APPENDIX A

Factors Affecting Striped Bass

Striped Bass Life History

Striped bass move regularly between salt and fresh water and usually spend much of their life-cycle in estuaries. Striped bass have three basic habitat requirements for successful completion of their life cycle: 1) a large river for spawning with sufficient velocity to keep the eggs and larvae suspended off the bottom, 2) a large body of water (e.g., San Francisco Bay, the Pacific Ocean) with large populations of forage fishes for the adults to feed on, and 3) an Estuary where juvenile striped bass can feed on invertebrates. In California, the Sacramento-San Joaquin system with its large complex Estuary, has satisfied all three requirements.

Sacramento-San Joaquin Estuary striped bass spend much of their lives in San Pablo and San Francisco bays, although they do move into ocean waters. There is a mass movement of the bass out of the western-most bays into fresher water in the fall. These fish overwinter in the upper bays and Delta, moving back into salt water in late spring or summer following the upstream spring spawning migration.

Spawning begins in April as bass move into suitable areas. Spawning peaks in May and early June. The exact time and location of spawning depends on the interaction of three factors: water temperature, flow, and salinity (Turner, 1976). Because of the interaction among these factors, there are two main spawning areas: the Sacramento River from Sacramento to Colusa, and the San Joaquin River and its sloughs from Antioch to Venice Island.

Population Status:

Following the introduction of striped bass from New Jersey in 1879, the bass population boomed. By the early 1900s the commercial net catch alone averaged over one million pounds annually. In 1934, commercial netting of striped bass was stopped by law. Except for a brief decline in the mid-1950s, angling success was very good through the early 1960s. At that time there were about three-million adult bass (greater than 16 inches in length) supported by approximately 20 million naturally-produced yearlings. The annual angler catch averaged 680,000 fish (Table A-1). Then the bass population began to decline.

By the late 1970s striped bass fishing had deteriorated. Fishery investigations revealed alarmingly low adult and juvenile striped bass populations. The 1980 adult bass population of about 1.1 million fish was only about one-third that of the early 1960s. Estimates since 1988 have been less than 1 million fish with "lows" of 663,000 and 700,000 in 1990 and 1992, respectively (Table A-1) and annual catch by anglers shrunk to only 64,000 fish 1992. (These figures do not include striped bass fisheries in the Colorado River and several reservoirs.)

Table A-1. Annual Estimates of Abundance of Adult Striped Bass and Catch

Year	Abundance	Catch
1960		744,000
1961		620,000
1962		643,000
1963		878,000
1964		509,000
1965		207,000
1966		368,000
1967		271,000
1968		207,000
1969	1,646,000	282,000
1970	1,727,000	209,000
1971	1,600,000	274,000
1972	1,883,000	320,000
1973	1,637,000	274,000
1974	1,477,000	338,000
1975	1,850,000	444,000
1976	1,581,000	329,000
1977	924,000	157,000
1978	1,152,000	188,000
1979	1,156,000	179,000
1980	1,116,000	137,000
1981	911,000	100,000
1982	825,000	131,000
1983	1,010,000	239,000
1984	1,048,000	234,000
1985	1,038,000	206,000
1986	1,064,000	173,000
1987	1,038,000	158,000
1988	967,000	129,000
1989	873,000	76,000
1990	663,000	84,000
1991	816,000	110,000
1992	700,000	64,000
1993	765,000	90,000

Stocked bass constituted 11 percent of the adult bass population in 1989, 14 percent in 1990 and 29 percent in 1993. Although estimates are not yet available, subsequent contributions of stocked fish will diminish due to the substantial reduction in stocking in 1992.

The major striped bass population and fishery is located in the lower Sacramento-San Joaquin rivers, the Delta, San Francisco Bay, and the ocean inshore-areas within 20 miles of the Golden Gate. Tagging studies indicate that, on average from 1980 to 1990, the catch of striped bass was distributed approximately as follows:

	Percent annual catch
Delta	38
San Pablo Bay-Carquinez Strait	19
Sacramento River upstream from Courtland	19
Suisun Bay	10
San Francisco Bay	10
Ocean	4
	100

Problems Affecting Striped Bass

Sportfishing is not a contributing factor to the decline of the striped bass population. The decline is due primarily to environmental/habitat problems. The DFG has identified 10 problems affecting striped bass populations. The following list is in general order of importance:

1. <u>Delta water diversions</u>. Water diversions entrain and remove striped bass eggs, larvae, and juveniles from the Delta, reduce the young bass food supply, and disrupt striped bass migrations.

2. <u>Reduced delta outflows</u>. Multiple water storage and diversion projects on tributaries of the Estuary have reduced Delta outflows past Chipps Island in spring and early summer. The reduced outflows fail to transport bass eggs and larvae into Suisun Bay and that spatially reduces the nursery area for young bass. Also, low flows may make the lower San Joaquin too salty for bass spawning.

3. <u>Water pollution, toxic chemicals, trace-elements</u>. Water pollution, including toxic chemicals (petrochemicals, pesticides, chlorinated hydrocarbons) and trace-elements (mercury, selenium, copper, cadmium, and zinc) potentially stress, debilitate, or kill bass eggs, larvae, young, and adults and their food (and possibly

reduce primary productivity) throughout the Estuary.

4. Dredging and spoil disposal. Dredging and in-bay spoil disposal recirculate toxic chemicals and trace-elements deposited previously in bottom muds whereby they then become concentrated in striped bass, probably partly via the food web. Additionally, turbidity abrades fish gills, reduces phytoplankton, smothers bottom organisms, and interferes with fishing.

5. Illegal take and poaching. Illegal take and poaching of striped bass are a significant problem in the Estuary. Wardens often cite anglers for undersized bass and overlimits, and arrest people using illegal nets for bass. Enforcement operations have uncovered marketing of illegally caught bass in the Estuary.

6. Exotic aquatic organisms. The discharge of ballast water from ships entering San Francisco Bay from foreign ports has introduced and established several exotic aquatic plants and animals (some are microscopic in size) which can have, and may already have begun to have, major detrimental impacts on populations of existing aquatic organisms, including striped bass and their food supplies.

7. Bay-fill projects. Obliteration of open water areas by filling Bay and Delta tidelands reduces habitats of bass and bass food organisms, and precipitates certain water quality problems which can also be detrimental to bass.

8. Commercial bay shrimp fishery. The commercial shrimp fishery in Suisun Bay and other areas kills young bass captured during netting operations. Shrimp harvest regulations are adjusted to reduce the capture of young bass.

9. Annual summer die-off of bass. Almost every year there is a summer die-off of bass near Carquinez Strait. The severity and locations vary annually, with observed numbers ranging from several hundred to about two thousand. The cause is unknown.

10. Diseases and parasites. Diseases and parasites stress, debilitate, or kill young and adult bass by varying degrees throughout the Estuary.

Historic Activities to Maintain Striped Bass Abundance

Actions to reduce entrainment losses of eggs, larvae, and young of striped bass and other fishes in water diversions of SWP, CVP, Pacific Gas and Electric Company (PG&E), and the estimated more than 1,800 Delta agricultural diversions. The CFG has attempted to reduce entrainment of striped bass and other fishes, including the listed species, in Delta water diversions in various ways including:

1. Cooperative studies and negotiations to improve efficiency of fish screens and reduce losses of striped bass and other fishes during fish screen salvage, handling, and release operations at the SWP and CVP diversions.

For three decades the CFG has been involved in cooperative studies to evaluate losses of striped bass and other fishes resulting from salvage activities at the CVP and SWP fish screens and to develop criteria and implement actions to reduce those losses. Examples of recent actions include:

a. Upgrading of screens at the SWP in the secondary system during 1982.

b. Through mutual agreement with DWR, CFG 's Bay-Delta Division personnel assumed fish handling and trucking operations of the SWP "John E. Skinner Fish Facility" on July 1, 1991. This change has improved the quality of the fish handling operation, allowed for more frequent removal of predatory fish and debris from the screening system, more frequent fish hauls which improve the survival of entrained fish, and permitted better estimation and reporting of fish salvage data through more frequent and longer sample counts and on-site data entry.

c. The SWP added three fish holding tanks (four original tanks) as a result of CFG recommendations. The tanks were installed in FY 1991-92 for $4 million.

d. The CVP has acquired new, improved fish hauling trucks.

e. Both the CVP and the SWP have installed better salting and aeration systems as a result of CFG recommended studies to improve striped bass survival and delta smelt biological opinions on the operations of the water projects.

f. An extensive, renewed evaluation of the SWP's John E. Skinner Fish Protective Facility began in 1994, largely prompted by biological opinions for delta smelt and winter-run chinook salmon. Likely improvements include better debris management to improve survival in the holding tanks and covering (darkening) the secondary screen system to improve fish passage.

g. Under the IEP, the USBR has begun a major evaluation and improvement program for the CVP's 40-year old Tracy Fish Collection Facility. Improvements being examined include control of predators in the system, better system control through improve instrumentation, and better light management around the facility. In addition, new release sites are under consideration.

2. Reducing predation at the SWP intake.

CFG's Bay-Delta Division, in collaboration with DWR, has been evaluating whether predator removal is an effective and practical method of reducing prescreen losses of entrained juvenile fishes--including striped bass, chinook salmon, delta smelt, and Sacramento splittail--at the SWP export facilities. Experiments have suggested that prescreen losses to predatory fishes (primarily larger striped bass and catfish) are a significant contributor to the direct loss of juvenile striped bass, salmon, and probably other species in the Clifton Court Forebay.

3. Presenting recommendations for restricting water diversions and other testimony regarding impacts of water diversions at hearings held by the SWRCB on Bay-Delta water rights and water quality.

CFG staff testified in major SWRCB hearings and workshops in 1969-1970, 1976-1977, 1987, 1992, 1994, and 1995.

4. Negotiating a "Two-Agency Fish Protective Agreement" with DWR in 1986.

This agreement, enacted in 1986 in response to the addition of four new pumps by the SWP, established a "Four Pumps Committee" with procedures and guidelines to use DWR funds to offset direct losses of striped bass (and other species) caused by the H. O. Banks Delta Pumping Plant. There is also an Article VII that calls for DWR and CFG to begin "...discussions on developing ways to offset adverse fishery impacts of the SWP which are not covered in this agreement including facilities needed to offset fishery impacts and provide more efficient conveyance of water..." These discussions/negotiations began in 1988 and subsequently included the USBR.

The Article VII negotiations resulted in the signing of a framework agreement in late 1990. This agreement identified a set of Delta fisheries resource problems (including striped bass related problems) to be addressed in the negotiations. However, these negotiations have been pre-empted by a December, 1994 Framework Agreement between the Governor's Water Policy Council of the State of California and the Federal Ecosystem Directorate (CALFED) (Appendix F) known as the Bay-Delta Accord. The Bay-Delta Accord established the CALFED consortium of state and federal agencies to develop a comprehensive, long-term program for environmental protection of the Bay Delta system and provide reliable water supplies for all water users.

5. Negotiating and implementing a 1992 agreement between CFG and USBR to reduce and offset fish losses directly associated with operation of the Tracy Pumping Plant (TPP) and TFCF.

This agreement was designed to both reduce direct losses of fish, specifically striped bass and chinook salmon, by evaluating and improving the 47-year old TFCF and to "replace" fish that are lost due to TPP water exports. The evaluation of the TFCF is underway, some minor improvements have been made, and some potential major improvements are under consideration. The agreement called for the USBR to provide $6.51 million during Federal fiscal years 1993 through 1997 to CFG to implement "mutually agreed upon programs" that "to the maximum extent possible, offset and replace the annual direct losses resulting from the export of water at the TPP".

A committee has been established, including CFG, USBR and USFWS staff to identify and develop projects for funding through the 1992 agreement. This committee, working in close cooperation with the Two Agency Agreement staff (see above), has approved funding for enhancement and extension of the Delta-Bay Enhanced Enforcement Program (DBEEP) and development of a fish screen on a Grizzly Island Wildlife Area water diversion. The committee is continuing to identify and develop projects.

6. Review of draft Delta water project environmental impact reports and statements.

For several decades, the CFG has responded to drafts of various environmental impact reports and statements concerning additional diversion of Delta water. The CFG has also provided resource background and impact assessment material for inclusion in Environmental documents. This has been a major CFG effort.

7. Review of Regional Water Quality Control Board (RWQCB) and PG&E water diversion permits.

The CFG has made recommendations to the Central Valley and San Francisco Bay RWQCB regarding conditions in operating permits for PG&E power plants as required by Section 316 of Public Law 92-500. The first renewal of the five-year operating permit was completed during 1990 for the Pittsburg and Contra Costa power plants. The permits incorporated a number of changes to improve protection of striped bass. The changes were based on operational experience obtained during the first five years of operation under the two original permits. As a result, PG&E has modified the operation of its power plants, the existing intake structures, and fish screens resulting in about 37 to 89 percent reductions in annual striped bass losses since 1984 (Table A-2). A new five-yea monitoring and mitigation agreement, required by a second renewal of operating permits, was negotiated between CFG and PG&E in 1995.

8. Seeking consolidation and relocation of Delta agricultural diversions to areas of lower bass abundance, and screening, if appropriate.

DWR is in the process of purchasing a major portion of Sherman Island and has completed purchase of a major portion of Twitchell Island. CFG and DWR have been negotiating a framework agreement which will provide for evaluating the suitability of screening and modifying water diversion intakes on these islands.

