Fish and Game Commission: A status report of the Delta smelt *(Hypomesus transpacificus)* in California. Candidate Species Report 90-2.

Banks Pumping Plant Losses

Various life stages of Delta smelt are often collected at the fish salvage facilities of the State Water Project. Time of peak abundance varies from year to year (Figure 4). Few or no Delta smelt were collected from September through November. Adults appear from December until about April, often resulting in a peak abundance about this time. A second, larger peak occurs from April to August, but primarily in May to June. These are juvenile smelt. Caution should be used when interpreting these salvage data, because juvenile Delta smelt are often confused with juvenile longfin smelt. The two species coexist over a large portion of their range (DWR 1992).

Since 1989, the South Delta Striped Bass Egg and Larval Survey has caught less than 20 Delta smelt larvae each year, usually in April and May (Figure 5). This catch comprises less than 1 percent of the study's total catch of all species each year. The larvae have been collected at Old River near Tracy and Grant Line Canal. Using this information, losses of Delta smelt larvae to Banks Pumping Plant were estimated using the same techniques used to estimate losses of striped bass eggs and larvae. As shown in Table 4, an average of about one Delta smelt larva per acre-foot of water was entrained during the study period for 1989 through 1991.

As indicated by the few larvae caught in this extensive sampling effort (every other day at seven sites from April through July), it appears few Delta smelt

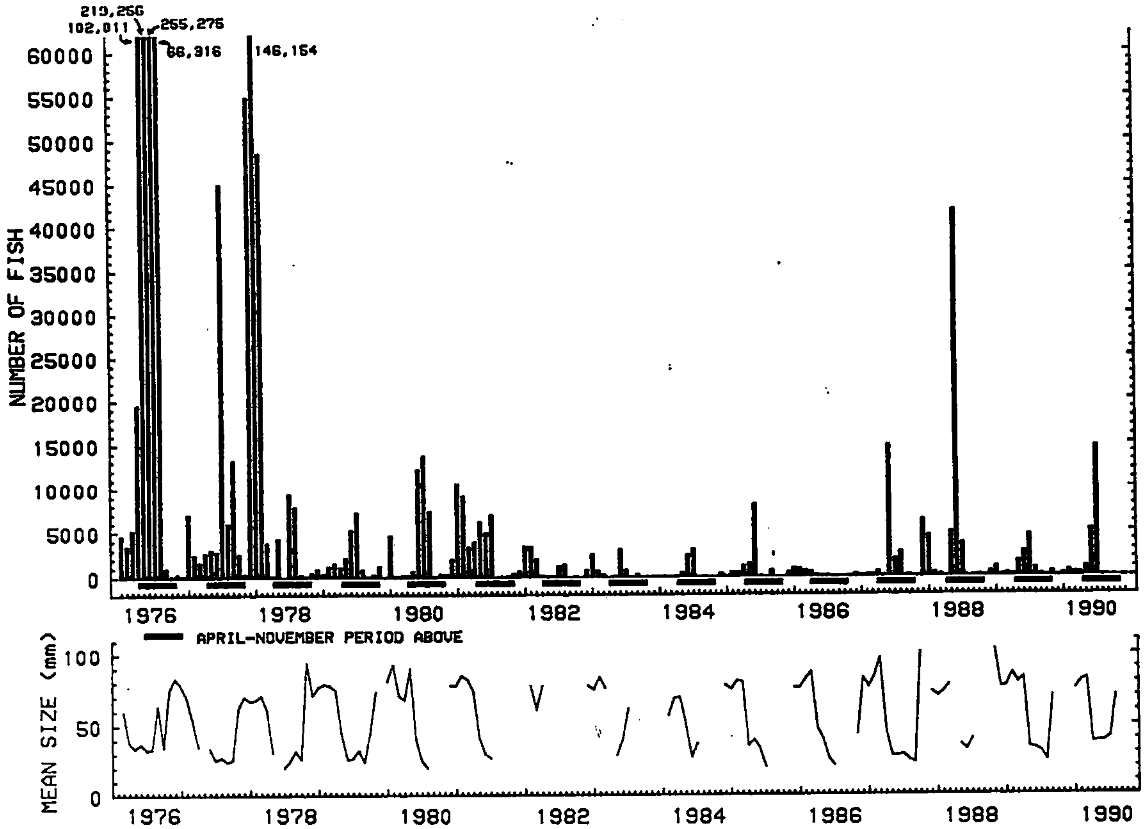


Figure 4

MEAN SIZE AND EXPANDED NUMBER OF DELTA SMELT SALVAGED MONTHLY AT THE SWP

SOURCE: Department of Water Resources. 1992. Biological assessment for the south Delta temporary barriers project. Environmental Services Office.

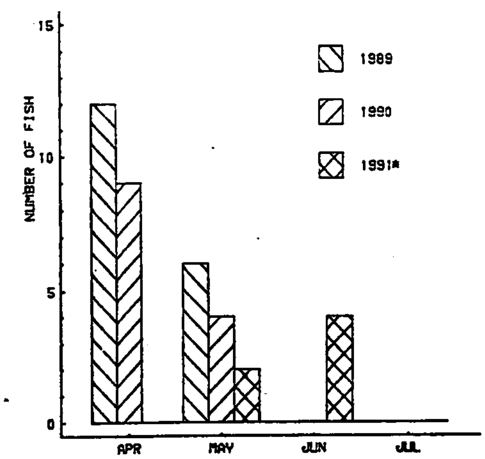


Figure 5

ACTUAL CATCH OF DELTA SMELT IN THE SOUTH DELTA EGG AND LARVA STUDY, 1989-1991

No Delta smelt were caught in February and March 1991.
No sampling April 17 to May 27, 1991.

SOURCE: Department of Water Resources. 1992. Biological assessment for the south Delta temporary barriers project. Environmental Services Office.

Table 4
ESTIMATED SWP ENTRAINMENT OF DELTA SMELT LARVAE, 1989-1991

	Number Entrained	SWP Inflow (Acre-Feet)	Larvae per Acre-Foot
1989	442,922	720,818	0.6145
1990	582,501	276,032	2.1103
1991	24,085	421,998	0.0571

Study Period: 1989 — April 10-July 17
1990 — April 10-July 11
1991 — February 4-July 12

spawn in the southern Delta (DWR 1992). Based on Department of Fish and Game egg and larval trawls over the last few years, it appears that, at least in low-flow years, a significant portion of Delta smelt spawning now takes place in the northern and western Delta (Dale Sweetnam, DFG, pers comm).

It is not yet possible to estimate direct losses of Delta smelt to Banks Pumping Plant as was done for striped bass, steelhead, and salmon. To estimate losses, information is needed, including predation rates of Delta smelt through Clifton Court Forebay. Large numbers of tagged fish are needed to develop this information. The Department of Water Resources is funding the development of methods to rear Delta smelt, which can be used to evaluate pumping plant losses and other research purposes.

Impacts on American Shad

American shad grow to maturity in the ocean, migrate through the Delta in spring and early summer, and spawn primarily in the Sacramento, Feather, Yuba, American, and Mokelumne rivers. Spawning is initiated when water temperatures reach a suitable level, usually in May and June. Spawning occurs in groups, and eggs are broadcast into the water column. The fertilized eggs drift downstream to nursery areas in the lower rivers and the Delta. The young American shad migrate downstream from May through early January, but most migrate in late July to November. Juvenile shad may spend up to several months in the Delta before moving into the ocean. Little is known about their life history in salt water along the Pacific Coast.

Many of the factors affecting the loss of young striped bass are likely to affect American shad. Both species spawn upstream about the same time. However a portion of young shad commonly remain in upstream rivers. Factors of concern for striped bass rearing, such as Delta outflow and entrainment, may also be important for young shad.

As shown in Figure 6, peak salvage of young shad at Skinner Fish Facility generally occurs during the main outmigration period between July and December. However, there is no information available on predation rate and screen efficiencies from which to calculate losses from the salvage estimates.

An important consideration in the management of American shad is that upstream conditions appear to play a critical role in determining the magnitude and distribution of recruitment to the population. Department of Fish and Game evidence suggests flow and temperature are the main factors regulating American shad reproduction in the Sacramento, Feather, Yuba, and American rivers (DFG 1991).

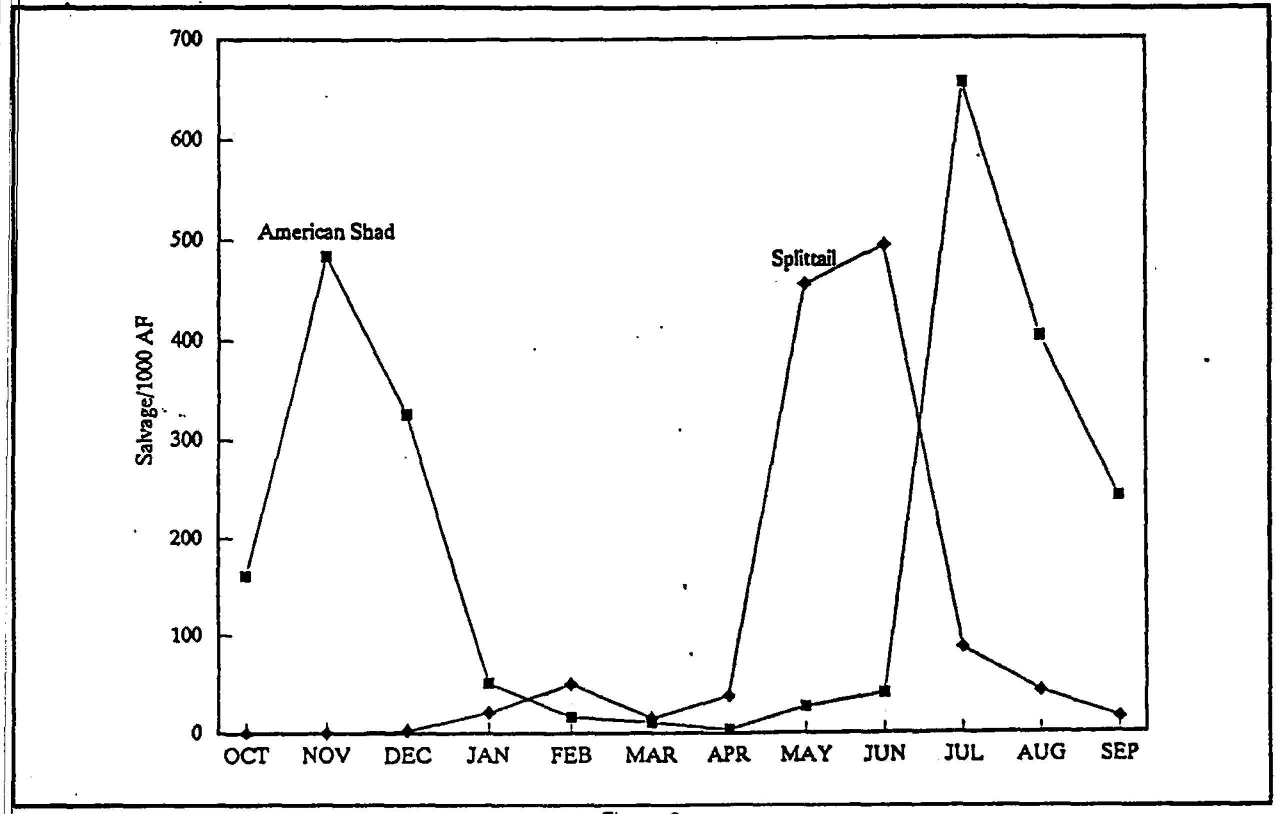


Figure 6
AVERAGE MONTHLY SALVAGE OF AMERICAN SHAD AND SPLITTAIL, 1980-1990

Impacts on Splittail

Splittail are large minnows distributed primarily in the Bay and Delta and most commonly found in slow-moving rivers and sloughs. Adults spawn from late January to July in sloughs of the Delta, Napa Marsh, and Suisun Marsh (Moyle 1976). Spawning seems to be triggered by increasing water temperature and day length. Splittail eggs are laid on submerged vegetation, and hatched larvae remain in shallow, weedy areas. The young move to deeper, offshore habitat later in the summer (Wang 1986). Young splittail may occur in shallow and open waters of the Delta and San Pablo Bay, but they are particularly abundant in the northern and western Delta.