Seeking Delta outflows beneficial for striped bass and other species. The CFG has sought greater delta outflows to benefit striped bass, the fishes listed under the ESA, and other species through many of the same activities identified to minimize entrainment losses.

Additionally, the CFG has been considering requirements of striped bass and the listed species while participating in planning to evaluate how to use 600,000-800,000 acre-feet of water annually allocated by the Central Valley Project Improvement Act (CVPIA) to improve fish populations in the Estuary. At least half of this CVPIA water is now allocated for the listed species due to the December, 1994 Bay-Delta Accord (Appendix F).

Table A-2. Reduction in Striped Bass Losses at PG&E Power Plants.

Year	Percent Reduction in Losses
1993	89.1
1992	79.6
1991	80.8
1990	81.1
1989	76.3
1988	37.5
1987	42.6
1986	73.4
1985	59.0
1984	63.0

Seeking ways to slow the rapid transfer of water through interior Delta channels. The State and Federal water projects system is designed to utilize Delta channels to convey water to the export pumps in the south Delta, therefore, major reductions in water exports and major modifications in the Delta water delivery system would be required to eliminate rapid transfers of water through southern Delta channels. Also, unless water exports are reduced and the delivery system modified, potential fishery benefits obtained by proposals to close the Delta Cross Channel or Georgiana Slough, major conduits to transfer water from the Sacramento River to the southern Delta, will be reduced. Fishery benefits are reduced because losses of young striped bass and other fishes from the San Joaquin spawning area increase due to increased transport of water to the pumps via the western Delta. The CFG has been considering these transfer effects on striped bass, the listed species, and other species in making recommendations during SWRCB hearings, commenting on environmental documents and in various negotiations with DWR and USBR.

Seeking reductions in toxic substances including petrochemicals, chlorinated hydrocarbons, pesticides, trace-metals, PAHs, PCDDs, and PCDFs contained in municipal, industrial, and agricultural discharges. CFG has monitored and evaluated waste discharges and provided recommendations to State and Regional Water Quality Boards to tighten waste discharge requirements and improve water quality for all fishes in the Estuary including striped bass and the listed species. Fish and Game wardens have investigated fish kills, toxic chemical spills, and suspicious waste discharges in the Estuary. The CFG Aquatic Toxicology Laboratory, funded largely from striped bass stamp revenues, has participated in these law enforcement activities by confirming the presence and quality of toxic conditions in suspected samples and by determining tolerance levels for striped bass and other species. Suspected violations of waste discharge requirements have been reported to the appropriate permitting Boards and Departments for mitigation or elimination. Past actions have increased protection of striped bass and other fishes and zooplankton in the Sacramento-San Joaquin Estuary.

Seeking restrictions on channel dredging and spoil disposal in Bay-Delta waters. Toxicity of dredge spoils to striped bass (and other aquatic life) has been assessed through the dredge permit process of the U.S. Army Corps of Engineers and the San Francisco Bay Conservation and Development Commission. The CFG has recommended types of tests to be used and appropriate locations for soil disposal. CFG reviews and comments on dredging and spoil disposal projects have been coordinated through the Environmental Services Division.

Reducing illegal take of striped bass and other species. Striped bass law enforcement efforts have included the following activities:

a. Targeting of illegal gill netting and set lines.

b. Conducting market inspections to ensure compliance with laws prohibiting the sale of striped bass taken from the Estuary.

c. Utilizing intelligence information gathered through investigations and the anonymous CFG Cal-Tip program to concentrate on persons trafficking in striped bass taken illegally.

d. Utilizing uniformed personnel to conduct high profile patrol to encourage compliance with sport regulations.

e. A special enforcement unit with focus on striped bass and salmon poaching in the Estuary. This unit has been funded by the DWR and USBR.

f. Enforcement of water pollution/water discharge laws.

Seeking curtailment of introductions of exotic aquatic organisms from maritime shipping. Introductions of exotic species occur when ships from foreign ports dump ballast water in the Estuary. These organisms potentially compete with and/or prey upon striped bass and other species including listed species. Once established, non-native organisms cannot be exterminated from the Estuary. The CFG has recommended Federal regulations and legislation that restrict discharge of ship ballast water and CFG is the lead agency responsible for monitoring ballast waters for exotic organisms under a recently passed State law.

Monitoring to determine status of striped bass and other species. Over the years, various monitoring programs have been implemented to determine status of striped bass and other species. In fact, knowledge of the status of delta smelt and splittail has been gained largely as a side-benefit of the by-catch of those species during monitoring aimed at striped bass. Specific monitoring for striped bass or a combination of striped bass and other species has included:

1. Summer Tow Net Survey

The summer townet survey has been run annually since 1959 (except 1966). It measures abundance of striped bass 17 to 50 mm fork length (FL). This survey also has provided a major measure of the status of delta smelt and may be of some limited value in indexing the trend in splittail. Information from this survey is required by the USFWS Biological Opinion for effects of the CVP and SWP on the delta smelt, Sacramento splittail, and proposed delta smelt critical habitat. Each annual survey has consisted of three to five sub-surveys that take five days to complete. These sub-surveys usually begin in mid-June and have consisted of sampling at 30 stations scattered from eastern San Pablo Bay to the eastern Delta. They occur at two-week intervals until the mean length of the bass in the catch exceeds 38 mm FL. This length generally has been attained between mid-July and mid-August.

Three 10-min, depth-integrated tows are made at each sampling station. These tows are diagonal from bottom to surface to reduce bias caused by variations in the vertical distribution of bass. The net is mounted on skis. The net's mouth area is about 1.5 m^2 and the net is 5.5 m long. It tapers to 39 cm in diameter at the cod end. The first 3.05 m of the cone is #6 thread webbing of 1.27 cm stretch mesh. The rest of the net is bobbinet with 3.1 holes per centimeter. These holes are about 2.5 mm in diameter. The bobbinet is sewn to the #6 thread webbing so that the webbing forms a fyke 60 cm long inside the bobbinet.

2. **Fall Midwater Trawl Survey**

The fall midwater trawl survey has been conducted monthly from September to December each year since 1967 (except 1974 and 1979). In addition to measuring fall abundance of striped bass, it has provided the most important measure of delta smelt abundance and is also of value for measuring the trend in splittail abundance. It is required by the USFWS Biological Opinion for effects of the CVP and SWP on the delta smelt, Sacramento splittail, and proposed delta smelt critical habitat.

Each monthly survey has taken about six days to complete. One tow is made at each of 87 sampling sites scattered from San Pablo Bay through the Delta. The midwater trawl has a 3.6- by 3.6-m mouth and this 17.7-m-long net is constructed of nine tapered panels of netting decreasing from 20-cm stretch mesh at the mouth to 1.3-cm at the cod end. The trawl is released to the river bottom, and then it is pulled to the surface as it is towed, resulting in depth-integrated samples. Towing speed is about 1.5 knots. Tow duration is 12 min.

3. **Mark-recapture of Adult Striped Bass**

Monitoring of adults has been based on mark-recapture estimates (annual from 1969-1994). Gill nets and fyke traps have been used to capture bass for tagging while on their spawning grounds in the spring. Summer-fall or year-round censuses of angler catches have obtained estimates of tagged: untagged ratios. Tags recovered through the mail also have been used to estimate harvest and mortality rates.

The fyke traps (Hallock et al. 1957) are about 20 feet long and 10 feet in diameter. In 1969-1976, 1979, 1980, and 1982-1988 they were fished at Clarksburg. In 1981, the traps were fished downstream of Colusa. In 1989, trapping was at Freeport, and since 1990, the traps have been fished at Knights Landing. The number of traps has varied from four to 14; most recently, 10-12 traps have been used. These traps have usually been checked for fish on alternate days, but have been allowed to fish over the weekend without being checked. In 1994, traps were tended daily, with no weekend fishing, when winter-run chinook salmon were likely to be present. The traps are pulled by rolling them up the bank to the surface. This is done with a cable wrapped around each trap and attached to an electric winch mounted in the bed of a pickup truck. A 20-foot pontoon boat tied up to the river side of the trap is used as a work platform when removing fish from the trap and tagging striped bass. Fish are dip-netted from the front compartment of the trap after removing a "door" on the side of the trap. Fish other than striped bass are released immediately, directly from the dip net, and are identified and counted as they are released.

The striped bass tagging program also has used two boats to fish gill nets in the western Sacramento-San Joaquin Delta (primarily in the San Joaquin River) since 1969. Tagging occurs from about April 1 to May 31. Nets are 600 feet in length and about 21 feet deep with variable mesh from 4 to 5½ inches stretched measure, in ½-inch increments. The nets are drifted with the tidal current for 15-30 minutes and then retrieved onto a hydraulically-powered net reel. Fish are removed from the net as they come on board; fish other than striped bass are immediately released.

4. Monitoring of Striped Bass Diet

To compliment studies of more than 30 years ago, in 1994 CFG began monitoring of striped bass diet through collection of stomach contents of striped bass observed during the year-round census of the striped bass fishery. This monitoring will help further evaluate the extent of striped bass predation on the listed species and determine if there are problem periods or areas that may require further attention.

Maintaining sport fishing regulations that protect striped bass and allow reasonable public angling opportunities. In response to the long-term downward trend in striped bass abundance, the CFG has periodically recommended changes in striped bass angling regulations which have been adopted by the California Fish and Game Commission. Prior to 1956, bag and size limits were liberal with a 12-inch minimum legal length and five fish daily bag generally in effect. In 1956, the minimum length was increased to 16-inches and the daily bag was reduced to three fish. The present regulations of an 18-inch minimum length and 2 fish daily bag were adopted in 1982. Generally, the striped bass regulations have allowed about 10-25 percent of the population to be harvested annually with the most recent years falling near the low end of that range.

Seeking mitigation of losses of striped bass entrained by water project and PG&E operations by stocking artificially propagated yearling bass or by stocking bass salvaged from State and Federal fish screens and reared for one-year in floating net-pens. As described previously, losses of young striped bass and numerous other species occur at State, Federal, and private water diversions in the Delta. Salvaged fish (all species) from both the State and Federal fish screens in the south Delta are routinely collected and returned to the Estuary. Survival of these fish is low due to mortalities during the salvage, trucking, and Delta release process and the normal high natural mortality rates experienced by small fish.

These losses led to replacing striped bass killed by water diversions with stocked fish, imarily bass spawned and reared in hatcheries to one-year of age. Striped bass culture in California was initiated in the early 1980s with revenue from sales of $3.50 striped bass stamps required of anglers wishing to catch and keep striped bass. The prospects for success were not encouraging: the technology for capturing and spawning wild adult bass and rearing large numbers of young bass in a hatchery was unreliable; and there was no tested system to mark, fin-clip, or tag young bass so that specific year classes could be identified several years later in creel censuses of angler catches.

Striped bass stocking began with the release of 62,640 bass from CFG Central Valleys Hatchery in Elk Grove in 1981. An evaluation study began with the marking (freeze brand/fin-clip) of 65,674 of 90,548 young striped bass released in 1982. Subsequently, striped bass culture improved and private aquaculturists became involved in the program. Innovative application of magnetic, coded-wire tags (CWT's) into the cheek muscle of striped bass in 1984 increased study sophistication. The project expanded continuously to 1990 when 951,906 of 2.4 million released bass were tagged; and in 1991 when 813,998 of 3.4 million were tagged. These fish have been stocked in various areas of the Estuary from the Delta to San Pablo Bay.

PG&E and DWR became cooperators in the evaluation in 1984 and 1988, respectively, by purchasing privately reared (or CFG hatchery-reared) bass as part of fishery mitigation requirements placed on their water diversions.

DWR became a cooperator as a result of the Two-Agency Fish Protective Agreement. That agreement established a "Four Pumps Committee" with procedures and guidelines to use specific DWR funds to offset direct losses of bass (and other species) caused by the H.O. Banks Delta Pumping Plant. That committee has approved DWR expenditures for stocking and equivalent measures that have compensated for the loss of 4.1 million yearling bass (Table A-3).

PG&E has paid to stock almost 2.5 million hatchery reared striped bass to offset unavoidable impacts of its two power plants (Table A-4).

Stocking of hatchery reared striped bass was halted in 1992 because of concerns of potential predation on winter-run chinook salmon. Subsequently, however, an experimental program started to rear striped bass salvaged at the State and Federal fish screens in net-pens anchored in the Estuary. These fish are progeny of bass spawning naturally in the Estuary. They have been released in San Pablo Bay from June to August after rearing for approximately one year after being collected from the fish screens. About 28,000 and 37,000 yearling bass were released in 1993 and 1994, respectively. About 243,000 bass were scheduled for released in June 1995, but the actual release was limited to 100,000 fish due to NMFS concerns about the status of winter-run chinook salmon. In June 1996, about 102,000 pen-reared bass were released; approximately 80,000 of these fish were 2-years old, holdovers from those scheduled for release in 1995. About 113,000 pen-reared yearling bass were released in July 1997.

Table A-3. Delta Pumping Plant Fish Protection Agreement Fish Loss Account, October 1995.

Year	Yearling Equivalent Losses of Striped Bass
1986	544,429
1987	683,712
1988	854,041
1989	796,240
1990	790,811
1991	636,525
1992	499,816
1993	481,694
1994	379,619
TOTAL LOSSES	5,666,887
	Yearling Equivalent Striped Bass Replaced
1988	345,292
1989	406,458
1990	1,235,787
1991	1,765,801
1992	0
1993	62,500[a]
1994	286,244[b]
1995	350,000[b]
TOTAL REPLACED	4,452,082
REMAINING LOSSES	1.2142,805

[a] Credit for funding an enhanced law enforcement effort targeted at illegal take of striped bass.