Average levels of splittail at the State Water Project salvage facilities from 1980 through 1990 are summarized in Figure 6, and monthly totals and size for 1979 through 1987 are shown in Figure 7. Salvage is highest from April through August, when juvenile splittail are collected. Few splittail are collected between September and January. Adequate data are not available to estimate direct losses.

Extensive sampling in the South Delta Striped Bass Egg and Larval Study indicates spawning is minimal near Banks Pumping Plant. However, upstream and downstream impacts are possible if outflow is changed. When outflows are high, reproduction appears to be enhanced, presumably because more spawning area (*ie*, flooded vegetation) is available (Daniels and Moyle 1983 in Moyle *et al* 1989).

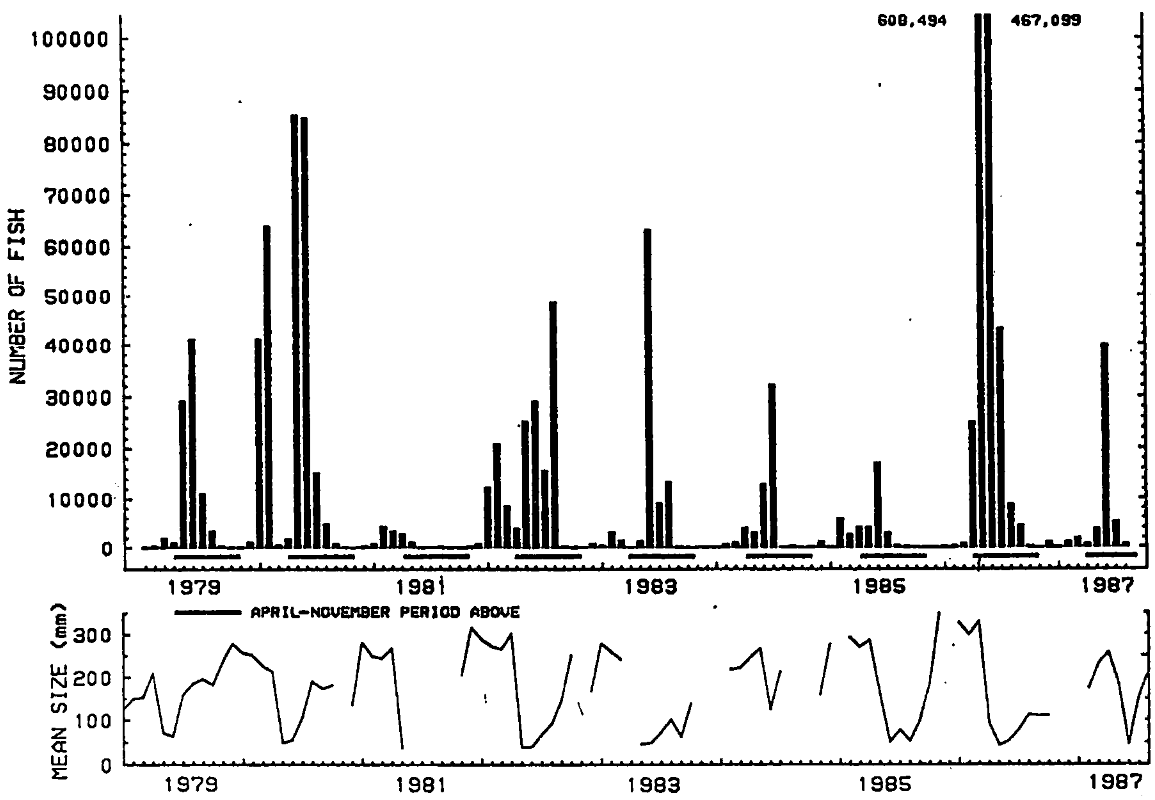


Figure 7

MEAN SIZE AND EXPANDED NUMBER OF SPLITTAIL SALVAGED MONTHLY AT THE SWP

SOURCE: Department of Water Resources. 1992. Biological assessment for the south Delta temporary barriers project. Office of Environmental Services.

Impacts on Longfin Smelt

Longfin smelt are native to the Bay/Delta estuary. The species was recently recommended for Category 2 status for federal listing under the Endangered Species Act. They are most abundant in mid- and shallow-water areas of San Pablo and Suisun bays, where salinities are generally at least 10 ppt. Their distribution appears to change seasonally; in early summer they are primarily in San Pablo and San Francisco bays, in August they move into Suisun Bay, and in winter they spawn in upper Suisun Bay and the lower Delta.

Spawning appears to occur from December through February with deposition of adhesive eggs on rocks or aquatic vegetation. In April and May, young smelt migrate downstream into the bays, where they feed on *Neomysis, Diaphanosma, Diaptomus*, and other small crustaceans.

A major effect of the State Water Project on longfin smelt appears to be due to entrainment into Clifton Court Forebay. Longfin smelt are most common at Skinner Fish Facility in April and May, when the young are migrating downstream (Figure 8). Data are not available to calculate direct losses from the salvage estimates.

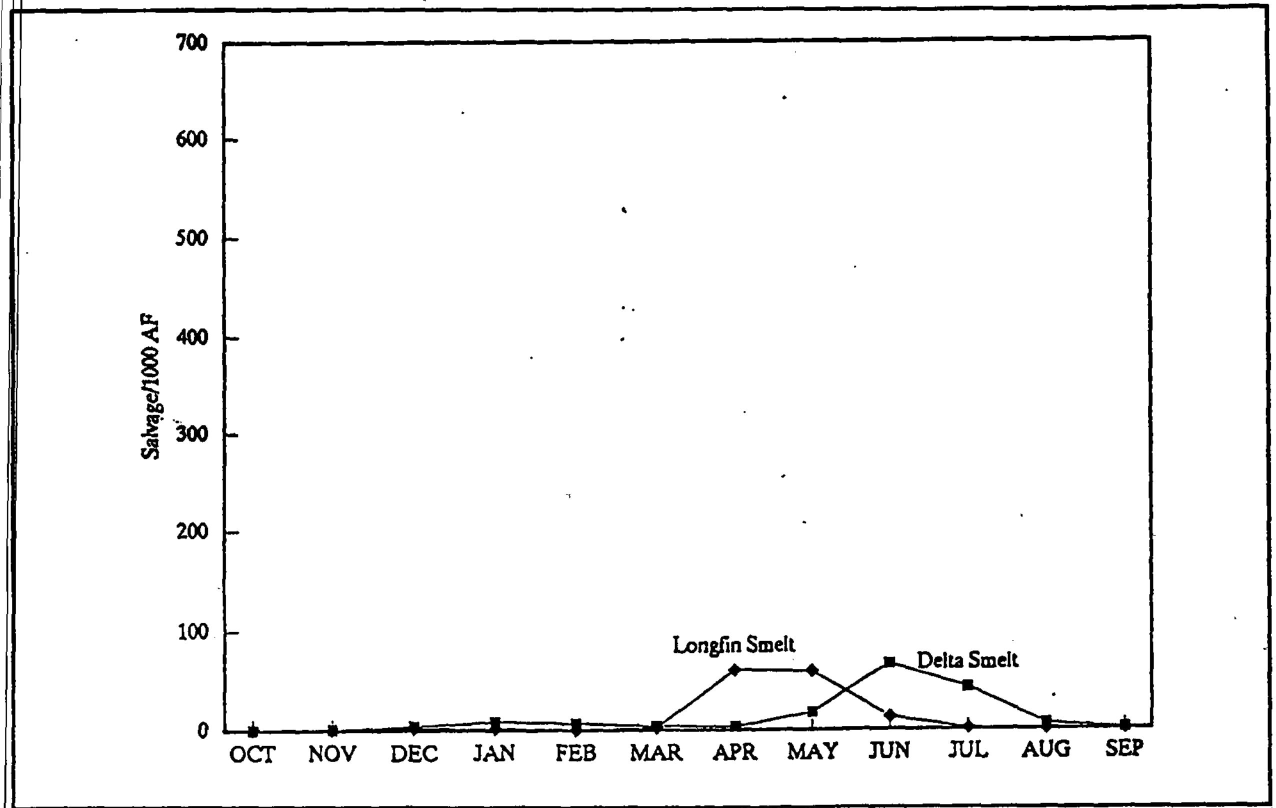


Figure 8
AVERAGE MONTHLY SALVAGE OF LONGFIN SMELT AND DELTA SMELT, 1980-1990

The State Water Project could also affect longfin smelt by altering Delta outflow. Department of Fish and Game has found that the abundance index of longfin smelt is closely correlated with total Delta outflow between January and June. One hypothesis is that reduced outflow during winter may decrease the amount of spawning area in the lower Delta. Changes in spring outflow could also alter the transport time for young smelt to reach downstream bays or affect the availability of rearing habitat. However, it is unclear whether total outflow or short-term peak flows are biologically most important during this period.

OTHER FACTORS AFFECTING DELTA FISH

A number of factors other than State Water Project operations affect Delta fish. Examples include weather phenomena such as droughts and floods, effects of El Niño, global warming or cooling, over-fishing, poaching, pollutants, introduction of exotic species, and agricultural diversions. The purpose of this section is to inform the Board of results of investigations into some of the more important factors. To some extent, impacts on Delta fish resulting from these factors can be controlled through the existing regulatory process. It is also important for the Board to recognize the extent to which they cannot be controlled.

Food Chain and Introduced Organisms

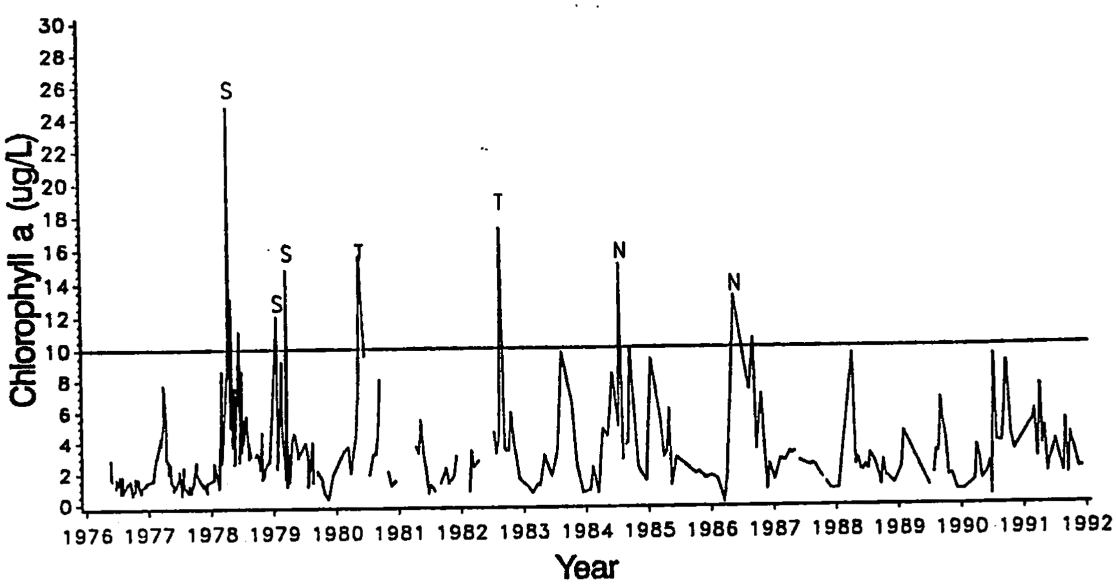
Organisms from several levels of the food chain have undergone substantial declines in abundance. Declines of various fish species have received the most attention, although trends in abundance of organisms from other levels of the food chain, such as phytoplankton and zooplankton, are also important and signify broad ecological changes in the estuary. Determining the cause for these declines has received substantial effort. Several factors, such as project operations, habitat loss and degradation, pollutants, and introduced species, have been identified as contributing to the decline of several organisms. In this section, the status and trends of phytoplankton, zooplankton, and introduced organisms are summarized, and factors that may be responsible for the decline of phytoplankton and zooplankton are discussed.

Phytoplankton

Phytoplankton are microscopic algae that occur throughout the Bay/Delta estuary. As a primary food of many zooplankton and benthic invertebrates, phytoplankton form the base of numerous food chains in the estuary. Food chain relationships are one link in the ecology of these organisms.

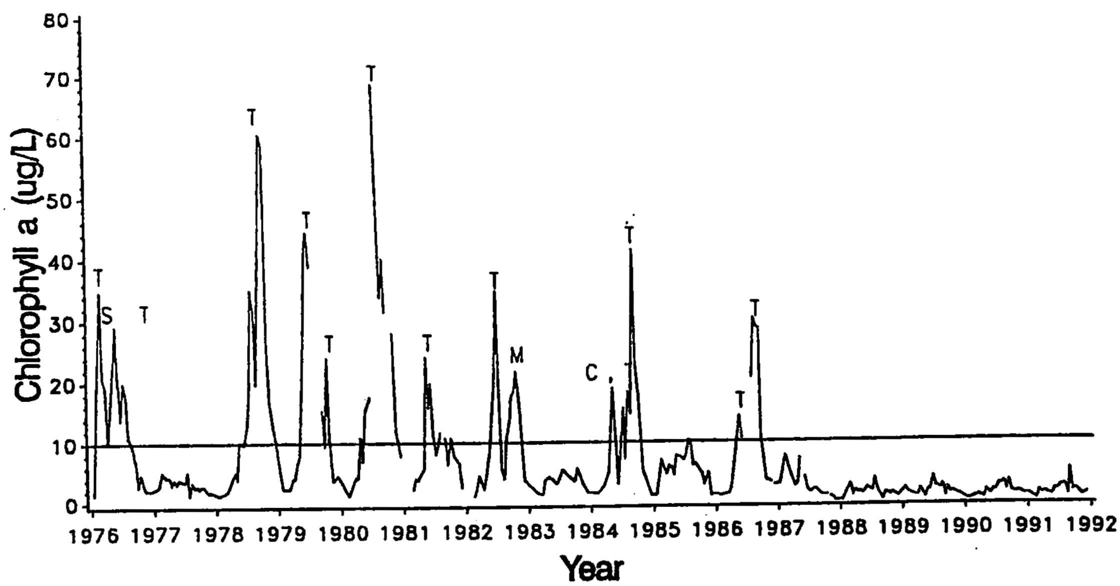
As part of the Decision 1485 water quality monitoring program, the Department of Water Resources routinely samples the composition and biomass of phytoplankton in Suisun Bay and the Delta. Genera composition is assessed through microscopic analysis of water samples collected from 18 sites in the upper estuary. Biomass estimates, used primarily to document abrupt increases in phytoplankton concentration (called phytoplankton "blooms"), are derived from measurements of chlorophyll *a* concentrations. Changes in phytoplankton biomass and composition between 1976 and 1991 are summarized here using data from sites in various regions of the upper estuary.

Between 1976 and 1991, phytoplankton blooms occurred in all upper estuary regions examined (Figures 9-13). Blooms typically occur during spring and fall and are most often dominated by one of four diatom genera: *Skeletonema, Thalassiosira, Cyclotella*, and *Melosira*. Over the last 17 years, blooms have been most intense in the southern Delta, where chlorophyll *a* concentrations have exceeded 300 µg/L, and



Letters above peaks denote dominant bloom organisms:
S = Skeletonema sp., T = Thalassiosira sp., and
N = No dominant organism. Breaks in line denote missing data.

Figure 9
CHLOROPHYLL a CONCENTRATIONS IN SAN PABLO BAY AT SITE D41,
NEAR PINOLE POINT



Letters above peaks denote dominant bloom organisms:
T = Thalassiosira sp., S = Skeletonema sp., M = Melosira sp.,
and C = Cyclotella sp. Breaks in line denote missing data.