[b] Credit for stocking striped bass reared in floating pens after being salvaged from SWP fish screens and funding enhanced law enforcement targeted at illegal take of striped bass.

able A-4. Summary of Striped Bass Stocking Funded by PG&E

Year	Yearling Hatchery Bass Stocked
1994	
1993	
1992	
1991	
1990	344,495
1989	627,645
1988	431,916
1987	300,000
1986	294,600
1985	281,349
1984	193,148
Total Stocked	2,473,153

Overall, releases of hatchery reared fish and the wild fish reared in net pens have only partially mitigated losses caused by CVP and SWP operations.

REFERENCES

Appendix A

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APPENDIX B1

Status of Sacramento River Winter-Run Chinook Salmon

Chinook Salmon Life History

The winter-run chinook salmon is one of four recognized chinook salmon races in California. Recent severe declines in the abundance of this race led to its classification as an endangered species by the California Fish and Game Commission pursuant to CESA, and by the National Marine Fisheries Service pursuant to the ESA. It can be distinguished from the other three races by several characteristics, including its migration pattern and timing of events in its life-cycle (Table B-1). Adult winter-run salmon enter the Bay and migrate upstream through the Delta from mid-November through mid-June. Spawning occurs in the upper Sacramento River from late April to mid-August, peaking in late June or early July. Hallock and Fisher (1985) found that most winter-run chinook return as 3-year-olds (67 percent), with the remainder returning as 2-year-olds and 4-year-olds (25 and 8 percent, respectively).

Some winter-run salmon smolts enter the Sacramento-San Joaquin Delta as early as September, probably as a result of fall storms. The peak migration of smolts through the Delta is in February, March, and April, with some also present in May.

Winter-run chinook salmon spawning historically occurred primarily in the upper Sacramento, Pit, and McCloud rivers where relatively cool water temperatures prevail in the summer incubation period. The historic run size may have numbered 200,000 spawners (Rectenwald, 1989).

Construction of Shasta Dam in 1942 prevented access to the historic spawning grounds, but summertime releases of cold water from the hypolimnion of Shasta Lake created favorable habitat conditions in the main stem Sacramento River below Keswick Dam and the winter-run population was able to persist.

The subsequent decline of winter-run chinook salmon has been attributed in part to the operation of RBDD, which prevented or delayed access to the favorable spawning ground below Shasta Dam in summer and early fall. Another factor contributing to the decline is unsuitable water temperatures. This condition occurs when water levels are low in Shasta Reservoir and the ability to release cold hypolimnetic water is limited by the dam's spill gate and powerhouse penstock design. The volume of available cold water within the reservoir is also limited.

Other mortality factors include toxic discharge from Iron Mountain Mine, entrainment at poorly screened diversions, and stranding of juveniles during major flow fluctuations in the rearing area.

Table B-1. Sacramento River Chinook Salmon Life History Patterns

	Time Period
Spring-Run Chinook Salmon	
Adult Upstream Migration	mid March through the end cf September
Spawning	mid August through mid October
Incubation	mid August through mid January
Juvenile Emigration past Red Bluff	early November through end of May may be some over summering in the Delta and River
Fall-Run Chinook Salmon	
Adult Upstream Migration	June through December
Spawning	mid October through end of December
Incubation	mid October through end of March
Juvenile Emigration past Red Bluff	late December through mid June
Juvenile Emigration through Delta	April through June, and October and November for yearlings
Juvenile Emigration through the Bay	April through June
Late-Fall-Run Chinook Salmon	
Adult Upstream Migration	early October to mid April
Spawning	early January to mid April
Incubation	January through end of June
Juvenile Emigration past Red Bluff	early April to end of November
Juvenile Emigration through Delta	November through March
Juvenile Emigration through the Bay	November through March
Winter-Run Chinook Salmon	
Adult Upstream Migration	
Enter into the bay	mid November through early May
Adults in the Delta	late November through mid June
Adults past Red Bluff Diversion Dam	mid December through early August
Spawning	late April through mid August
Incubation	late April through mid-late September
Fry Emergence	mid June through September
Rearing	mid June through end of February
Juvenile Emigration	
Emigration past Red Bluff Diversion Dam	early July through end of March
Emigration past Glenn-Colusa Irrigation District	late July through October
Emigration in the Delta	September through May
Emigration through the Bay	September through May

The majority of research on Delta water quality and hydrodynamic conditions affecting chinook salmon have been conducted with fall-run chinook salmon. Some of this information can be applied to the winter-run as well. Limited information specific to the winter-run chinook salmon is also available.

Due to periodic closure of the Delta Cross Channel gates during higher levels of runoff in late winter and early spring, typically a smaller proportion of winter-run smolts are diverted from the main stem Sacramento River into the central Delta through the Delta Cross Channel. Like fall-run smolts, any winter-run smolts diverted into the central Delta will have a longer migration route and greater exposure to the effects of the water export facilities.

Population Status:

Since 1967, accurate counts of all four chinook salmon runs have been made at RBDD (Table B-2). These counts illustrate the drastic decline in the number of winter-run chinook salmon migrating past RBDD.

Problems Affecting Winter-Run Salmon Populations:

CFG has identified 11 major problems that adversely affect winter-run chinook salmon populations:

1. Shasta and Keswick dams blocked the winter-run chinook salmon from reaching their historic spawning area. However, release of cool water from below the thermocline of Shasta Lake has improved conditions downstream so that, in most years, conditions are suitable for reproduction. In dry years when water levels in Shasta Lake are low, warm surface water releases can be detrimental.

2. Spawning habitat has been degraded by decreases in the rate of gravel replenishment for spawning. Construction of Shasta and Keswick dams precluded recruitment of new gravel from the river and its tributaries above the dams, and gravel mining in tributary streams below these dams has decreased the recruitment of new gravel into the main stem of the Sacramento River. Consequently, the amount of suitable spawning habitat has been shrinking.

3. Red Bluff Diversion Dam has been an impediment to salmon migration since its operations began in 1966. Fish ladders at RBDD have not been adequate to effectively pass adult salmon upstream, particularly during high winter flows, when winter-run chinook are migrating upstream. Additionally, the RBDD adversely affects downstream migrating winter-run salmon. The Tehama-Colusa Canal, which diverts Sacramento River water at the RBDD, is now equipped with a rotary drum fish screen, but evaluations of its effectiveness have not been completed.

Table B-2. Chinook Salmon Counts at Red Bluff Diversion Dam: 1967-1991

Year	Fall	Late-Fall	Winter	Spring	Total	% Winter-Run
1967	89220	37208	57306	23347	207081	27.7
1968	122095	34733	84414	14864	256106	33.0
1969	133815	38752	117808	26505	316880	37.2
1970	80935	27670	40409	3652	152666	26.5
1971	63918	16741	53089	5830	139578	38.0
1972	42503	32651	37133	7346	119633	31.0
1973	53891	23010	24079	7762	108742	22.1
1974	54952	7855	21897	3933	88637	24.7
1975	63091	19659	23430	10703	116883	20.0
1976	60719	16198	35096	25983	137996	25.4
1977	40444	10602	17214	13730	81990	21.0
1978	39826	12586	24862	5903	83177	29.9
1979	62108	10398	2364	2900	77770	3.0
1980	37610	9481	1156	9696	57943	2.0
1981	53744	6807	20041	21025	101617	19.7
1982	48431	4913	1242	23438	78024	1.6
1983	42096	15190	1831	3931	63048	2.9
1984	73254	7163	2663	8147	91227	2.9
1985	97707	8436	3960	10747	120852	3.3
1986	104874	8286	2424	16691	132314	1.9
1987	103063	16049	1998	11206	132313	1.5
1988	9976	11597	2096	9771	163438	1.3
1989	84057	11639	533	5255	101484	0.5
1990	55710	7305	441	3922	67378	0.7
1991	44937	7089	191	773	52990	0.4
1992	41376	10370	1180	431	53357	0.8
1993	56896	a/	341	388		
1994	83933	a/	189	740		
1995	133653	a/	1364	394		
1996	119347	a/	940	326		

a/ Estimate not available because Red Bluff Diversion Dam gates were raised

4. Anderson-Cottonwood Irrigation District Diversion Dam is an antiquated structure on the Sacramento River in Redding. Flashboards are manually installed between mid-March and mid-April after part of the winter-run adults have moved above the dam site. Suitable spawning conditions exist downstream from the dam so effects are not as serious as at RBDD. However, flooding of the reservoir when the flashboards are installed covers salmon redds above the dam, possibly reducing survival. Fluctuating river flows and intermittent removal of the flashboards adversely affect salmon by dewatering redds, reducing flows of aerated water through the redds, and stranding juvenile fish.

5. Runoff from inactive mining operations in the Spring Creek drainage, a tributary to the Sacramento River near Keswick Dam, leaches heavy metals which can reach levels lethal to juvenile fish, alevins, and eggs. A dam was constructed on Spring Creek in 1963 to collect eroded debris and control release of toxic water into the Sacramento River. Under normal conditions, released Spring Creek water is diluted by water releases from Shasta Lake. During years of heavy precipitation, however, spills from Spring Creek result in uncontrolled releases of toxic water, usually in the winter prior to winter-run chinook salmon spawning activities. It is probable that sublethal effects such as reduced fecundity occur. In 1986, a year of heavy precipitation, a full reservoir of waste was held over for disposal (downriver) in summer (June-September) when the early life stages (eggs, alevins, fry) of winter-run salmon were present. In 1988 an incident of release of toxic waters occurred in May that adversely impacted the winter-run salmon spawning area. The U.S. EPA states: "Iron Mountain Mine is the single largest discharger of toxic pollutants in the country identified under EPA's Clean Water Act, Section 304 L Program".

6. Bank stabilization activities, particularly riprapping, probably affect the quality of rearing habitat. Studies have shown that juvenile salmon show a marked preference for nonriprapped areas (Schaffter, et al., 1983, Michny and Hampton, 1984).

7. Overutilization for commercial, recreational, scientific, and education purposes is a possible threat to any utilized species of fish, unless adequate regulations are enacted and enforced. Commercial and sportfishing regulations have been modified in recent years to minimize harvest of the winter-run salmon.

8. Predation by squawfish, and probably also by striped bass below RBDD has been a chronic problem. This situation is caused by RBDD. Predators congregate below the dam and feed extensively on downstream migrating juvenile salmon. Raising the dam gates during the period December 1-April 1 alleviates migration problems for adult salmon, but has no effect on the young fish as the peak of the downstream migration past Red Bluff is mid-September to mid-October (Hallock

and Fisher, 1985).

9. Significant losses of fry and juvenile winter-run chinook salmon occur at the Glenn-Colusa Irrigation District water diversion and pumping facility. Inadequate screening facilities contribute to entrainment of fish at this facility.

10. Numerous unscreened diversions exist along the main stem Sacramento River and in many Delta channels. Unquantified numbers of young salmon are lost at these locations each year.

11. State Water Project and Federal Central Valley Project pumping facilities draw large amounts of water across the Delta from the Sacramento River, carrying many downstream migrating salmon into areas where normal migration routes did not occur. Fish moved into these areas encounter disrupted migration routes and escape is difficult. Fish are rescued at fish screens at these facilities and are transported and released at downstream locations. However, some salmon pass through the screens, are killed during the handling and trucking process, or are victims of localized predation. Clifton Court Forebay (CCF) poses a particular threat as estimated losses due to predation there range from 63 to 97 percent of the salmon (winter-run salmon were not tested) that enter CCF. The large losses of small salmon released into CCF during December 1992 (Table B-3) suggests concentrations of prey sized fish such as occur in CCF and during screening and trucking to release sites may actually induce feeding by striped bass that otherwise reduce feeding activity in winter. The portion of the total downstream migration of Sacramento river winter-run chinook salmon that approaches the CCF intake is not precisely known.

ıble B-3. **Summary of Clifton Court Forebay Pre-Screen Juvenile Chinook Salmon Loss Studies Conducted by the Department of Fish and Game**

Date	Pre-Screen Loss Rate (%)	Temperature (avg/day °F)	Pump Exports (avg. af/day)	Predator Abundance	Size at Entrainment (mm fl)
Oct. '76	97.0	65.4	2,180		114
Oct. '78	87.7	57.5	4,351		87
Apr. '84	63.3	61.2	7,433	35,390	79
Apr. '85	74.6	64.1	6,367		44
Jun. '92	98.7	71.7	4,760	162,281	77
Dec. '92	77.2	45.4	8,146	156,667	121
Apr. '93	94.0	62.0	6,368	223,808	66
Nov. '93	99.2	53.7	7,917		117

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Appendix B1

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APPENDIX B2

Status of Central Valley Spring-Run Chinook Salmon

Life History

The spring-run chinook salmon was formerly the most abundant of the four recognized chinook salmon races in California. In recent years its abundance has been much reduced and on August 28, 1998, the California Fish and Game Commission voted to list it as threatened under the California Endangered Species Act. It is also listed as threatened under the federal Endangered Species Act (Federal Register Vol 64, No. 179, September 16, 1999). Spring-run salmon are distinguished from other races by the timing of their spawning migration, spawning period, and smolt emigration. Spring-run chinook salmon are the first race to migrate upstream. This migration is primarily from February through June but they spawn from mid-August to mid-October. Juvenile fish move downstream primarily from early November through January although some may migrate as late as May.

Historically, spring-run salmon spawned in the San Joaquin River as well as in the Sacramento, Feather, McCloud, and Pit rivers. The annual spawning run was about one million fish. The San Joaquin run was eliminated by the construction of Friant Dam in 1948. In the Sacramento River, Shasta Dam cut off access to major spawning grounds in the McCloud, Pit and upper Sacramento viers. This restricted spawning to the mainstem Ssacramento River, the Feather, Yuba, and American rivers, and several tributary creeks downstream of Red Bluff Diversion Dam, including Deer, Mill, Butte, Big Chico, and Antelope creeks. However, due to hybridization with hatchery-produced fall-run salmon, pure spring-run chinook now spawn only in Mill and Deer creeks, and possibly Big Chico and Butte creeks.

Population Status:

From 1991 to 1994, the spring-run salmon population averaged 1196 fish in Deer, Mill, Big Chico and Butte creeks. In contrast, in 1995, about 7500 spwaners used Butte Creek and the total estimated run in the four creeks was 9315 spawners. However, the estimated 1996-1997 average for these creeks was only 1792.

Problems Affecting Spring-Run Salmon Populations:

1. Access to historic spawning areas has been eliminated by construction of dams, particularly Shasta and Friant dams.

2. Adverse hydrodynamic conditions in the delta are a major problem affecting spring-run salmon. When export pumping rates are high and outflows low, spring run-fish are probably entrained in the water project diversions and/or drawn away from their normal seaward migration path. Reverse flows caused by project pumping moves smolts into the south delta and toward the pumps. High water temperatures in the delta may cause smolt mortality. Low through-delta flows decrease smolt migration rates and thus prolong exposure to a variety of mortality sources in the delta.

3. Ocean harvest is a threat since any catch of the depleted spring run is detrimental.

4. Habitat condition in tributary streams have been degraded by agricultural diversions.

5. Timber harvesting threatens holding and spawning areas.

6. Runoff from inactive mining operations in the Spring Creek drainage, a tributary of the Sacramento River near Keswick Dam can affect migrating adults under unusual conditions as in 1986 when a full reservoir of waste was discharged into the Sacramento River during June-September.

7. Numerous unscreened diversions along the mainstem Sacramento River in addition to those in the delta pose a threat to smolts.

(The Red Bluff Diversion Dam, Keswick Dam and the Anderson-Cottonwood Irigation District dam are upstream from Mill and Deer creeks and so do not affect what is left of the spring run.)

APPENDIX B3

Status of Central Valley Fall-Run Chinook Salmon

Life History

Fall-run chinook salmon were historically the second-most abundant run. Because much of the fall-run spawning grounds was downstream from from major dam sites the fall run was the least affected of the four runs and is presently the most abundant run. Fall-run salmon are distinguished from the other races by the timing of their spawning migration, spawning period, and smolt emigration. Adults migrate upstream from July through December and spawn from early October through the end of December. Juvenile fish move downstream from late December through mid-June. A very small number (<5%) of fall-run juveniles spend more than a year in fresh water and emigrate as yearlings the following November through April. Two principal movements of juvenile fall-run chinook salmon into the Sacramento-San Joaquin Estuary have been identified. Fry start to enter the estuary in January and peak abundance occurs in February and March. A later emigration of smolts occurs from April through June. Many fry continue to rear in the upper estuary and emigrate as smolts during the normal smolt emigration period.

Fall-run spawning historically occurred in the Sacramento River and its tributaries and to a lesser extent in the San Joaquin drainage.

Population Status:

Annual run size declined from an average of 179,000 adults from 1953 to 1966 in the mainstem Sacramento to an average of 77,000 adults from 1967 to 1992. Run size increased considerably in 1995 and 1996 and was higher in those years than in any year since 1969 (Table B-2).

Problems Affecting Fall-Run Salmon Populations:

1. Red Bluff Diversion Dam delays and blocks fall-run salmon. After the completion of this dam in 1966, the proportion of fall-run chinook salmon spawning above it declined from an estimated average of 94% during 1964-1968 to an average of 63% during 1977-1981 (USFWS 1995). Potential effects of blocked or delayed migration of adult chinook salmon include pre-spawning mortality, reduced egg viability, and shifts in spawning distribution.

2. The fish passage ladder at the Anderson-Cottonwood Irrigation District Diversion Dam does not effectively attract and convey upstream migrating chinook salmon past the dam (USFWS 1995). A new fishway has been installed on the opposite side of the dam but its effectiveness has not yet been evaluated.

3. High water temperatures in the upper Sacramento River during summer and fall limit the range of successful spawning for fall-run salmon during July-October (USFWS 1995).

4. Shasta and Keswick dams blocked the supply of spawning gravels from upstream sources t the upper Sacramento River. Lack of new gravel and increases in the average size of gravel have degraded spawning habitat below Keswick Dam to at least Clear Creek.

5. Warm water releases from reservoirs on the Sacramento basin cause high mortality in incubating fall-run chinook salmon eggs.

6. Heavy metal pollution caused by acid mine runoff principally from the Spring Creek basin is a major source of fish mortality in the upper Sacramento River. The Spring Creek Debris Dam was constructed in 1963 to control toxic discharges but because of limited storage in Spring Creek Reservoir and availability of dilution flows, copper and zinc levels in downstream water periodically exceed levels considered toxic to aquatic life.

7. Flood control structures on the Sacramento River divert Sacramento River water from the main river into the Butte Creek basin and the Sutter and Yolo bypasses during major flood events. Juvenile chinook salmon migrating down the Sacramento River can be diverted into the bypasses where they are subject to potential delays or entrapment.

8. Loss of riparian vegetation in the middle and lower reaches of the Sacramento River and in the delta has negative impacts on juvenile chinook salmon. Juvenile densities are 4-12 times higher in undisturbed areas as in riprapped sites (USFWS 1995).

9. In the delta, smolt survival is much lower when the smolts are diverted through the delta cross-channel than when they move down the Sacramento River. Smolt survival is also inversely related to temperature in the delta.

10. Fall-run chinook salmon are particularly vulnerable to irrigation diversion-related mortality because the smolt emigration period (April-June) coincides with the onset of the irrigation season in April.

11. Fall-run salmon are lost to predation by squawfish and probably striped bass below Red Bluff Diversion Dam as are all downstream migrating juvenile salmon.

APPENDIX B4

Status of Central Valley Late-Fall-Run Chinook Salmon

Life History

Because high flows and turbid water generally prevail during the late-fall chinook salmon spawning period, annual abundance estimates of the run could be made only after the construction of Red Bluff Diversion Dam and its fish-counting facilities in 1967. Late-fall run fish are distinguished from other chinook salmon by the migration pattern and timing of events in their life cycle (Table B-1). Adults migrate into the Sacramento River from mid-October to mid-April and spawn from early January to mid-April. Juvenile fish emigrate from October to December and possibly in January.

Population Status:

The number of late-fall-run chinook salmon passing the Red Bluff Diversion Dam declined from an average of 35,000 adults in the late 1960s to between 7,000 and 10,000 in the early 1990s, the last years for which counts at Red Bluff Diversion Dam are available (Table B-2).

Problems Affecting Late-Fall-Run Salmon Populations:

The problems affecting late-fall-run chinook salmon are similar to those affecting the winter and fall runs. These are Red Bluff Diversion Dam, the Anderson-Cottonwood Irrigation District Diversion Dam, degradation of spawning habitat in the Sacramento River, heavy metal pollution from Spring Creek basin, the loss of riparian habitat, predation by squawfish and striped bass, and unscreened diversions along the mainstem Sacramento River and in many delta channels.

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APPENDIX B-5

Status of Central Valley Steelhead

Steelhead Life History

There are two recognized forms of native *O. mykiss* within the Sacramento River Basin: coastal steelhead/rainbow trout (*O. m. irideus*, Behnke 1992) and Sacramento redband trout (*O. m. stonei*, Behnke 1992). It is not clear how the coastal and Sacramento forms of *O. mykiss* interacted in the Sacramento River prior to construction of Shasta Dam in the 1940s which blocked anadromous fish passage. Behnke (1992) reported that coastal and resident redband trout were spawned together at the McCloud River egg-taking station (1879-1888). Therefore, it appears the two forms co-occurred historically at spawning time, but may have maintained reproductive isolation. In addition, the relationship between anadromous and non-anadromous forms of coastal *O. mykiss*, including possible residualized fish upstream from dams, is unclear.

General life history information for steelhead (*Oncorhynchus mykiss*) is summarized below followed by information on general biological requirements. Further detailed information is available in the NMFS Status Review of west coast steelhead from Washington, Idaho Oregon, and California (Busby et al. 1996), the NMFS proposed rule for listing steelhead (61 FR 41541), the NMFS Status Review for Klamath Mountains Province Steelhead (Busby et al. 1994), and the NMFS final rule listing the Southern California Coast steelhead ESU, South Central California Coast steelhead ESU, and the Central California Coast steelhead ESU (62 FR 43937).

Adult freshwater migration and spawning. The most widespread run type of steelhead is the winter (ocean-maturing) steelhead, while summer (stream-maturing) steelhead (including spring and fall steelhead in southern Oregon and northern California) are less common. In the Central Valley, all steelhead are considered winter steelhead by the California Department of Fish and Game, although "three distinct runs," including summer steelhead, may have occurred as recently as 1947 (CDFG 1995, McEwan and Jackson 1996). Steelhead within this ESU have the longest freshwater migration of any population of winter steelhead. There is essentially a single continuous run of steelhead in the upper Sacramento River. River entry ranges from July through May, with peaks in September and February; spawning begins in late December and can extend into April (McEwan and Jackson 1996).

Steelhead may spawn more than once before dying, in contrast to other species of the *Oncorhynchus* genus. In Oregon and California, the frequency of two spawning migrations is higher than in more northern areas, but more than two spawnings is unusual.

Juvenile rearing and outmigration. Juvenile steelhead live in freshwater between one and four years (usually one to two years in the Pacific Southwest) and then become smolts and migrate to the sea from November through May with peaks in March, April, and May. The smolts can range from 14 to 21 cm in length. Steelhead spend between one and four years in the ocean (usually two years in the Pacific Southwest) (Barnhart 1986).

Ocean Migration. North American steelhead typically spend 2 years in the ocean before entering freshwater to spawn. The distribution of steelhead in the ocean is not well known. CWT recoveries indicate that most steelhead tend to migrate north and south along the Continental Shelf (Barnhart 1986).

Biological Requirements. The timing of upstream migration is correlated with higher flow events, such as freshets or sand bar breaches, and associated lower water temperatures. Unusual stream temperatures during spawning migration periods can alter or delay migration timing, accelerate or retard mutations, and increase fish susceptibility to diseases. The minimum stream depth necessary for successful upstream migration is 18 cm (Thompson 1972). Reiser and Bjornn (1979) indicated that steelhead preferred a depth of 24 cm or more. The preferred water velocity for upstream migration is in the range of 40-90 cm/second, with a maximum velocity, beyond which upstream migration is not likely to occur, of 2.4 m/second (Thompson 1972, Smith 1973).

Steelhead spawn in cool, clear streams featuring suitable gravel size, depth, and current velocity. Intermittent streams may be used for spawning (Barnhart 1986; Everest 1973). Reiser and Bjornn (1979) found that gravels of 1.3 cm to 11.7 cm in diameter and flows of approximately 4 cfs were preferred by steelhead. The survival of embryos is reduced when fines of less than 6.4 mm comprise 20 - 25% of the substrate. Studies have shown a higher survival of embryos when intragravel velocities exceed 20 cm/hour (Phillips and Campbell 1961, Coble 1961). The number of days required for steelhead eggs to hatch varies from about 19 days at an average temperature of 60° F to about 80 days at an average of 42° F. Fry typically emerge from the gravel two to three weeks after hatching (Barnhart 1986).

After emergence, steelhead fry usually inhabit shallow water along perennial stream banks. Older fry establish territories which they defend. Streamside vegetation and cover are essential. Steelhead juveniles are usually associated with the bottom of the stream. In winter, they become inactive and hide in any available cover, including gravel or woody debris.

The majority of steelhead in their first year of life occupy riffles, although some larger fish inhabit pools or deeper runs. Juvenile steelhead feed on a wide variety of aquatic and terrestrial insects, and emerging fry are sometimes preyed upon by older juveniles. Water temperatures influence the growth rate, population density, swimming ability, ability to capture and metabolize food, and ability to withstand disease of these rearing juveniles. Rearing steelhead juveniles prefer water temperatures of 45° to 58° F and have an upper lethal limit of 75° F.

Dissolved oxygen (DO) levels of 6.5 to 7.0 mg/L affected the migration and swimming performance of steelhead juveniles at all temperatures (Davis et. al. 1963). Reiser and Bjornn (1979) recommended that DO concentrations remain at or near saturation levels with temporary

-ductions no lower than 5.0 mg/L for successful rearing of juvenile steelhead. Low DO levels ...rease the rate of metabolism, swimming speed, growth rate, food consumption rate, efficiency of food utilization, behavior, and ultimately the survival of the juveniles.

During rearing, suspended and deposited fine sediments can directly affect salmonids by abrading and clogging gills, and indirectly cause reduced feeding, avoidance reactions, destruction of food supplies, reduced egg and alevin survival, and changed rearing habitat (Reiser and Bjornn 1979). Invertebrate production decreases proportionately as the size of the substrate particles decreases. Bell (1973) found that silt loads of less than 25 mg/L permit good rearing conditions for juvenile salmonids.