Figure 10
CHLOROPHYLL a CONCENTRATIONS IN SUISUN BAY AT SITE D7,
GRIZZLY BAY AT DOLPHIN NEAR SUISUN SLOUGH

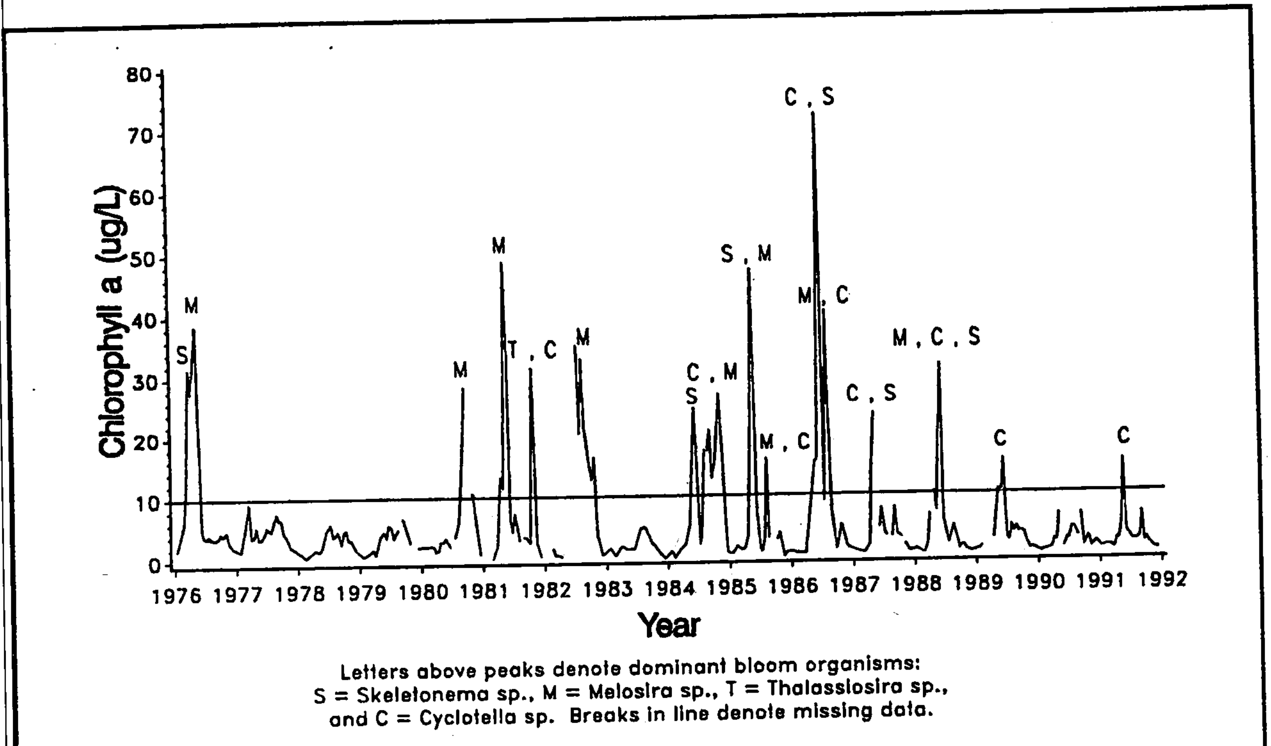


Figure 11
CHLOROPHYLL a CONCENTRATIONS IN THE WESTERN DELTA AT SITE D15,
SAN JOAQUIN RIVER AT JERSEY POINT

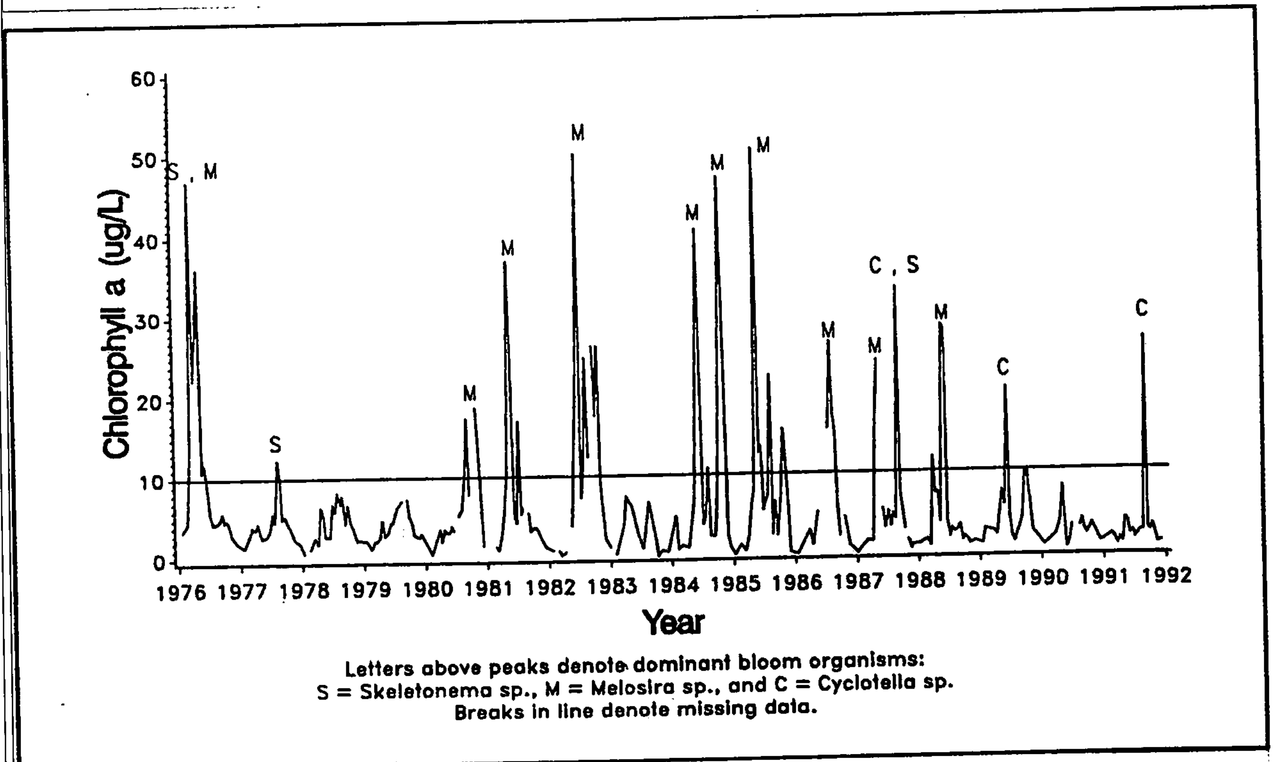


Figure 12
CHLOROPHYLL a CONCENTRATIONS IN THE CENTRAL DELTA AT SITE D28A,
OLD RIVER OPPOSITE RANCHO DEL RIO

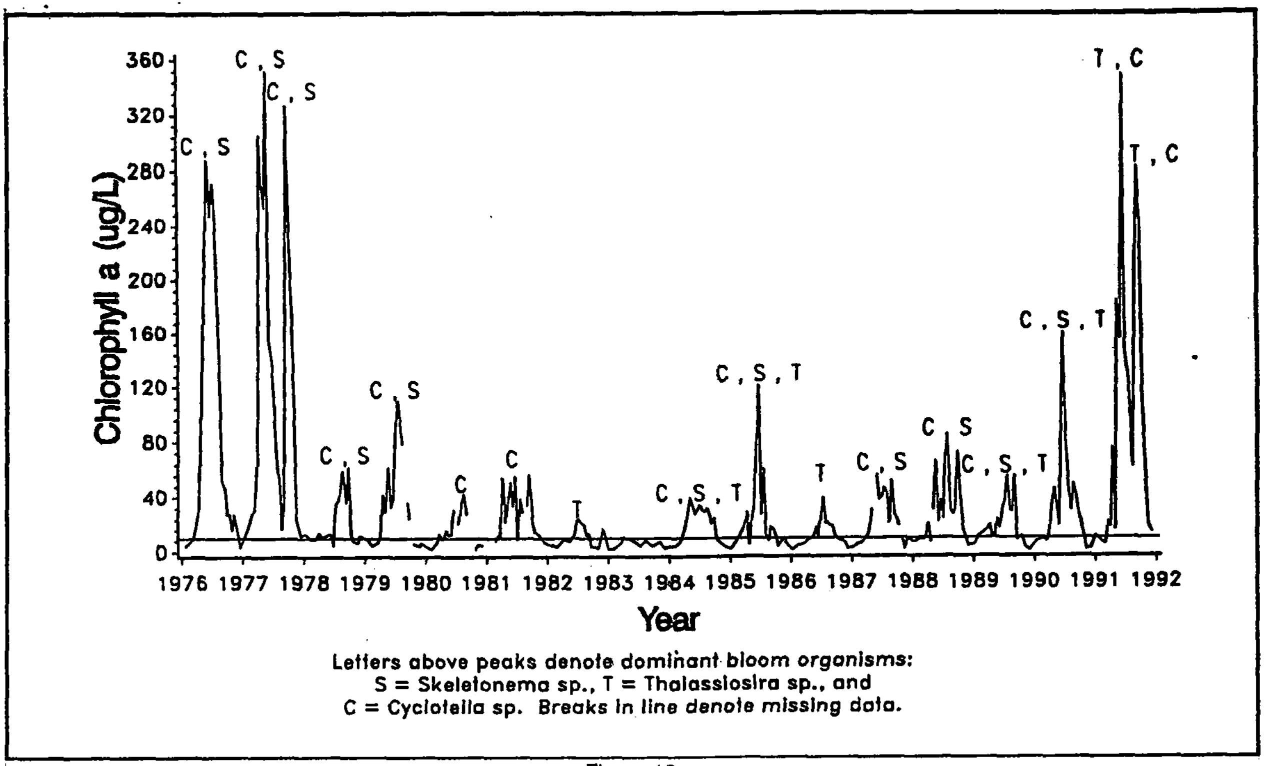


Figure 13
CHLOROPHYLL a CONCENTRATIONS IN THE SOUTHERN DELTA AT SITE C7,
SAN JOAQUIN RIVER AT MOSSDALE BRIDGE

least intense in the San Pablo Bay ship channel, where chlorophyll *a* concentrations have not exceeded 26 µg/L.

Frequency and intensity of phytoplankton blooms have both decreased in many regions of the upper estuary. A decreasing trend in bloom intensity (*ie*, peak chlorophyll *a* concentrations) beginning in the mid- to late-1980s has occurred in all regions examined except the southern Delta (Figures 9-13). During drought years 1977 and 1987 through 1991 and during the extremely wet year of 1983, phytoplankton biomass was substantially depressed — often below the background level of 10 µg/L — in all upper estuary regions examined except the southern Delta. Throughout the upper estuary, substantially fewer blooms occurred between 1987 and 1991 than in any other 5-year period examined.

In the southern Delta, peak levels of phytoplankton biomass increased during periods of drought compared to other years (Figure 13). ~~These higher biomass levels may have developed in response to increases in water residence time~~, which can occur during periods of reduced inflow. The increased residence time, combined with the eutrophic conditions that generally exist in this region, could result in high levels of phytoplankton biomass. The drought-associated increases in phytoplankton biomass suggest State Water Project exports have not adversely impacted phytoplankton activity in the southern Delta during droughts (Figure 13). Additionally, short-term studies have found no enhancement of phytoplankton biomass during periods of curtailed exports.

The central Delta is the region where phytoplankton levels could most likely be impacted by State Water Project operations. Increases in channel water velocities and changes in flow patterns (*eg*, cross-Delta flows and reverse flows) result in reduced residence times, increased amounts of Sacramento River water, and decreased amounts of San Joaquin River water in the central Delta. The net effect of these impacts is not known; seasonal phytoplankton blooms do occur in the central Delta (Figure 12), but the intensity, duration, and species composition may be altered by project operations.

The introduced clam *Potamocorbula amurensis* may have also caused sustained reductions in phytoplankton biomass in some regions of the estuary. In 1987, this clam became abundant in Suisun Bay and has resulted in lower phytoplankton biomass levels ever since (Alpine and Cloern 1992). Phytoplankton biomass levels in other regions may also be affected by establishment of this clam. *P. amurensis* is a highly efficient suspension feeder (Hollibaugh and Werner 1992) that has become established at high concentrations in San Pablo Bay, Suisun Marsh, and Suisun Bay (Hymanson 1991).

Changes in sewage treatment practices and loadings could also affect the abundances of phytoplankton, zooplankton, and the organisms that feed on them. Recent studies from the Potomac estuary suggest reductions in sewage treatment plant nutrient loads lowered the fertility of striped bass spawning and nursery regions and contributed to the recent decline of striped bass there (Tsai *et al* 1991). Although no such study has been completed for this estuary, a similar situation could exist.

Although phytoplankton biomass declined at about the same time as did abundance of some zooplankton and fish, there is no evidence from this estuary directly linking these declines. Declines at one level of the food chain could be due to the same factor or factors causing declines at another level. Zooplankton, which probably have the greatest dependence on phytoplankton, are capable of meeting their food requirements from consumption of particulate organic matter and, via the microbial loop, bacteria. Several factors have most likely contributed to the decline of biota in this estuary.

Zooplankton

Zooplankton are small, sometimes microscopic aquatic animals found throughout the estuary. Zooplankton often occupy an intermediate level in estuarine food chains because many feed on phytoplankton and organic detritus and because they are a major food source for various life stages of several estuarine fishes, including striped bass and Delta smelt.

A comprehensive analysis of Fish and Game's zooplankton compliance monitoring data was recently completed (Obrebski *et al* 1992), which updates and expands information presented by Fish and Game during the Phase I hearings (Orsi 1987). Results from this comprehensive analysis show abundance of 12 of the 20 zooplankton taxa routinely monitored has declined significantly between 1972 and 1988; 7 taxa exhibited no trend in abundance; and abundance of one introduced copepod, *Oithona davisae*, increased (Table 5).

Table 5
SUMMARIES OF CHANGES IN SUISUN BAY/DELTA ZOOPLANKTON ANOMALIES
Results of Regression Analysis of Annual Mean Anomalies

	POOLED DATA (All Months)	SPRING (March-May)	SUMMER (June-August)	FALL (September-November)
COPEPODS				
Acartia	0	0	0	0
Diaptomus	D**	0	D**	D***
Eurytemora	D***	D**	D***	D**
Harpacticoids	D**	D**	D*	D*
Cyclopoids	D*	0	0	D*
Sinocalanus	0	0	0	0
Limnoithona	0	0	0	0
Oithona davisae	I*	0	I*	I*
CLADOCERA				
Bosmina	0	0	0	0
Daphnia	D*	0	D*	D*
Diaphanosoma	D*	U*	D*	D***
ROTIFERA				
Asplanchna	D**	D*	D**	D**
Keratella	D***	D**	D**	D***
Polyarthra	D***	D***	D***	D***
Synchaeta spp.	0	0	0	0
Synchaeta bicornis	D***	D**	D***	D***
Trichocerca	D***	D**	D**	D**
OTHER				
Neomysis	D*	0	0	D**
Barnacle Nauplii	0	0	0	0
Crab Zoea	0	0	0	0

0 = NO CHANGE D = DECLINE I = INCREASE U = U SHAPED TREND
* 0.01 < P < 0.05
** 0.001 < P < 0.01
*** P < 0.001

SOURCE: S. Obrebski, J.J. Orsi, and W. Kimmerer. 1992. Long-term trends in zooplankton distribution and abundance in the Sacramento-San Joaquin estuary. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary. Technical Report 32.

The comprehensive analysis by Obrebski *et al* (1992) included an examination of zooplankton data for regional and seasonal trends (Table 6). In general, results show declines in zooplankton abundance were scattered throughout the upper estuary, but declines were more prevalent in the Sacramento and San Joaquin rivers than in Suisun Bay. Some species showed season-specific declines, but no overall trend was apparent.

Several introduced zooplankton are now routinely collected in this estuary. It is thought that these exotic zooplankton species may adversely impact native zooplankton abundances, but there is no substantiating evidence from this estuary. Several introduced zooplankton may benefit some resident fishes; striped bass and Delta smelt are known to consume the exotics *Sinocalanus doerrii, Pseudodiaptomus forbesi,* and *Gammarus daiberi.* However, it may be harder for fish to catch these exotic zooplankton compared to native species, reducing the actual benefit of these introduced species to fish.

Table 6

SUMMARY OF REGIONAL CHANGES IN ABUNDANCE OF ZOOPLANKTON TAXA THAT DECLINED BETWEEN 1972 AND 1987

Numbers are adjusted R^2 for either a *linear or quadratic model*, whichever yielded the highest R^2.
AL = data pooled for all months, SP = spring, SU = summer, FA = fall

	SUISUN BAY				SACRAMENTO RIVER				LOWER SAN JOAQUIN RIVER				UPPER SAN JOAQUIN RIVER				WESTERN DELTA				ENTRAPMENT ZONE			
	AL	SP	SU	FA	AL	SP	SU	FA	AL	SP	SU	FA	AL	SP	SU	FA	AL	SP	SU	FA	AL	SP	SU	FA
Diaptomus	.33*	NS	NS	.55**	.29*	NS	.24*	.36*	.23*	NS	NS	.41*	.62**	.25*	.57***	.60**	.52**	NS	.31*	.67***	.26*	NS	NS	.57**
Eurytemora	.26*	NS	.20*	.22*	.57**	.50**	.42*	NS	.67***	.50***	.44**	.61**	.40*	.36*	.42*	NS	.68***	NS	.52**	.63**	.39**	NS	.61***	.21**
Harpacticoids	NS	NS	NS	NS	.20*	NS	.29*	NS	.73***	.58***	.58**	.61**	NS	NS	.23*	NS	.57**	NS	NS	.59**	NS	NS	NS	NS
Cyclopoids	NS	NS	NS	NS	NS	NS	NS	NS	.22*	NS	NS	.23*	.40*	NS	.31*	.34*	.37*	NS	NS	NS	NS	NS	NS	NS
Daphnia	NS	NS	NS	NS	NS	NS	NS	NS	.32*	NS	.31*	.36*	.48*	NS	.38*	.41**	.59**	NS	.41*	.41**	NS	NS	NS	NS
Diaphanosoma	NS	NS	NS	NS	.72***	.60**	.63**	.41**	.78***	NS	.45*	.74***	.44**	NS	.35*	.64*	.37*	NS	NS	.60**	NS	NS	NS	NS
Neomysis	.45**	NS	.45*	.70***	.62**	.46**	NS	.62**	.39*	NS	NS	.57**	.65***	.62**	NS	.47**	.55**	.58**	NS	.57**	.36**	NS	.23*	.61**
Trichocerca	.61**	.54**	.59**	.58**	NS	NS	.29*	NS	.30*	.21*	.51**	NS	NS	NS	NS	NS	.58**	.46**	.52**	NS	.59**	.48**	.59**	.55**
Polyarthra	.69***	.74***	.47**	.64**	.87***	.58**	.86***	.69***	.93***	.72***	.91***	.73**	.89***	.73**	.86***	.88***	.93***	.78***	.87***	.80***	.73**	.73**	.64**	.70**
Synchaeta bicornis	.46**	.30*	.68***	.47**	.62***	.51**	.49**	.35*	.53**	.34*	.50**	.31*	.59***	NS	.49**	.34*	.58**	.38*	.54**	.54**	.50**	.30*	.45*	NS
Asplanchna	.39*	NS	NS	NS	.84***	.77***	.79***	.75***	.82***	.70***	.81***	.74***	.50**	NS*	.59**	.46*	.76***	.62**	.72***	.60**	.53**	.38*	.23*	NS
Keratella	NS	NS	NS	NS	.89***	.74***	.83***	.75**	.90***	.60**	.87***	.71**	.78***	.57**	.74***	.85***	.91***	.74***	.70**	.88***	.77**	.64**	.51*	.71**

NS Not Significant
* $0.01 < P < 0.05$
** $0.001 < P < 0.009$
*** $P < 0.001$

SOURCE: S. Obrebski, J.J. Orsi, and W. Kimmerer, 1992. Long-term trends in zooplankton distribution and abundance in the Sacramento-San Joaquin estuary. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary. Technical Report 32.