Population Status

Historical abundance estimates are available for some stocks within this ESU, but no overall estimates are available prior to 1961. In the Sacramento River including San Francisco Bay, the total run-size of steelhead was estimated at 40,000 in 1961 (Hallock et al. 1961). In the mid-1960s, steelhead spawning populations in this ESU were estimated at 27,000 fish (CDFG 1965). The present total run size for this ESU is probably less than 10,000 fish based on dam counts, hatchery returns and past spawning surveys.

At the Red Bluff Diversion Dam, counts have averaged 1,400 fish over the last 5 years, compared with runs in excess of 10,000 in the late 1960s. In the American River, estimates of hatchery produced fish average less than 1,000 fish, compared to 12,000 to 19,000 in the early 1970s (McEwan and Jackson 1996). Data to estimate populations trend was available from counts at the Red Bluff Diversion Dam. These data showed a significant decline of 9 percent per year from 1966 to 1992.

The majority of native, natural steelhead production in this ESU occurs in the upper Sacramento tributaries (Antelope, Deer, Mill, and other creeks), but these populations are nearly extirpated. The American, Feather, and Yuba rivers (and possibly the upper Sacramento and Mokelumne rivers) also have naturally-spawning populations (CDFG 1995). However, these rivers have also had substantial hatchery influence, and their ancestry is unknown. In the San Joaquin River Basin, there are reports of: (1) a small remnant steelhead run in the Stanislaus River (McEwan and Jackson 1996); (2) observations of steelhead in the Tuolumne River; and (3) large rainbow trout (possibly steelhead) at the Merced River hatchery.

Problems Affecting Central Valley Steelhead Populations

Major problems adversely affecting Central Valley steelhead is summarized below. More detailed information main be found in the "NMFS Factors for Decline, a supplement to the Notice of Determination for West Coast Steelhead under the Endangered Species Act" (NMFS

1996) and the NMFS proposed rule for listing steelhead (61 FR 41541).

1. Hydropower development. Construction of dams has blocked access to miles of previously productive habitat. Modification of natural flow regimes by dams has resulted in increased water temperatures, changes in fish community structure, and increased travel time by migrating adult and juvenile salmonids. Attempts to mitigate adverse impacts to these structures have been met with limited success. Numerous hydropower developments in the Central Valley have eliminated or severely hindered access to historical spawning and rearing habitat and have altered the natural flow regimes within the basins. These include: Shasta and Keswick Dams on the Sacramento River, Friant Dam on the San Joaquin River, Folsom Dam on the American River, Oroville Dam on the Feather River, Don Pedro Dam on the Tuolumne River, New Melones on the Stanislaus River and Exchequer Dam on the Merced River. Salmon and steelhead spawning and rearing habitat of the Central Valley has been reduced from about 6,000 miles prior to the construction of dams to less than 300 miles today (California Advisory Committee on Salmon and Steelhead Trout 1988; Reynolds et al. 1993).

2. Water withdrawal, conveyance, storage and flood control. Depletion and storage of natural flows have drastically altered natural hydrological cycles. In the Central Valley, the river systems are regulated to the point that high flows below dams typically occur in late spring and summer during the irrigation season and low flows occur in the fall, winter and early spring during the storage system -- the inverse of natural conditions (Reynolds et al. 1993).

   Adverse affects from altered streamflows on juvenile salmonids include: migration delay resulting from insufficient flows or habitat blockages; loss of sufficient habitat due to dewatering and blockage; stranding of fish resulting from rapid flow fluctuations: entrainment of juveniles into poorly screened or unscreened diversions; and increased juvenile mortality resulting from increased water temperatures (California Advisory Committee on Salmon and Steelhead Trout 1988; CDFG 1991; Cramer et al. 1995; Reynolds et al. 1993). Reduced flows also negatively affect fish habitats due to increased deposition of fine sediments in spawning gravels, decreased recruitment of new spawning gravels, and encroachment of riparian and non-endemic vegetation into spawning and rearing areas resulting in reduced available habitat.
   Other negative impacts include the operations of the Central Valley Project (CVP) and State Water Project (SWP) pumping plants in the Delta, which have caused reverse flows that delay migration of adult and juvenile steelhead. entrain fish into the pumping facilities and increase predation at water facilities (CDFG 1991; Reynolds et al. 1993).

   Water development and flood control projects have also altered the natural flow regimes and sediment transport characteristics of the Sacramento and San Joaquin rivers. Flood control projects in the Central Valley that affect steelhead populations include: the Sacramento River Flood Control Project; the Chico Landing to Red Bluff Comprehensive

Bank Stabilization Project. Flood control operations at the Folsom Reservoir on the American River have also affected steelhead populations, by abruptly reducing releases causing excessive mortality of juveniles.

3. Land use activities. Land use activities that have significantly altered fish habitat include logging, road construction, urban development, mining, agriculture and recreation. The impacts include: alteration of streambank and channel morphology; alteration of ambient stream water temperatures, degradation of water quality; elimination of spawning and rearing habitat, fragmentation of available habitats; elimination of downstream recruitment of spawning gravels and large woody debris; removal of riparian vegetation resulting in increased stream bank erosion; and degradation of water quality.

4. Overutilization. Over fishing in the early days of European settlement led to the depletion of many stocks of salmon and steelhead even before extensive habitat degradation. However, following the degradation of many west coast aquatic and riparian ecosystems, exploitation creates may have been higher than populations could sustain. During periods of decreased habitat availability, the impacts of recreational fishing on native anadromous stocks may be heightened. Steelhead are not generally targeted in the commercial fisheries. However, high seas driftnet fisheries in the past may have contributed slightly to a decline of this species in local areas, but this could not be solely responsible for the large declines in abundances observed along most of the Pacific coast over the past several decades.

5. Predation. Introductions of non-native species and habitat modifications have resulted in increased predator populations in numerous river systems, thereby increasing the level of predation experience by salmonids.

6. Natural Factors. Natural climatic conditions have served to exacerbate the problems associated with degraded and altered riverine and estuarine habitats. Persistent drought conditions have reduced already limited spawning rearing and migration habitat. Further, climatic conditions appear to have resulted in decreased ocean productivity which, during more productive periods, may help (to a small degree) offset degraded freshwater habitat conditions.

7. Artificial Propagation. In an attempt to mitigate the loss of habitat, extensive hatchery programs have been implemented throughout the range of steelhead on the West Coast, including the Central Valley. While some of these programs have been successful in providing fishing opportunities, the impacts of these programs on native, naturally-reproducing stocks are not well understood. Competition, genetic introgression, and disease transmission resulting from hatchery introductions may significantly reduce the production and survival of native, naturally-reproducing steelhead. Furthermore, collection of native steelhead for hatchery broodstock purposes may result in additional negative impacts to small or dwindling natural populations. It is important to note,

however, that artificial propagation could play an important role in steelhead recovery and that some hatchery populations of steelhead may be deemed essential for the recovery of Central Valley steelhead.

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APPENDIX C

Status of Delta Smelt

Delta Smelt Life History

The delta smelt, *Hypomesus transpacificus* (McAllister, 1963), is a small euryhaline fish which reaches adult sizes of about 55-70mm standard length (Moyle 1976; Moyle et al. 1992) although some may reach lengths near 130mm (Stevens, et al. 1990). It is translucent with a silvery, steel-blue streak along its sides.

Delta smelt can be distinguished from other smelt by: 1) a small flexible maxilla (upper jaw bone) that does not extend past the middle of the eye, 2) the lack of strong striations on the gill cover, 3) pectoral fins that reach less than two-thirds of the way to the base of the pelvic fins, and 4) fin ray counts of 9-10 on the dorsal fin, 10-12 on the pectoral fins, 8 on the pelvic fins, and 15-17 on the anal fin (Moyle 1976). Further descriptions are in Wang (1986; 1991).

Although many smelt species are highly prized for their flavor, delta smelt are not fished (Wang 1986). They do, like some other smelts, have a distinct odor of cucumbers (Moyle 1976; Wang 1986).

Delta smelt are found only in the Sacramento-San Joaquin Estuary (Stevens, et al. 1990; Moyle, et al. 1992). They have been found as far upstream in the Sacramento River as the mouth of the Feather River (Wang 1991) and as far as Mossdale on the San Joaquin River (Moyle, et al. 1992). Their normal downstream limit appears to be western Suisun Bay, although during episodes of high outflow they can be washed into San Pablo and San Francisco bays (Moyle, et al. 1992; Fry 1973). Delta smelt are usually found in euryhaline, or brackish waters where salt and freshwater mix, but they move to freshwater to spawn (Moyle 1976).

Delta smelt are fast growing and short-lived (Moyle 1976). Until recently, little was known about their early development with most of the information being derived from other closely related species such as the wakasagi, *H. nipponensis*, (Wales 1962; Moyle et al. 1992). The majority of growth is within the first 7 to 9 months of life when the fish grow to about 50 to 70mm (Erkkila, et al. 1950) after which growth slows to allow for reproductive development (Radtke 1966, Moyle 1976).

Most delta smelt die after spawning in the spring (Radtke, 1966), although a few survive to a second year (Moyle 1976; Stevens, et al. 1990). Gonadal development does occur in second year fish so those fish should be capable of spawning (Randy Mager, University of California). Second year fish can grow to lengths near 130mm (FL) (Stevens, et al. 1990).

Delta smelt feed entirely on zooplankton (Stevens, et al. 1990; Moyle, et al. 1992). At larval stages, gut samples indicate that the diet consists of harpacticoid copepods, calanoid copepods, and copepod nauplii (Stevens, et al. 1990). As delta smelt grow larger, the primary dietary objects are calanoid copepods. In 1974 samples, *Eurytemora affinis* was the primary prey item with mysid shrimp *Neomysis mercedis* second (Stevens, et al. 1990). In 1988 and 1991 samples, *Pseudodiaptomus forbesi*, an exotic copepod first observed in the Sacramento-San Joaquin Estuary in 1987, was the dominant prey item (Stevens, et al. 1990; Moyle, et al. 1992; Moyle unpub. data). Other prey items observed in gut samples include: another exotic copepod, *Sinocalanus doerii* (Moyle, et al. 1992); the amphipod, *Corophium sp.*; and the cladocerans *Bosmina sp.* and *Daphnia sp.* (Stevens, et al. 1990).

Delta smelt spawning may occur from late winter to early summer. Moyle (1976) found ripe females from December to April with most collected from February to March. Recently, Wang (1991) using 1989 and 1990 data found that spawning occurred from mid-February to late June or July with peaks in late April and early May. He suggested that because of the long spawning season, delta smelt might be fractional spawners or, alternatively, that different individuals mature at different times to ensure better chances of survival. Recent histological analyses do not support the fractional spawning theory because all of the eggs develop synchronously (Serge Doroshov, University of California. There is also evidence that in some years nearly complete spawning failure may occur (Erkkila, et al. 1950).

Delta smelt spawn in freshwater (Moyle, et al. 1992) or possibly in slightly brackish water in or above the entrapment zone (Wang 1991). Possible spawning locations are reported to include dead-end sloughs (Radtke 1966), inshore areas of the delta (Moyle 1976), edges of rivers (Moyle, et al. 1992), or river areas under tidal influence with moderate to fast flows (Wang 1991). Water temperature at spawning has been reported to be about 7°-15°C (≈45°-59°F) (Wang 1986), however, this range is inconsistent with April-June temperatures in the Delta which typically range from 15°-23°C (≈59°-73°F). In 1990, newly post-hatch larvae (5.0 mm TL, total length) were collected at water temperatures as high as 22.8°C (73°F) (CDFG unpublished data); 7-14 days beforehand when spawning presumably occurred, the water temperature ranged from 20.8°-21.7°C (69.5°-71°F) at the same location and in surrounding areas.

Female delta smelt mature at 55-70mm and fecundity ranges from 1247 to 2590 eggs for females 59 to 70mm (SL) (corrected range from Moyle,et al. 1992). No relationship between fecundity and length has been observed (Moyle, et al. 1992).

Spawning occurs in the water column above vegetation or in open water above sandy or rocky substrates (Wang 1986). As smelt eggs descend through the water column, the outside adhesive layer of the chorion folds back and attaches to the substrate (Wang 1986). Delta smelt eggs likely attach to rocks, gravel, tules, cattails, tree roots, and emergent vegetation (Wang, 1986; Moyle, et al. 1992). Delta smelt hatched in 9-14 days at temperatures from 13-16°C during laboratory observations in 1992 (Randy Mager pers. comm.). Exogenous feeding starts at 5-6 days posthatch at 14-16°C with two-thirds of the yolk absorbed (Randy Mager, pers. comm.).

After hatching, the larvae float to the surface and drift with the currents downstream toward the entrapment zone (Stevens, et al. 1990; Moyle, et al. 1992). The location of the entrapment zone in the Estuary depends on flow conditions (e.g., outflow, water export rates, Delta cross-channel open or closed, etc.), but in most springs it is in Suisun Bay. Circulation currents apparently allow larvae that have drifted to the entrapment zone to remain instead of being swept farther west into salt water (Stevens, et al. 1990). The entrapment zone and the low salinity reach immediately upstream support peak concentrations of the zooplankton on which delta smelt feed (Orsi and Knutson 1979; Kimmerer 1992; Arthur and Ball 1979). This region is important to the young of may fish species, hence the term "nursery area" (Stevens, et al. 1985). In recent years, the entrapment zone generally has been confined to small channel areas of the Delta due to low inflows and high water exports (Moyle, et al. 1992). Larval growth is rapid and juveniles may reach lengths of 40-50mm (FL) by August (Erkkila, et al. 1950).