Predation by the exotic clam *Potamocorbula amurensis* is thought to have a significant impact on *Eurytemora affinis* in Suisun Bay (Wim Kimmerer, pers comm). Laboratory studies found *P. amurensis* are able to consume the nauplii of *E. affinis*. The clam became abundant in Suisun Bay in 1988 and *E. affinis* abundance decreased substantially at the same time (Obrebski *et al* 1992). Additional investigations show State Water Project exports probably have not significantly affected abundance of the native copepod *E. affinis* (Kimmerer 1992).

Pollutants may also be a factor in the decline of zooplankton in the upper estuary. Investigations have shown rice pesticides in Colusa Basin Drain water are toxic to *Neomysis mercedis*, a native zooplankton important to striped bass (Foe and Connor 1991). Studies of the impacts of toxins and introduced organisms show there are several probable causes for the large-scale decline of zooplankton in the upper estuary.

Reasons for the systemwide decline of several zooplankton taxa are not known. The declines occurred at about the same time as declines in phytoplankton and various fish species, but no cause-and-effect relationships have been established. The Interagency Food Chain Group is investigating the causes.

Zooplankton are a primary food for several fish species, but there have been few studies as to whether these fish are, in fact, food-limited. One recent study by Bill Bennett and David Hinton of U.C. Davis found no significant indication of starvation in wild striped bass larvae (Bennet *et al* 1990). There are several reasons this might be so: food abundance is sufficient for the number of bass larvae in the estuary; introduced organisms have substantially supplemented the native food supply of striped bass; larval bass are able to feed successfully at times and locations of high zooplankton abundance; or starved larvae are not being sampled due to rapid removal by predation or other means.

It does appear that zooplankton levels are much lower in our estuary than in the Chesapeake and that larvae may be receiving less than optimum rations. If these larvae are growing slowly, their exposure to predators may be increased. Preliminary results of recent studies (W. Bennett, pers comm) have shown undernourished larvae are more susceptible to predation by a common Delta fish, inland silverside.

Introduced Organisms

Benthic organisms in general, and mollusks in particular, have entered the estuary with almost regular frequency (Figure 14). Documented introductions of organisms to this estuary began in the mid-1800s and, as shown in Table 7, they continue unchecked. Table 7 is not a complete listing of all organisms introduced into this estuary (for instance, the chameleon goby, the silverside, and several species of catfish are also introduced), but it does point out the magnitude of the problem. Several organisms, particularly fish and oysters, were introduced intentionally to provide new and desirable food sources. Most introductions were not desirable, and several have had substantial economic or ecologic impact.

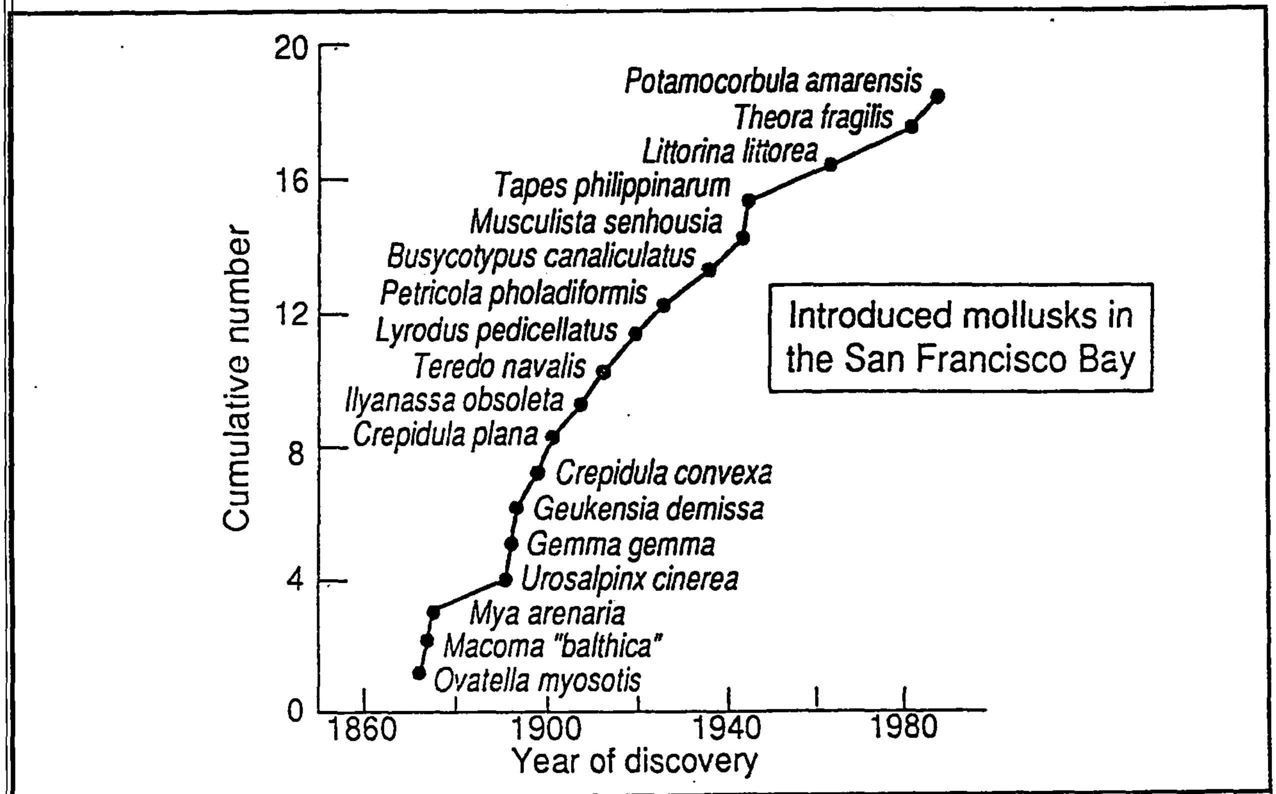


Figure 14

INTRODUCED MOLLUSKS IN SAN FRANCISCO BAY

SOURCE: F. Nichols and J. Thompson, U.S. Geological Survey.

Striped bass have received by far the most attention of any fish species introduced into this estuary. Striped bass abundance increased rapidly after it was introduced and remained quite high for many years. Over the last several years, striped bass has been pointed to as an "indicator species" for the health of the estuary, and its decline has been cited as primary evidence of the need for more stringent management actions. However, numerous factors probably have contributed to the decline of this species, some of which may be beyond our ability to control.

Whether intentional or accidental, introduction of exotic organisms constitutes biological pollution, with many of the same effects as other, more familiar forms of pollution. The most recent example of such impacts is the introduction and establishment of the Asian clam, *Potamocorbula amurensis* (Carlton *et al* 1990). In little more than 4 years after it was first detected, this clam became the most abundant benthic organism in several regions of the upper estuary and is among the most widely distributed (Hymanson 1991). This clam has altered trophic dynamics by adding a new, abundant food source for bottom-feeding organisms. It also competes with other benthic organisms for space and food and with other pelagic organisms for food (Nichols *et al* 1990). In addition, this clam can bioaccumulate high concentrations of selenium, which could result in higher tissue concentrations in organisms that feed on it (Urquhart *et al* 1991).

Table 7
GENERAL CHARACTERISTICS OF INTRODUCED ORGANISMS IN SAN FRANCISCO BAY

Common Name (Scientific Name)	Descriptor	Date of Introduction	Origin	Mode of Introduction	Economic/Ecologic Impact
Isopod (*Sphaeroma quoyanum*)	Pillbug	1850-90	Australasia	Shipping	Bores and weakens dikes and banks
Eastern Oyster (*Crassostrea virginica*)	Oyster	1869	Atlantic	Intentional/Railroad	Commercial aquaculture
American Shad (*Alosa spadissima*)	Fish	1871	Eastern No.America	Intentional/Railroad	Commercial/ sport fishery
Gribbles (*Limnoria* spp.)	Pillbug	1873	Unknown	Shipping	Destruction of wood structures
Soft Shell Clam (*Mya arenaria*)	Clam	1874	Atlantic	Accidental with oysters	Sport fishery
Striped Bass (*Morone saxatillis*)	Fish	1879	Eastern No.America	Intentional/Railroad	Commercial/sport fishery
Shipworm (*Teredo navalis*)	Boring Clam	1913	Atlantic	Shipping	Destruction of wood structures
Japanese Oyster (*Crassostrea gigas*)	Oyster	1930	Japan	Intentional/Shipping	Commercial aquaculture
Japanese Littleneck (*Tapes japonica*)	Clam	1946	Japan	Accidental with oysters	Sport fishery
Asian Clam (*Corbicula fluminea*)	Clam	1946	SE Asia	Ballast water or Intentional	Commercial fishery; Fouls freshwater canals
Yellowfin Goby (*Acanthogobius flavimanus*)	Fish	1963	Japan	Ballast water	Competes with native fish for food
Copepod (*Oithona davisae*)	Zooplankton	1966	Japan	Ballast water	Unknown
Snail (*Littorina littorea*)	Snail	1968	Atlantic	On algae used to pack eastern lobster	Unknown
Copepod (*Sinocalanus doerrii*)	Zooplankton	1978	China	Ballast water	May compete with or prey upon other zooplankton
Copepod (*Limnoithona sinensis*)	Zooplankton	1979	China	Ballast water	Unknown
Clam (*Theora fragilis*)	Clam	1982	Japan	Ballast water	Unknown
Amphipod (*Gammarus daiberi*)	Amphipod	1983	Eastern No.America	Unknown	Consumed by striped bass
Asian Clam (*Potomocorbula amurensis*)	Clam	1986	Asia	Ballast water	Alters food chain
Crustacean (*Hemileucon hinumensis*)	Crustacean	1986	Japan	Ballast water	Unknown
Copepod (*Pseudodiaptomus marinus*)	Zooplankton	1986	Japan	Ballast water	Additional food source for fish
Copepod (*Pseudodiaptomus forbesi*)	Zooplankton	1987	Asia	Ballast water	Additional food source for fish
Snail (*Malanoides tuberculata*)	Snail	1988	Unknown*	Unknown	Unknown
Polychaete (*Potamilla* sp.)	Worm	1989	Unknown**	Unknown	Unknown
European Green Crab (*Carcinus maenas*)	Crab	1991	Atlantic	Unknown	Voracious predator of mollusks
Polychaete (*Spionid* sp.)	Worm	1991	Unknown	Unknown	Unknown

*Reported to have a nearly worldwide distribution.
**May be new to science.

SOURCE: Adapted from information compiled by F. Nichols and J. Thompson, U.S. Geological Survey.