Population Status:

Delta smelt were historically one of the most common open water fish in the upper Sacramento-San Joaquin Estuary (Erkkila, et al. 1950, Radtke 1966, Stevens and Miller 1983). Historically, delta smelt abundance has fluctuated considerably from year to year.

The annual summer townet survey, initiated in 1959, provides one of the two best measures of delta smelt abundance and represents the longest historical record of smelt abundance. The abundance index indicates that the smelt population declined to low levels in the early 1980s where it remained until 1995 with the exception of a small increase in 1986. Only three times before this decline did the index fall below 10 during the 31 year record, and these low values were only for one year at a time. Following 1982, the index was less than 10 every year until 1994 when the index increased to 13.0, apparently in response to restrictions on water project operations imposed by ESA requirements and an increased adult population that developed in response to good environmental conditions in 1993. In 1995, 1996, 1997, and 1998, extremely high spring outflows transported many young delta smelt seaward, and the summer townet index varied from only 2.7 to 4.0. In 1999 this index increased to 11.7.

The fall midwater trawl survey covers the entire range of delta smelt abundance. The annual fall midwater trawl abundance index for 1993 was 1078 (Figure C-1). This index represents the greatest abundance of delta smelt pre-spawning adults since 1980. However, despite this 1993 increase and an improved summer tow net index in 1994, the fall 1994 index fell to an all time low of 101.2--apparently in response to renewed drought. The index rebounded again in 1995 at 899. In 1996, 1997, and 1998, it was 128, 361, and 418 respectively. From 1982 to 1992 the mean fall index was 350. From 1967 to 1981 the fall index ranged from 338 to 1678 and the mean was 841.

From 1985 to 1992, the remnant delta smelt population in the fall was concentrated largely in the lower Sacramento River between Collinsville and Rio Vista. In 1992, 90% of all delta smelt caught in the midwater trawl survey were from this region. In 1994, 65% were there. In 1993 and historically, when delta smelt were more abundant, the population was spread from Suisun Bay and Montezuma Slough through the Delta. The reasons for this recent concentration in the lower Sacramento River are that downstream habitat in Suisun Bay has been unsuitable for delta smelt due to increased salinities resulting from reduced outflows caused by drought and water management, and delta smelt are scarce in the San Joaquin portion of the Delta, perhaps due to losses in water diversions.

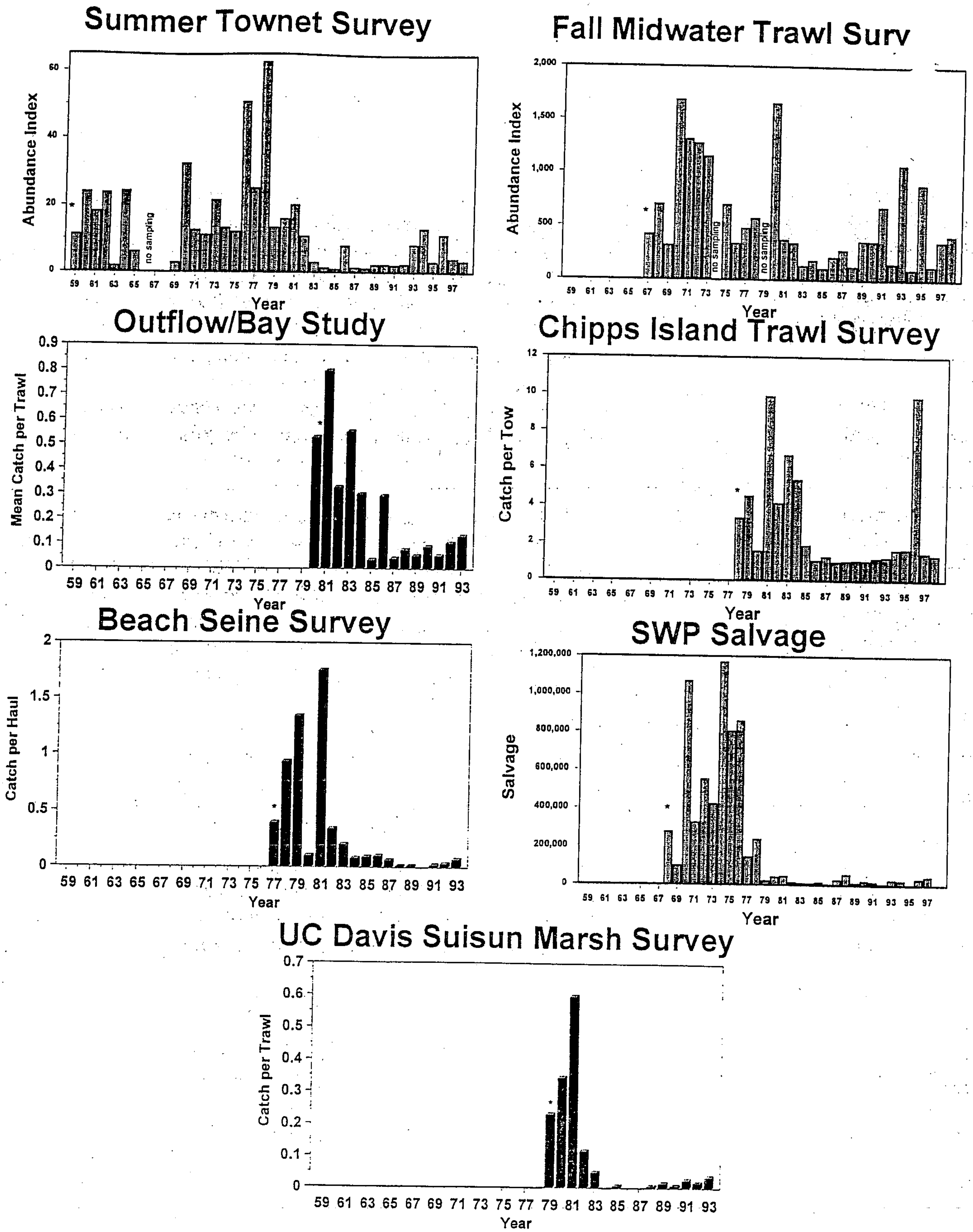

FIGURE C-1. Trends in Delta Smelt Abundance as Measured by Seven Independent Indicies. Asterisks represent the first year of sampling.

Five other independent measures of delta smelt abundance also indicate that the population has generally been at a low level since the early to mid 1980s (Figure C-1):

1. The Delta Outflow-Bay Study survey is comprehensive in that it samples monthly throughout the year. Its main deficiency in measuring delta smelt abundance, however, is that it does not sample in the Delta east of Antioch and Collinsville; thus, a portion of the delta smelt's geographical range is not covered.

2. The Interagency Salmon Trawl Survey has been conducted from April through June, since 1976, at Chipps Island. The major deficiency in this data set is that the survey is one location; thus, the indices are affected by changes in delta smelt distribution.

3. The Interagency Beach Seine Survey is generally run from January to June in the Delta and Sacramento River. This survey generally reflects the numbers of smelt making spawning migrations although small smelt around 20-30mm have also been taken.

4. Fish salvage operations at the State Water Project (SWP) and the Central Valley Project (CVP) fish screens provide enormous samples of fish populations in the Delta. However, because the diversion sites are in the southern Delta, they are biased by seasonal and annual changes in distribution of delta smelt. In addition, annual variations in water export rates affect the numbers of fish that are diverted and the screen efficiencies at which the fish are salvaged. These salvage values (Figure C-1) represent estimated salvage of delta smelt at the fish screens, not losses of smelt to the diversions. Losses of delta smelt cannot be estimated as they are for striped bass and salmon because studies have not measured either predation losses of delta smelt in Clifton Court Forebay or screen efficiencies.

5. The UC Davis Suisun Marsh Survey has used otter trawls to sample fish populations in Suisun Marsh sloughs since 1979. But, because the sampling locations are limited geographically and because the geographical distribution of delta smelt varies annually, other data sets provide a better depiction of the overall population trend.

Problems Affecting Delta Smelt

Based on CFG analyses, and discussions and conclusions of expert groups, formed by USFWS and California agencies, it is believed that the following factors are those most likely inhibiting recovery of the population:

1. **Direct entrainment of larval, juvenile, and adult delta smelt.** All life stages of delta smelt are vulnerable to entrainment in water diversions of the CVP, SWP, Contra Costa Canal, North Bay Aqueduct, Delta agriculture, the Pacific Gas and Electric Company's power generating stations, and other industry using water in the Estuary.

Substantial entrainment losses of larvae occur at the CVP and SWP despite thei intakes being located at the southern edge of the Delta, miles from the current primary spawning and nursery areas. These losses occur due to the magnitude the water project diversions, their impact on Delta flow patterns, and the tendency for young delta smelt to be transported to the intakes by estuarine currents. At high CVP/SWP export rates, water is drawn up the San Joaquin River reversing its normal flow pattern. While the relationship between abundance and reverse flow is not statistically significant, Moyle and Herbold (1989) found that high frequencies of reverse flows in the San Joaquin River during spring were always associated with low abundances of delta smelt in Suisun Bay in the fall while low frequencies of reverse flows sometimes were associated with high abundances of delta smelt. Recently, there has been a trend of increasing reverse flows in the San Joaquin River, especially during the spawning months (Moyle, et al. 1992).

Actual losses of delta smelt salvaged at the SWP and CVP cannot be calculated with certainty because no information is available on either pre-screening losses (predation rates) in Clifton Court Forebay and at the CVP or efficiencies of the diversion louver screens. If loss rates for delta smelt are similar to loss rates measured on other fish species of similar size (salmon, striped bass), the annual salvage estimate of 15,966 delta smelt at the SWP facility in 1991 may equate to an annual loss of about 200,000 delta smelt. In January 1993, 3,087 delta smelt were salvaged at the SWP intakes yielding a calculated loss on the order of 18,000 pre-spawning adults. Salvage of young-of-the year delta smelt from May 1 to May 23, 1993 was 10,768 delta smelt averaging about 25mm in length. This is substantially higher than the May monthly average for the SWP of just under 2,000 delta smelt salvaged. Because the screen efficiency of diverting fish of this size is small (conservatively estimated to be about 20% for a 25mm fish), the actual loss may have been on the order of 200,000 delta smelt.

Survival of delta smelt which have been salvaged probably is low due to stress caused by handling and trucking. In fact, survival of delta smelt retained at SWP's Byron growout facility was reported to be 0% in 1989 (total of 2590 delta smelt, Odenweller 1990). There was also consensus by the experts appointed to the USFWS Delta Smelt Working Group that mortality of delta smelt salvaged and transported back to the Estuary from the State and Federal water diversions was near 100%.

Because of the difficulty in separating larval longfin smelt from delta smelt, estimation of larval entrainment losses of delta smelt to the SWP and CVP was not initiated until 1989. Sampling of larval entrainment losses at both the SWP and CVP was done by DWR from 1989 to 1992; however, there was a gap in sampling during the peak spawning period in 1991 (Table C-1). Despite the collection of less than 20 larval delta smelt, the estimated entrainment losses from the combined facilities exceeded 1 million delta smelt larvae in 1992.

Table C-1. Estimated Entrainment of Delta Smelt Larvae in the SWP and CVP 1989-1992. Data from the Department of Water Resources

	STATE WATER PROJECT	CENTRAL VALLEY PROJECT
Year	Estimated Entrainment	Estimated Entrainment
1989	442,922	136,191
1990	582,501	348,745
1991	24,085*	16,901*
1992	554,407	645,496

* No sampling was done from April 17th to May 27th, 1991.

The Pacific Gas and Electric Company (PGE) power plant intakes are screened, but these screens are ineffective on larval fish. In 1978-1979, more than 50 million and 16 million smelt larvae (both delta and longfin smelt) were estimated to have been entrained at PGE's Pittsburg and Contra Costa power plants, respectively (PGE 1981a, 1981b). Also, estimates of impingement of larger delta smelt juveniles and adults on the power plant screens were 11,000 fish at Pittsburg and 6,400 fish at Contra Costa. Currently, there are no requirements to report delta smelt losses.

There are more than 1,800 agricultural diversions in the Delta which may divert between 2,000 and 5,000 cfs from delta channels during the irrigation season which is normally from April through September (Brown 1982). This is the period in which larval and juvenile delta smelt would be most vulnerable to entrainment. Studies were implemented by the Department of Water Resources in 1992 to assess the extent to which delta smelt are lost to these diversions and to test fish screens. Sampling documented take of five juvenile delta smelt from a Bacon Island diversion in 1993. No delta smelt were found in sampling at Bacon Island in 1992 or at three other diversions in 1992 and 1993 (DWR and USBR 1994).

2. **Delta outflows outside the range necessary to transport young smelt to their optimum habitat in Suisun Bay and keep them there.** Moderately high outflows move young smelt away from the various water diversions which are concentrated in the Delta and maintain much of the delta smelt nursery and the freshwater/saltwater mixing zone of the Estuary in Suisun Bay. The Suisun Bay shallows often are highly productive and likely provide a better living environment than the deeper channels of the Delta. Kimmerer (1992) observed that maximum zooplankton production occurs when the entrapment zone was located west of the confluence of the Sacramento and San Joaquin Rivers. It was estimated that this would require a maintenance outflow of at least 8,000 to 9,000 cfs and perhaps as much as 16,200 cfs to provide the optimum geographic location (Kimmerer and Monismith 1992). Although not specifically for delta smelt, Jassby (1993) also reported that increased abundance and survival of organisms from a variety of trophic levels and a variety of life history stages was observed when entrapment

zone (x-2) position was in Suisun Bay.

The period of the delta smelt decline included years not only characterized by drought and high water exports leading to flows too low to transport young fish to Suisun Bay, but also years with unusually wet periods and exceptionally high outflows. Periods of exceptionally high outflow also may be detrimental to delta smelt because their planktonic larvae may be transported out of the Delta into San Pablo and San Francisco bays and have no means to move back upstream.

3. **Increased competition and reduced productivity of the delta smelt's food chain due to accidental introductions of exotic species.** Since the early 1970s, several exotic species, including both fish and invertebrates, have been accidentally introduced into the Sacramento-San Joaquin Estuary and become firmly established. Most of these species have been introduced through the discharge of organisms carried in ballast water of ships. In particular, the Asian clam (*Potamocorbula amurensis*) has become extremely abundant in Suisun Bay since 1988, and its filtering may be responsible for a simultaneous major decline in the abundance of the native copepod, *Eurytemora affinis*, historically the most common component of the delta smelt diet. The efficiency of delta smelt feeding may also have been affected by several copepods which have become abundant within the past 15 years, one of which, *Sinocalanus doerii*, has been shown to be less vulnerable prey than the native *Eurytemora*. Increased competition for food may also be occurring due to the introduction in 1988 and population explosion in 1990 of the Shimofuri goby, *Tridentiger bifasciatus*.

Effects of competition among species are difficult to determine. While the decline in delta smelt did not coincide with the obvious increase in exotic species, competition could have played some role in the decline; however, most of these exotic species have only recently become abundant. Subsequent increases in exotic species may inhibit recovery of the delta smelt. Conversely, the exotic copepod, *Pseudodiaptomus forbesi*, is now a major component of the delta smelt diet.

4. **Genetic dilution and/or competition by immigration of wakasagi from Central Valley Reservoirs.** A closely related smelt, the wakasagi was introduced into several California reservoirs in the late 1950s and 1960s. The six original reservoirs in which wakasagi were planted are: Dodge Reservoir, Lassen County; Dwinnell reservoir (also know as Shastina Reservoir), Siskiyou County; Freshwater Lagoon, Humbolt County; Spaulding Reservoir, Nevada County; Jenkinson Lake, El Dorado County; and Big Bear Lake, San Bernardino County (Wales 1962). Currently, known "escape" populations occur in Oroville Reservoir, Folsom Reservoir, and the American River below Lake Natomas. There is potential for dilution of the delta smelt gene pool and elimination of its existence as a separate species if wakasagi should become established in the Delta and hybridize with delta smelt. Although an electrophoretic analysis suggests hybridization is unlikely, recent taxonomic identifications suggest both wagasaki and hybrids now occur in the delta. Increased competition from wakasagi also is possible because both fish have similar feeding habits and diets.

5. **Toxic substances in the Estuary.** The effects of toxic substances including agricultural pesticides, heavy metals, and other products of our urbanized society on delta smelt have never been tested. However, inspection of larval delta smelt tissues and body form to look for evidence of toxicity are planned. Similar studies have identified probable toxic effects in young striped bass. Histological tissue analyses involve microscopic examination of retina attachment, digestive tract tissue development, and liver condition. Body form (morphometric) analyses consist of examining ratios of fish length and body depth measurements at various locations along the length of the fish. Body shape is then used to evaluate health condition. Although the effects of chemical compounds on fishes generally are poorly understood, some of these compounds are found in the Estuary at levels that may inhibit fish reproduction (Jung, et al. 1984) or are sufficient to trigger health warnings regarding human consumption of fishes. Although there is no direct evidence of delta smelt suffering direct mortality or stress from toxic substances, currently this factor cannot be eliminated as a potential agent adversely affecting the delta smelt population.

6. **Predation.** Delta smelt evolved with native predators such as squawfish (*Ptychocheilus grandis*), Sacramento perch (*Archoplites interruptus*), and steelhead (*Onchorhynchus mykiss*); however, predation by these species, none of which are currently abundant in the Estuary, is unlikely to be responsible for the relatively recent decline observed in delta smelt. Striped bass which were introduced into the Estuary in 1879, have been the most abundant predator (adults and sub-adults) and competitor (young) in the portion of the Estuary inhabited by delta smelt, but striped bass have also suffered a serious decline which began in the 1970s and preceded the decline in delta smelt. Previously, much larger populations of both striped bass and delta smelt coexisted. Other potential competitors or predators, which include longfin smelt, threadfin shad, and white catfish, also show signs of population erosion approximately coinciding with, or in the case of white catfish, preceding the decline of delta smelt. The inland silversides, *Menidia beryllina*, a potential larval predator appeared in the Estuary in the 1970s, but its measured abundance has been highly variable. In essence, there has not been a consistent increase in the abundance of any potential predator or competitor that could obviously account for the decline in delta smelt. However, recent analyses (Bennett 1995), while still inconclusive, support a hypothesis that delta smelt abundance is affected by combined effects of silverside abundance and position of the salinity gradient. The recent appearance and explosion of the Shimofuri goby (*Tridentiger bifasciatus*), a potential larval competitor and predator, also potentially could inhibit recovery of the delta smelt. The effort to mitigate erosion of the Sacramento-San Joaquin striped bass population through the stocking of hatchery-reared fish has recently been suggested as contributing to the decline in delta smelt. Striped bass are highly pisciverous; however, comprehensive striped bass food habit studies in the 1960s when delta smelt and striped bass were both much more abundant indicated that, while delta smelt were occasionally consumed, they were not a significant prey of striped bass. That and the small size of the present striped bass population,

including stocked bass, indicate that striped bass have not been a major factor in the decline of the smelt. The CFG discontinued the stocking of hatchery-produced striped bass into the Estuary in 1992, although from 28,000 to 100,000 striped bass salvaged from the SWP fish screens and pen-reared in the Estuary for one-year have been released into San Pablo Bay annually from 1993 to 1995.

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APPENDIX D1

Status of Sacramento Splittail

Much of the information presented here has been summarized from DWR/USBR (1994).

Splittail Life History

The Sacramento splittail (*Pogonichthys macrolepidotus*; Family: Cyprinidae) is one of California's largest native minnows growing to 30–40 cm in length. These fish are distinctive in having the upper lobe of the caudal fin larger than the lower lobe. The body shape is elongate with a blunt head. Small barbels may be present on either side of the subterminal mouth. Sacramento splittail are thought to be one of the most primitive North American cyprinids (Hopkirk 1973) and are an irreplaceable part of the California and Sacramento-San Joaquin Valley fish fauna.

Life history characteristics and ecology of splittail have been investigated and described by Caywood (1974), Daniels and Moyle (1983), Moyle (1976), Moyle et al. (1989), and Wang (1986). Splittail are endemic to California, and have a moderately complex life cycle possibly tied to seasonal flooding in the Central Valley.

Adults have a distinct upstream migration into fresh water in late fall and early winter prior to spawning. Their life cycle consists of mature adults (generally age-2+) spawning over an extended period from mid-winter through mid-summer, eggs and larvae from early spring to summer, and juveniles from summer through fall.

Sacramento splittail are a relatively long-lived minnow, reaching ages of 5 and possibly up to 7 years (Moyle *et al.* 1989, Caywood 1974). The adult growth rate ranges from 5 to 7 mm per month. During gonad development, primarily from September through February, the growth rate slows to less than 5 mm per month (Daniels and Moyle 1983).

Adult splittail generally reach sexual maturity at about 2 years (Caywood 1974; Daniels and Moyle 1983). However, Caywood (1974), observed that some males mature at the end of their first year and a few females mature in the third year. Wang (1986) noted male sexual maturity by the end of the first year and female maturity by the first or second year. Gonad development is usually initiated in fall, and gonads reach full maturity by late winter or early spring. Wang (1986) found eggs of various sizes and stages of development from females collected in the Estuary, indicating that spawning may occur over extended periods.

Splittail have high fecundity, like most cyprinids. Caywood (1974) documented fecundity ranging from 5,000 to 100,800 eggs per female. Daniels and Moyle (1983) measured fecundity of 20 females 175 mm SL or larger collected from January through March in Suisun

Marsh and found from 17,500 to 266,000 ova per female. It was also observed that fecundity increased with length and weight of the female. Generally, female splittail produce more than 100,000 eggs each year (Moyle *et al* 1986).

The spawning period of splittail seems to vary depending on environmental conditions such as water temperature, photoperiod, seasonal runoff, and possibly endogenous factors. Splittail may have a protracted spawning period based on the observed variations in size and development of eggs sampled from individual females (Wang 1986).

Timing of splittail reproduction has varied between different locations during separate investigations. In the upper Delta in 1973 and 1974, splittail spawned between early March and mid-May (Caywood 1974). In a Suisun Marsh study from January 1979 to January 1982, splittail apparently spawned in late April or early May, with young-of-the-year fish collected in late May or early June (Daniels and Moyle 1983). Splittail spawning occurs in water temperatures from 9 to 20° C (Caywood 1974; Wang 1986).

Timing and magnitude of winter and spring runoff, with corresponding fluctuations in water temperature, probably influence the spatial and temporal distribution of splittail spawning in the Estuary (Caywood 1974; DFG 1992; Daniels and Moyle 1983; Meng 1993, 1994; Moyle 1976; Moyle *et al.* 1986, 1989, Wang 1986). Spawning activity of splittail seems to be associated with high runoff periods in winter and spring and concomitant flooding of low-lying flood plains. Ripe and spent adult splittail and eggs attached to vegetation were collected from shallow flooded vegetation in the floodplain of Cosumnes River sloughs (Caywood 1974). Other studies found adult and young-of-the-year splittail within the temporarily flooded Sutter Bypass during high runoff in 1993 (Jones and Stokes 1993).

Normally, runoff patterns in the Central Valley peak in winter as a result of large winter storms followed by high flows from spring snow melt during warmer weather. Flooding during these periods provides the shallow water areas of submerged vegetation that seems to be the preferred spawning habitat of splittail (Caywood 1974; Daniels and Moyle 1983). This is supported by correlations of strong year classes with annual, monthly, and seasonal high outflows that flood peripheral areas of the Estuary (Daniels and Moyle 1983; Meng 1993, 1994).

Mature splittail eggs are 1.3 to 1.6 mm diameter with a smooth, transparent, thick chorion (Wang 1986). The eggs are adhesive or become adhesive soon after contacting water (Caywood 1974). Eggs appear to be demersal, and it is assumed that they are laid in clumps and attach to vegetation or other submerged substrates (Caywood 1974; Wang 1986). Under laboratory conditions, fertilized eggs incubated in fresh water at 19° C (±0.5°) start to hatch after about 96 hours. Asynchronous hatching of egg batches from single females has been observed in preliminary culturing tests. Eggs laid *en masse* were first to begin hatching, apparently due to higher concentrations of hatching enzymes released from adjacent eggs. Larvae are 7.0-8.0 mm TL when they complete yolk-sac absorption and become free swimming (Daniels and Moyle 1983; Wang 1986). When exogenous feeding actually begins is not known.

Young-of-the-year splittail collected through May and June in the lower Sacramento River and west to Antioch by Caywood (1974) and in Suisun Marsh by Daniels and Moyle (1983) ranged from 24 to 40 mm FL (mean 22 mm) and 23 to 54 mm SL (mean 32 mm), respectively. Daniels and Moyle (1983) found young-of-the-year grew about 20 mm/month from May through September and then decreased to < 5 mm/month through February. In their second season, they grew at about 10 mm/month until the fall, when somatic growth declined and gonadal development began.

Young-of-the-year splittail appear to seek out shallow, vegetated areas protected from strong currents near spawning grounds and move downstream as they grow (Caywood 1974; Wang 1986). Some apparently move or are carried with higher spring flows downstream into the Estuary and bays, where they have been captured by midwater trawl sampling in Suisun Bay and sometimes as far downstream as Carquinez Strait and San Pablo Bay (CFG midwater trawl data, 1967 to 1993; Caywood 1974; Wang 1986). There is also a record of larval splittail collected near Berkeley Marina in San Francisco Bay in April 1982 (Wang 1986), a year with a wet spring and copious freshwater outflows from the delta. Salinity tolerances are unknown for young-of-the-year and juvenile splittail, yet may be significant to survival and growth of early life stages.

Sacramento splittail are one of the few cyprinids that are tolerant of brackish water (Daniels and Moyle 1983; Moyle 1976; Meng 1994). Historically, the species was found extensively in freshwater habitats of rivers draining to the Delta (Caywood 1974; Moyle 1976; Rutter 1908). Fishery surveys have also found these fish populating tidal freshwater and euryhaline low-velocity rivers and sloughs in the Delta, concentrating in and around Suisun Marsh (Caywood 1974; Meng 1993; Moyle 1976; Daniels and Moyle 1983; Moyle *et al* 1989; Spaar 1988; Wang 1986; IEP 1994). In Suisun Bay, Meng (1993) consistently found all sizes of splittail in shallow water at less than 2-3 ppt salinity. Splittail have been collected at salinities as high as 12-18 ppt (Meng 1994; Messersmith 1966; Moyle 1976; Daniels and Moyle 1983). As salinity increases, splittail apparently move upstream. In Petaluma Marsh, when salinity is high, splittail have not been collected (Caywood 1974).