Entrapment Zone

The entrapment zone is a transient region of the estuary where freshwater and saltwater flow interact to elevate particulate concentration. Other terms such as "turbidity maximum zone", "estuarine turbidity maximum", or "null zone" refer to related phenomena but do not have the same meanings (Kimmerer 1992).

The entrapment zone forms principally as a result of 2-layered flow. As fresh water flows downstream over the more dense, landward-flowing salt water, some of the water in each layer moves vertically due to frictional forces between the layers. The combination of vertical mixing between the freshwater and saltwater layers and the horizontal flows within these layers traps particles with certain settling velocities. The appropriate settling velocities and particle residence time in the zone vary with size of the entrapment zone and velocity of horizontal flows. The location and size of the entrapment zone are both affected by the magnitude of freshwater and tidal flows, bottom topography, and wind.

The position of the entrapment zone is most accurately determined by measurements of tidally averaged water velocities or water column turbidity. However, because of the difficulty in collecting these types of measurements, an operational definition based on salinity or specific conductance has been used to define entrapment zone location in this estuary. In a comprehensive evaluation of existing information on the entrapment zone of the estuary, Kimmerer (1992) uses an operational definition developed by Arthur and Ball (1978) of 2 to 10 milliSiemens per centimeter at the surface to define entrapment zone location.

Importance of the Entrapment Zone to Biomass and Growth Rates

Biological production has two components: biomass, a quantity of mass or weight of living material per some unit area or volume; and growth rate, the change in size of an organism over time. Both biomass and growth rate vary within the estuary, and a measurable increase in either component could be interpreted as an increase in production. Based on his analysis, Kimmerer (1992) made the following conclusions:

- Phytoplankton growth rates are probably depressed in the entrapment zone relative to other areas of similar depths because of reduced light penetration.
- Phytoplankton biomass and probably production are enhanced, probably due to entrainment brought on by the physical characteristics of mixing and net upward flow in the entrapment zone.
- There is no evidence that growth rates of zooplankton or larval striped bass are higher in the entrapment zone than outside the entrapment zone. Growth of larval bass do not vary between those captured in and upstream of the entrapment zone.
- Elevated abundance of zooplankton and fish is likely a result of entrapment in this zone rather than a biological response to higher food levels.

In addition, the point is made that production estimates for zooplankton and fish are a function of both biomass and growth rates. Thus, to accurately measure production, measures of both biomass and growth rates must be obtained, since increases in one component may be negated by decreases in the other. Since growth rates of zooplankton and fish have not been measured in this estuary, it is not known whether their production varies within or outside the entrapment zone.

Importance of Entrapment Zone Position to Biomass

Positioning the entrapment zone to maximize the benefit to estuarine biota has been the subject of considerable debate. Results from several studies show entrapment zone location is correlated with the abundance of many organisms within this estuary, but the mechanism for this is unknown. In fact, the correlations may be due to underlying relationships with flow, strength of entrapment, or other variables rather than a direct effect of entrapment zone position (Kimmerer 1992). Additionally, correlations between organism abundance and entrapment zone position do not permit a determination of whether increased abundance in the entrapment zone is the result of increased biological productivity or simply a result of entrapment and physical concentration of individuals.

Between 1972 and 1988, abundance of numerous organisms declined significantly. These resources include phytoplankton (as measured by chlorophyll *a*), native zooplankton such as *E. affinis* and *N. mercedis,* striped bass (as measured by the young-of-the-year index), and Delta smelt. It has been suggested these declines are at least partially attributable to changes in entrapment zone position; specifically, the movement of the entrapment zone upstream to the narrow, deeper channels of the Sacramento and San Joaquin rivers and away from the broad shoals in Suisun Bay.

In his recent analysis of the physical and biological significance of the entrapment zone, Kimmerer (1992) draws the following conclusions in regard to these biological resources.

- Most of the annual measures of biological abundance, and probably production, were related to entrapment zone position. Highest values occurred when the entrapment zone was below the confluence of the Sacramento and San Joaquin rivers. However, for *E. affinis* and *N. mercedis*, the variation of abundance with entrapment zone position probably is not due to changes in exposure of the population to export pumping. In other words, export pumping has rarely (if ever) had a direct effect on the population size of these zooplankton.
- The long-term declines in abundance of these organisms cannot be attributed to long-term (1972 through 1989) changes in entrapment zone position, because there was no trend in entrapment zone position.

Importance of the Entrapment Zone as Habitat in Suisun Bay

Kimmerer (1992) points out that the ~~volume of habitat provided~~ by the entrapment zone (defined as a range of surface salinity values) ~~does not vary with entrapment zone position~~. Mean depth is lowest when the entrapment zone is downstream of Chipps Island and highest when it is upstream of Chipps Island, implying that shallow-water habitat (and presumably surface area) is greatest when the entrapment zone is in Suisun Bay. Therefore, maintaining the entrapment zone in Suisun Bay, where depths are less, would provide more shallow water habitat for some planktivorous fish such as Delta smelt. Kimmerer also notes that larval striped bass appear to survive better when the entrapment zone is downstream of the Delta, and Delta smelt may have higher year classes when the entrapment zone is downstream. These hypotheses are not tested or substantiated by definitive analyses. Kimmerer does point out, however, that correlations may be due to underlying relationships with flow, strength of entrapment, or other variables rather than a direct effect of entrapment zone position. Mechanisms for these relationships are not yet fully understood.

doesn't volume change with flows?

Pollutants

In November 1982, the Striped Bass Working Group, a group of scientists convened by the State Water Resources Control Board, distributed a report listing four reasons for the striped bass decline (Striped Bass Working Group 1982). These reasons are:

- Inadequate food supply for the young bass,
- Entrainment losses in diversions,
- Lack of striped bass eggs,
- Toxic substances.

The scientists found evidence that adult bass have accumulated toxins in their flesh at levels exceeding those recommended for aquatic life. They also concluded that pesticides drained from rice fields in the spring could sometimes affect eggs, larvae, or adults in the Sacramento River. Due to insufficient data, it could not be concluded that toxins were a major cause of the striped bass decline, but many of the scientists believed toxicants were contributing to the decline. The report recommended continued investigation.

Investigations have continued in the 10 years since that report was published. In particular, toxicity of the Sacramento River and adjacent channels has been investigated by the Central Valley Regional Water Quality Control Board and the University of California at Davis; the striped bass annual summer die-off has been investigated by researchers at the University at Davis, San Francisco, and Berkeley; and histological work on striped bass livers has been conducted by researchers at Davis. Conclusions from all the investigations implicate toxic substances as inducing mortality on different life stages of striped bass. Based on their studies, some of the researchers believe toxic substances have played a significant role in the decline of striped bass (Foe and Connor 1989, Bailey 1992). The investigations are discussed below.

Sacramento River Toxicity

During the mid-1970s, rice farmers switched to growing short-stemmed rice, which entailed higher applications of pesticides. Consequently, toxic contamination of Sacramento River water flowing into the Delta increased sevenfold. Concentrations high enough to kill fish and invertebrates were found during surveys in several sloughs near rice fields in the Sacramento Valley (Foe 1989). Bioassays showed drain water entering the Sacramento River was toxic to striped bass larvae (Foe 1988, 1989).

A major finding of a study conducted by the Central Valley Regional Water Quality Control Board in 1987 employing the Environmental Protection Agency's 3-species test procedure was the low growth and high mortality rate of fish at almost all sites sampled in late May and early June along the Sacramento River, both in the Central Valley and in the Delta. This finding is significant, because timing of the toxicity observations coincides with the striped bass spawning season (Foe 1987).

For 1970 through 1986, Foe (1989) developed a correlation between pounds of methyl parathion applied annually to rice fields divided by the flow rate of the Sacramento River, and the annual difference between the predicted and observed number of larval bass in the Delta. The correlation is statistically significant ($p<0.01$). Foe showed that including a Sacramento River pesticide concentration factor in Fish and Game's striped bass index accounts for 42 percent of the unexplained variance between the predicted and observed indexes. He proposed two hypotheses for this finding:

- One or more chemicals associated with the rice discharge are toxic to larval bass while they are in the Sacramento River and western Delta.
- The associated chemicals are toxic to the bass' principal food organisms, resulting in a lower ration and poorer survival for larval fish while in the river and Delta.

Howard Bailey at U.C. Davis conducted toxicity studies of the Colusa Basin Drain using striped bass larvae for three consecutive seasons: 1989 through 1991 (Bailey 1992). Of 14 samples tested in 1989, 10 exhibited significantly higher mortality compared with the controls (81 percent mortality in drain samples; 15 percent mortality in the controls). The 1990 results were similar. All 22 samples exhibited significantly greater mortality (84 percent) compared with the controls (20 percent).

In addition, toxicity tests with *Neomysis mercedis* were conducted in 1989 and 1991 (Bailey 1992). These tests also showed that Colusa Basin Drain samples were acutely toxic to *Neomysis mercedis*, the predominant food organism of juvenile striped bass in the Delta. Of the 18 samples tested in 1989, 14 produced mortality (78 percent), generally affecting all the test organisms within 24 hours (Bailey 1992). In 1991, 20 samples were subjected to toxicity tests with striped bass larvae. Average mortality was 40 percent, compared to 13 percent for the controls. Only 5 of the samples exhibited more than 75 percent mortality, and 10 samples exhibited less than 25 percent mortality. The 1991 results may reflect the mandates of the Regional Water

Quality Control Board and the Department of Food and Agriculture to reduce toxicity of the drain water by holding field water for a longer period before discharge (Bailey 1992).

To determine if a relationship exists between striped bass larval recruitment and pesticides applied to rice, Bailey (1992) estimated the instream concentration of six pesticides applied to rice over a period of 18 years. Estimated instream concentrations of each chemical were regressed against the annual 38-millimeter index to evaluate their relationships to recruitment during their periods of use. Bailey discovered that individually the chemicals could account for 23 to 63 percent of the variation in annual recruitment during their period of use. Combinations of pesticides account for at least 90 percent of the variation in annual recruitment during 1973 through 1981. Bailey contrasts these findings with the flow and exports regression, which accounts for only 16 percent of the variation in annual recruitment during the same period. For 1973 through 1988, the chemicals account for 86 percent variation; the flow and export model accounts for 43 percent of the variation in recruitment.

Beginning in 1984, holding times for chemicals were required in the field before release. Through the years, the holding periods became progressively longer. In 1986 through 1991, the predicted and the actual 38-millimeter index again became significantly correlated (Bailey 1992).

Bailey concludes that, for at least 1973 through 1986, the data support the hypothesis that discharge of water containing pesticides from rice culture has adversely affected the Sacramento-San Joaquin striped bass population (Bailey 1992).

Striped Bass Summer Die-Off

Each year, during May and June, hundreds to thousands of dead adult striped bass are seen in the Sacramento-San Joaquin estuary — in the water and washed up along the shoreline. The largest numbers of dead and nearly dead fish are in Carquinez Strait.

In 1985, researchers from U.C. Berkeley analyzed tissue and blood samples from three moribund striped bass collected at Carquinez Strait during the 1985 summer die-off. The fish were distressed, surfacing, rolling, and moving passively with tidal currents, and they offered little resistance when captured with a landing net (Brown 1987). Results of the laboratory analysis were compared to tissue and blood samples collected from four healthy striped bass caught by hook and line from a boat, also in Carquinez Strait. According to Brown (1987), histological appearance of liver samples from the moribund fish and the controls was strikingly different. All the moribund fish displayed liver dysfunction. They exhibited yellow deposits in the scales, and their plasma was yellowish, indicating jaundice. Other indications of liver disease in the moribund fish included widespread inflammation, pyknotic cells, and blood stasis, indicating chronic pathology of the liver. Livers of the control fish exhibited none of these characteristics (Brown 1987).

In 1987 researchers from U.C. San Francisco, Berkeley, and Davis also studied the livers of moribund and healthy striped bass for chemical contamination. The purpose was to identify the specific chemical constituents found in the livers (Cashman *et al* 1992). The livers of three groups of striped bass (8 moribund fish from Carquinez Strait, 8 healthy fish caught by hook and line in the Delta, and 8 healthy fish caught by hook and line in the Pacific Ocean off Pacifica) were examined for chemical contamination by gas chromatography, mass spectrometry, and immunoassay. The researchers concluded that the moribund striped bass livers were greatly contaminated by chemicals compared to the healthy fish caught in the Delta and Pacific Ocean. Contaminants included a variety of industrial (*eg,* aliphatic hydrocarbons, oxygen-containing hydrocarbons, aliphatic esters), agricultural (*eg,* herbicide-like materials, stabilizers), and urban (*eg,* benzothiazole, petroleum-based constituents, and dialkyl phthalates) pollutants. Due to the variety of contaminants, no one causative agent was identified. However, the large amount of pollutants clearly suggests chemical contamination may contribute to the striped bass die-off, possibly as a result of multiple stressors (Cashman *et al* 1992).

Sacramento River Striped Bass Liver Studies

Other evidence of toxic contamination comes from D. Hinton and W. Bennett of U.C. Davis. Liver sections of striped bass larvae from the Sacramento River show much higher incidence of malformation than larvae from elsewhere. About 26 percent of the larvae they sampled in the Delta in 1988 and 1989 exhibited liver abnormalities characteristic of exposure to toxic chemicals (Bennett *et al* 1990). However, no quantitative estimates of mortality due to toxic contaminants were made. Although concentrations of contaminants in striped bass flesh are now being monitored, no comparable data exist from before the decline of the striped bass population in the 1970s that would allow for estimates of changes in contamination (Herbold *et al* 1992).

Poaching

Poaching of undersized striped bass may cause a serious loss to the population. Department of Fish and Game staff recently concluded that "... it is not unreasonable to speculate that well over 500,000 undersized striped bass are taken illegally each year ... [in addition to] tens of thousands of adult bass" (Johnston 1991). The potential impact on the legal-sized population can be estimated by making the conservative assumptions that poached fish average 2 years old and that 25 percent of them would have survived to legal size. The net result would be the equivalent of at least 125,000 legal-sized adults lost each year. By contrast, Banks Pumping Plant operation is estimated to result in an average loss of an equivalent of 86,000 legal-sized bass per year, which are mitigated in accordance with the Two-Agency Fish Agreement.

Upstream and Downstream Factors

Although the Delta is recognized as an important part of the life cycle of many aquatic species, factors upstream and downstream often play a greater role in regulating population levels. While efforts have been made to mitigate through hatcheries and gravel and streambed restoration, spawning and rearing habitat remains severely degraded in many of the Delta's tributaries.

Upstream impacts are most serious for migratory species such as salmon, striped bass, and American shad, which rely on upper tributaries to complete their life cycles. Major factors include blockage of upstream spawning areas by impoundments; unscreened or inefficient agricultural diversions; insufficient streamflow; and habitat degradation from gravel mining, logging, or other land use practices. For example, the reproductive success of American shad appears to depend on the quantity and distribution of flows in upstream tributaries (DFG 1991).

Upstream effects also play an important role in the status of winter-run Chinook salmon populations. In 1988, a 10-point plan was agreed to by the Bureau of Reclamation, Fish and Wildlife Service, National Marine Fisheries Service, and Department of Fish and Game to reduce the impact of upstream factors on winter-run salmon. Key provisions of the plan include reoperation of Red Bluff Diversion Dam gates, correction of water quality problems, habitat restoration, predator control, and reduction of entrainment at Anderson-Cottonwood Irrigation District Diversion Dam.

For Chinook salmon, the primary impact downstream of the Delta is commercial and sport fishing in the ocean. This is closely regulated by the Pacific Fishery Management Council; nonetheless, it represents a significant factor. The Department of Fish and Game also regulates salmon and other fishing activities in San Francisco Bay and California's coastal waters.

Delta Agricultural Diversions

The peak agricultural diversion season in the Delta is April through August, coinciding with months when large numbers of young Chinook salmon, striped bass, American shad, Delta smelt, and other fish are present. The estimated total average diversion rate from Delta channels during the growing period ranges from 2,500 to 5,000 cubic feet per second (Brown 1982). Allen (1975) estimated that, from 1959 to 1973, agricultural diversions averaged about 27 percent of the June/July inflow.

Several estimates of impacts of agricultural diversions on fish have been made over the years. Brown (1982) estimated that several hundred million striped bass less than 16 millimeters long are impacted. Chinook salmon losses have been estimated to be in the tens of thousands. Based on a limited study on Sherman Island, Allen (1975) reported concentrations of eggs and young striped bass from the diversions were statistically identical to those in the adjacent San Joaquin River (up to 5.8 eggs per cubic meter of water, and up to 2 bass per cubic meter). It is possible that agricultural diversions impact Delta fish by at least the same order of magnitude as do facilities of the Central Valley Project and State Water Project.

In April 1992, as part of the Interagency Ecological Studies Program, the Department of Water Resources began a 3-year study of impacts of Delta agricultural diversions on fish. The study is also a part of the Interagency Program's Delta smelt study plan and south Delta barriers mitigation project. The objective is to develop reliable estimates of losses of various fish species and their life stages to Delta agricultural diversions relative to abundance of those species in adjacent channels. The study currently encompasses four sites on islands in the northern, central, and southern Delta (Figure 15). The adjacent channels are representative habitats for anadromous and resident Delta fish.

The northern Delta site is on Twitchell Island, adjacent to the San Joaquin River. In the central Delta, one site is on the east side of Bacon Island, adjacent to the Middle River, and another is on the east side of McDonald Island, adjacent to Turner Cut. The southern Delta site is near Tracy, just south of Fabian Tract and adjacent to Old River. The site on McDonald Island contains an experimental fish screen, the efficiency of which will also be tested during this study. Agricultural operations at all four sites are representative of Delta agricultural diversions.

Samples are collected at least four times a week in agricultural ditches on the islands, first using an egg and larval net, then a larger mesh net as the season progresses. Adjacent channels are sampled by an egg and larval net towed by a boat on the same days samples are collected on land. All the samples are delivered to a consultant for analysis. Eggs and fish larvae are counted and identified to species, where possible.

On McDonald Island, samples will be collected with and without the fish screen in operation.

A report will be prepared when sampling has been completed for this year. The report will describe susceptibility of fish and their life stages to agricultural diversions and will recommend sampling procedures for 1993.

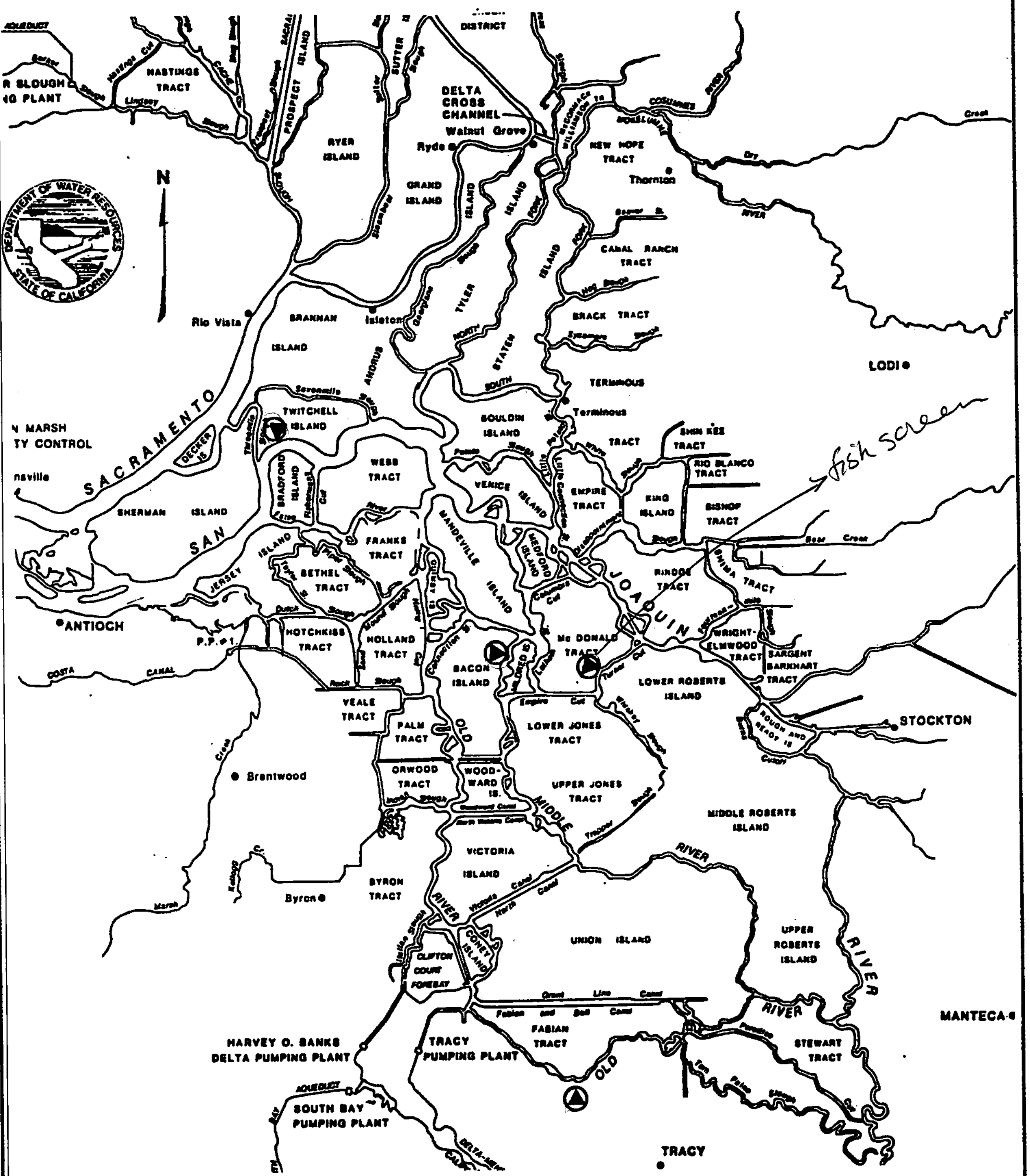


Figure 15
SAMPLING LOCATIONS, AGRICULTURAL DIVERSION STUDY, 1992

ACTIONS TO IDENTIFY, AVOID, AND MITIGATE STATE WATER PROJECT IMPACTS

Since the Phase I hearings in 1986, the Department of Water Resources has continued to work with the Department of Fish and Game, U.S. Fish and Wildlife Service, and National Marine Fisheries Service to lessen known and potential adverse effects of the State Water Project on Bay/Delta resources and to mitigate losses that could not be reasonably avoided. We have reduced and shifted exports, made other operational changes, and constructed new facilities to minimize impacts on fish. We have also agreed with Fish and Game on a method to estimate and mitigate direct losses of striped bass, salmon, and steelhead at Banks Pumping Plant. We have offset a large portion of these direct losses by improving upstream fish habitat, reducing losses to poaching and to Delta diversions by others, and stocking replacement fish.

Export Limitations

From August through April, diversion to Banks Pumping Plant is limited to an average of about 6,400 cubic feet per second, in accordance with terms outlined in Corps of Engineers Public Notice 5820A, Amended, October 13, 1981. This is about 60 percent of the plant's capacity of 10,300 cfs. The 6,400 cfs limit was originally established to avoid risk of scouring channels leading to Clifton Court Forebay and risk of drawing water levels down to where they would adversely affect navigation and agricultural diversions in the southern Delta. However, in the Two-Agency Fish Agreement, the Department of Water Resources committed to maintain diversions within these limits (even if the Corps' limitation is removed) until we reach an agreement with Fish and Game on offsetting impacts not covered in the agreement.

Decision 1485 further limits diversions to Banks Pumping Plant to an average of 3,000 cfs in May and June and to 4,600 cfs in July to protect Delta fish. The pumping limits were applied to these three months because bass, salmon, and a number of other species are most abundant at the pumping plant during this period. In 1987, the Department of Water Resources also committed to curtail the transfer of water from upstream storage reservoirs through the Delta in May and June whenever it would cause diversion to Banks Pumping Plant to exceed an average of 2,000 cfs (Mullnix 1987). This more restrictive operational criterion keeps fish losses even lower than they would have been with Decision 1485 alone.

Water Resources, Fish and Game, Fish and Wildlife Service, and National Marine Fisheries Service staff meet several times a year to identify ways to better schedule State Water Project operations to minimize fish impacts and provide more suitable conditions for fish studies. Although contractual obligations have not allowed us to do everything the fishery agencies would have liked, we have made some significant adjustments. For example, we limited Delta diversions for the 1991 Water Bank in early summer when fish densities in the southern Delta are highest and in late fall when the Department of Fish and Game had concerns that winter-run salmon might be in the Delta. We also cut back diversions to less than 400 cubic feet per second in early February 1992 and again during most of April 1992 to reduce winter-run salmon impacts. As a result of the latter export limits, we diverted about 140,000 acre-feet less water from the Delta than we would have otherwise.

during that time period or what?

Fish Salvage Improvements

The Department of Water Resources has spent nearly $5 million for design and operational improvements to Skinner Fish Facility during the last few years to reduce losses at Banks Pumping Plant. We recently installed three additional holding tanks to reduce water velocities and fish losses in the tanks, improve accuracy of the salvage estimates, and thereby improve efficiency of the salvage operation. The Department of Fish and Game has been given control of the salvage operations, and personnel have been added to improve their effectiveness.

Predator Removal

Most of the calculated fish losses at Banks Pumping Plant are assumed to be due to predation by subadult striped bass in Clifton Court Forebay. To determine the State Water Project's mitigation obligation, the Department of Water Resources and Department of Fish and Game have assumed a 75 percent forebay predation loss rate for salmon smolts and steelhead trout and a size-dependent predation rate that varies from 0 to 100 percent for striped bass. Using these assumptions, predation accounted for up to 70 percent of the average annual losses calculated for striped bass and 90 percent of losses for salmon at the pumping plant during water years 1980 through 1987.

Because predation is thought to be responsible for such a high percentage of the fish losses, Water Resources and Fish and Game have put considerable effort into evaluating ways to better quantify and reduce predation losses in the forebay. Tagging and recapture studies indicated a substantial population of juvenile bass, which could account for such high losses during some times of the year. During the last 2 years, we have been evaluating the relative effectiveness of various techniques to catch and remove these fish. In March 1992, Fish and Game removed about 2,000 bass from Clifton Court Forebay. These efforts were the result of conditions contained in a February 1992 Biological Opinion related to CVP and SWP operations.

Beginning this fall, we will initiate a predator management program to reduce losses to predators. The goal is to reduce predation to background levels, or about 15 percent.

To facilitate this removal program, Water Resources is contracting with a commercial fisherman who will use large nets to capture striped bass and other predators in the forebay. If necessary to improve the efficiency of fish capture, modifications will be made at the forebay, such as removing snags, improving beaches, and installing anchors to which the ends of the nets can be attached. Captured fish will be released alive in the Sacramento River or other locations designated by the Department of Fish and Game.

Other fish capture techniques will continue to be evaluated. These include gill-nets (especially in the intake channel), hook and line, and dewatering channels leading to the secondary screens. If practical, the forebay may be drawn down periodically to concentrate the predators to enhance removal efficiency.

Concurrent with the removal efforts, Fish and Game and Water Resources will evaluate impacts on predators and the predation rate. Periodic population estimates or catch-per-unit-effort statistics will be used to determine whether removal causes substantial changes in predator populations. Also, mark/recapture, hydroacoustics, and netting studies will be used to determine changes in the predation rates themselves.

We recognize that predator control is only a partial solution to Delta fisheries concerns. It does offer the potential to significantly reduce losses due to direct entrainment at the State Water Project intake. Reduced entrainment-related losses would be particularly important for striped bass and Chinook salmon, populations of which have declined. Those declines have been partly attributed to losses of juveniles in Clifton Court Forebay.

Delta Channel Closures

For decades, barriers have been constructed in Delta channels to improve water quality and hydrodynamic characteristics for fish and water diversions. In cooperation with Fish and Game, the Department of Water Resources installs a temporary rock barrier at the head of Old River each fall to increase flow and thereby improve dissolved oxygen concentrations near Stockton for adult salmon migrating up the San Joaquin River.

We also installed the barrier at the head of Old River for several weeks this spring. Fish and Game and the Fish and Wildlife Service believe the barrier could significantly improve survival of salmon smolts migrating out of the San Joaquin River. The Fish and Wildlife Service studied the barrier's effect on survival of San Joaquin smolts and winter-run smolts in the central Delta. Although data analysis is not yet complete, preliminary results are that the barrier did improve survival. We plan to continue the study three more years.

Two-Agency Fish Agreement

On December 30, 1986, the Directors of the Department of Water Resources and Department of Fish and Game signed an agreement to provide for offsetting direct losses of fish caused by diversion of water at Banks Pumping Plant. The agreement, commonly referred to as the Two-Agency Fish Agreement (Phase I DWR-560), was adopted as part of the mitigation package for four new pumps at Banks Pumping Plant.

For purposes of the agreement, direct losses are defined as losses occurring from the time fish enter Clifton Court Forebay until the surviving salvaged fish are returned to Delta channels. Direct losses include those fish that are eaten by predators or otherwise lost in Clifton Court Forebay, those that pass through the Skinner fish screens, or those that die as a result of handling and trucking stresses during the salvage process.

Among other things, the Two-Agency Fish Agreement:

- Establishes a procedure to annually estimate direct losses of striped bass, salmon, and steelhead at Banks Pumping Plant and provides for modification of this procedure as new information becomes available.
- Provides for development of information needed to calculate and offset direct losses of other species.
- Sets forth criteria and a procedure to evaluate and implement projects to offset annual direct losses of striped bass, salmon, and steelhead.
- Establishes a $15 million lump-sum fund to implement fish projects in addition to those needed to offset annual direct losses.
- Provides for discussions between the Department of Water Resources and Department of Fish and Game to develop ways to offset adverse impacts of the State Water Project not covered in the agreement, including facilities needed to offset fish impacts and provide more efficient conveyance of water.

Water Resources and Fish and Game have implemented over a dozen fishery improvement projects to comply with provisions of this agreement. These have resulted in the stocking of about 4.5 million yearling equivalent striped bass, about 800,000 more than needed to replace losses at Banks Pumping Plant since 1986 (Table 2). Water Resources has also stocked about 1~~64~~79,000 yearling steelhead, ~~nearly~~ about 2~~1~~0,000 ~~more~~ less than needed to replace losses since 1986 (Table 3).

We raised another 2.5 million yearling striped bass to be stocked this year. However, in May, Department of Fish and Game temporarily suspended stocking of all hatchery-reared striped bass in the Delta to avoid any risk of the bass eating winter-run salmon. Therefore, the fish were planted in canals, reservoirs, and rivers south of the Delta.

While we have fully replaced direct losses of striped bass ~~and steelhead~~ since 1986, we have not done nearly as well replacing salmon losses. As of early June 1992, about 200,000 salmon smolts had been replaced by improving spawning habitat in Mill Creek and the Merced River (Table 1). Up to 700,000 more salmon were replaced in June 1992 from an expanded and modernized Merced River Fish Facility. We also hope to complete some additional habitat improvements on the Tuolumne River next summer. The total capacity of these habitat and hatchery projects should be sufficient to replace nearly a million smolts each year — about what we expect our annual losses to average over the next few years.

Because the salmon projects have taken longer than expected to develop, we have accumulated a mitigation obligation of about 7 million fish. The drought has compounded this problem by reducing San Joaquin Valley salmon stocks to such low levels that we are unlikely to get full production from these projects for several years. Until then, our mitigation obligation is expected to increase. Department of Fish and Game recognizes these problems and is trying to accelerate development of additional mitigation projects. (Remember also that 90 percent of these losses were attributed to predation, which we believe was actually less than assumed in calculating this loss.)

The Department of Water Resources has implemented six of the fishery improvement projects using the $15 million account, for which we do not receive credit to offset annual losses. These projects are:

- Placement of 100,000 cubic yards of salmon spawning gravel in the Sacramento River near Redding.
- Construction of two wells adjacent to Mill Creek to produce ground water for a local irrigation district in exchange for reductions in stream diversions when the water is needed for spring-run salmon spawning migration.
- Participation in control of water hyacinth in the Merced River to improve salmon migration.
- Stocking an additional 800,000 striped bass in the Bay/Delta.
- Construction and evaluation of a movable pen for rearing up to 50,000 yearling striped bass in Delta channels.
- Providing six additional wardens in the Delta to reduce poaching.

We are also screening Fish and Game's diversion from Montezuma Slough to Grizzly Island Wildlife Refuge.

During the last 6 years, Water Resources has spent or committed to spend over $15 million on fishery projects pursuant to the Two-Agency Fish Agreement. We expect to spend about the same amount over the next 6 years to offset accumulated and new annual losses and to implement additional fishery projects with the remainder of the lump-sum funds. Offsetting annual losses after 6 years will likely cost over $1.5 million a year.

SUMMARY

The Department of Water Resources has done several things to minimize adverse effects of State Water Project operations on biological resources of the Bay and Delta. Actions have included:

- Limiting exports when fish are most likely to be entrained.
- Reducing entrainment losses by reducing predation in Clifton Court Forebay and improving the design and operation of Skinner Fish Facility.
- Improving conditions for migration of anadromous fish through the Delta and reducing entrainment by closing selected channels.

The Department of Water Resources has been unable to avoid all impacts with existing facilities and still meet water delivery obligations of the State Water Project. Unavoidable effects have been due primarily to:

- Entrainment of fish at Banks Pumping Plant.
- Changes in magnitude and direction of flow in Delta channels.
- Diversions through the Delta Cross Channel.
- Changes in timing and magnitude of Delta outflow.

The Two-Agency Fish Agreement sets forth a method to estimate and mitigate direct losses of striped bass, salmon, and steelhead at Banks Pumping Plant. The Department of Water Resources believes some of the assumptions used in this method probably result in overestimates of direct losses, particularly in winter and spring. Nevertheless, we have offset estimated losses of striped bass and steelhead by stocking hatchery-reared fish. ~~Offset of estimated salmon losses~~ has been delayed because of:

why only non flow measures may not be adequate

- Longer development times than expected for mitigation projects.
- Low streamflows during the drought.
- Depressed salmon stocks in the San Joaquin Valley.

At this time we cannot quantify entrainment losses of other species at Banks Pumping Plant or State Water Project losses associated with changes in flow in Delta channels, Delta Cross Channel gate operation, and Delta outflow. Impacts of these effects on the population of most, if not all, species is not known.

Any decline of biological resources during 1972 through 1989 cannot be directly attributed to location of the entrapment zone, because there was no trend in change of location during that period.

Pollutants, poaching, agricultural diversions, introduced species, and poor upstream conditions appear to adversely affect biological resources in the Delta. The magnitude of these effects on some key species could be comparable to or greater than the effects of the State Water Project. In cooperation with the Department of Fish and Game, the Department of Water Resources is trying to better quantify these effects. We have also taken steps to reduce poaching and improve upstream habitat to offset adverse effects of the State Water Project on Delta resources.

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