Population Status

Abundance data for splittail are available from eight databases.

Fall Midwater Trawl Survey

The fall midwater trawl survey, conducted since 1967, represents one of the longest and most geographically extensive measures of splittail abundance. However, the midwater trawl is relatively inefficient at catching splittail; from 1967 to 1992, less than 500 splittail were caught. Analysis of length frequency data for 1980 to 1992 indicates most of those were young-of-the-year, but at least 30 percent were year 1 or older. Baxter (1994) suggests that the relatively large size of 1-year-olds and adults may allow them to successfully avoid open-water trawls. The present indices are calculated based on all sizes combined; additional analyses are needed to separate young-of-the-year, age-1 and age-2+ fish in the databases.

Calculated indices shown in Figure D-1 are assumed to primarily represent trends in young-of-the-year, which appear to have been most abundant in 1967, 1982, 1983, and 1986; all of which are wet years. Recruitment apparently was particularly low during the 1976-1977 drought and remained fairly low since 1987.

Summer Tow-Net Survey

Like the fall midwater trawl survey, the summer tow-net survey is geographically extensive but relatively inefficient at catching splittail. Since 1976, only 320 splittail have been caught. Length-frequency analysis of the data indicate the survey catches almost exclusively young-of-the-year splittail.

The highest tow-net indices were in 1963, 1978, 1982, and 1986. In contrast to a number of other surveys, abundance levels since 1987 have not been particularly low relative to other years. For example, the 1991 index (5.0) was the sixth highest on record.

CVP and SWP Salvage

A major advantage of the CVP and SWP salvage facilities with regard to their use to index fish abundance is that large numbers of fish are counted and measured relative to all the other surveys. A limitation of the database is that salvage levels may vary depending on screen efficiency, exports, flows, and the number of predators present. The salvage facilities sample only a small area within the range of splittail, and therefore, would be sensitive to shifts in splittail distribution.

Annual abundance indices for different age classes of splittail were estimated from records of salvage at Tracy and Skinner fish facilities since 1979, the period of most accurate data. The salvage data were separated into age classes using tentative size criteria developed using data from Skinner Fish Facility and the DFG Outflow/Bay study.

Annual abundance indices were calculated for young-of-the-year, age 1 and age-2+ (≥ 2) by summing salvage for a specific time interval, dividing by the average export rate for this period, and multiplying the result by 1,000, a convenient scaling factor. Results for young-of-the-year are shown in Figure D-1. Annual young-of-the-year abundance indices show similar variability for both facilities, with major peaks in 1980, 1983, and 1986, followed by consistently low recruitment from 1987 until 1993. The index for 1995 has not been calculated, but salvage has been at a record high, exceeding 5 million splittail, and apparently reflecting a major rebound in production this year.

Age-1 salvage is fairly erratic through the year. Salvage is generally highest from April-July, but large numbers were sometimes observed in February and March. Abundance indices

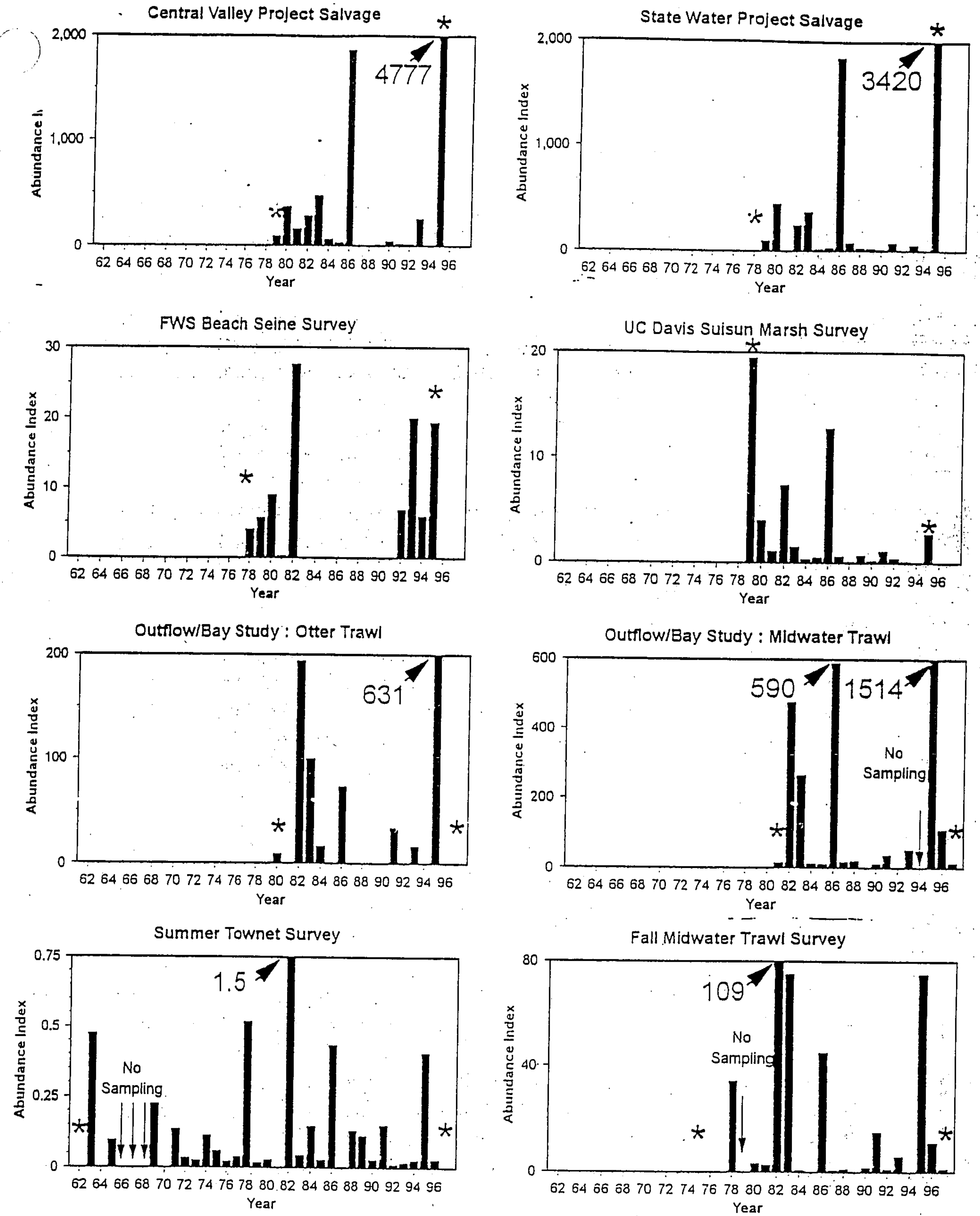

FIGURE D-1. Trends in Young-of-the-Year Splittail Abundance, as Indexed by Eight Independent Surveys. Asterisks Indicate Start of Survey and End of Data Available.

for April-July were developed using an approach similar to that described for young-of-the-year. The CVP and SWP indices both suggest that age-1 abundance was highest in 1984 and relatively low in 1982, 1985, 1986, and all years after 1987 (Figure D-2). Results are somewhat incongruous for the other years.

Age 2+ salvage was usually highest in February-April, with irregular but occasionally high levels in January. Annual abundance indices calculated from total February-April salvage are shown in Figure D-3. Although the highest indices were at the CVP in 1981 and 1982 and at the SWP in 1980 and 1982, there does not appear to be a consistent trend in age 2+ abundance (Figure D-3).

Delta Outflow/San Francisco Bay Study

As part of the Interagency Program, the CFG Delta Outflow/San Francisco Bay study has sampled 35 locations from South Bay to the western Delta between 1980 and 1993. Sampling includes 5-minute tows (bottom time) using an otter trawl and 12-minute oblique tows using a midwater trawl. The splittail catch was separated into young-of-the-year, age-1, and age-2+ using appropriate size criteria. Monthly catch-per-unit-effort for each embayment was calculated as catch per 10,000 m^2 for the otter trawl and catch per 10,000 m^3 for the midwater trawl. Monthly abundance indices were calculated by multiplying average catch-per-unit-effort for each embayment by area (otter trawl) or volume (midwater trawl) weighting factors, then summing the embayment indices. Annual splittail abundance indices for each trawl were calculated as the average of the monthly indices for the following periods: young-of-the-year (May-October), age 1 (February-October), and age 2+ (February-October).

A weakness of this database is that the area east of Antioch has not been sampled until recently, so an important part of the species' range is excluded. Because the survey region is the westernmost range of splittail, abundance measurements may be sensitive to shifts in distribution. Nonetheless, the high frequency of samples taken using different gear types provides a valuable source of information about splittail trends.

Otter and midwater trawl indices both indicate that recruitment of young-of-the-year splittail to the lower Estuary has been poor since 1987. Peak abundance was in 1982, 1983, and 1986.

Annual abundance indices for age-1 splittail were generally consistent with young-of-the-year catch in the previous year using the same gear type. High young-of-the-year catches in the otter trawl in 1982, 1983, and 1986 were followed by large numbers of age-1 in the following year. Relatively poor catches of young-of-the-year in 1980, 1981, 1985, and 1987-1989 were followed by low age-1 indices the next year. In the midwater trawl, high young-of-the-year indices in 1982, 1983, and 1986 and low indices in 1981, 1984, 1985, and 1987-1992 were also

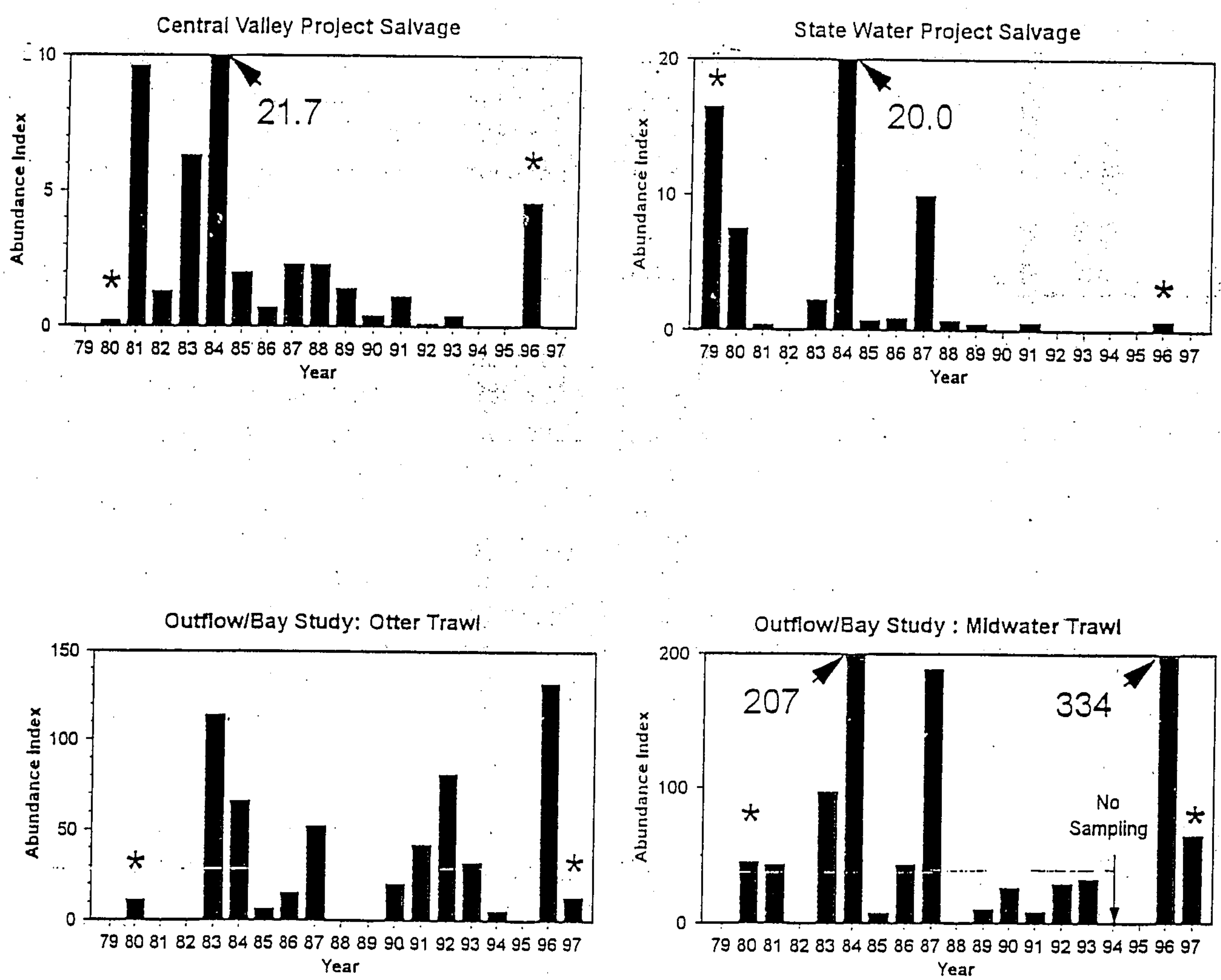

FIGURE D-2. Trends in Age-1 Splittail Abundance, as Indexed by Four Independent Surveys. Asterisks Indicate Start of Survey and End of Data Available.

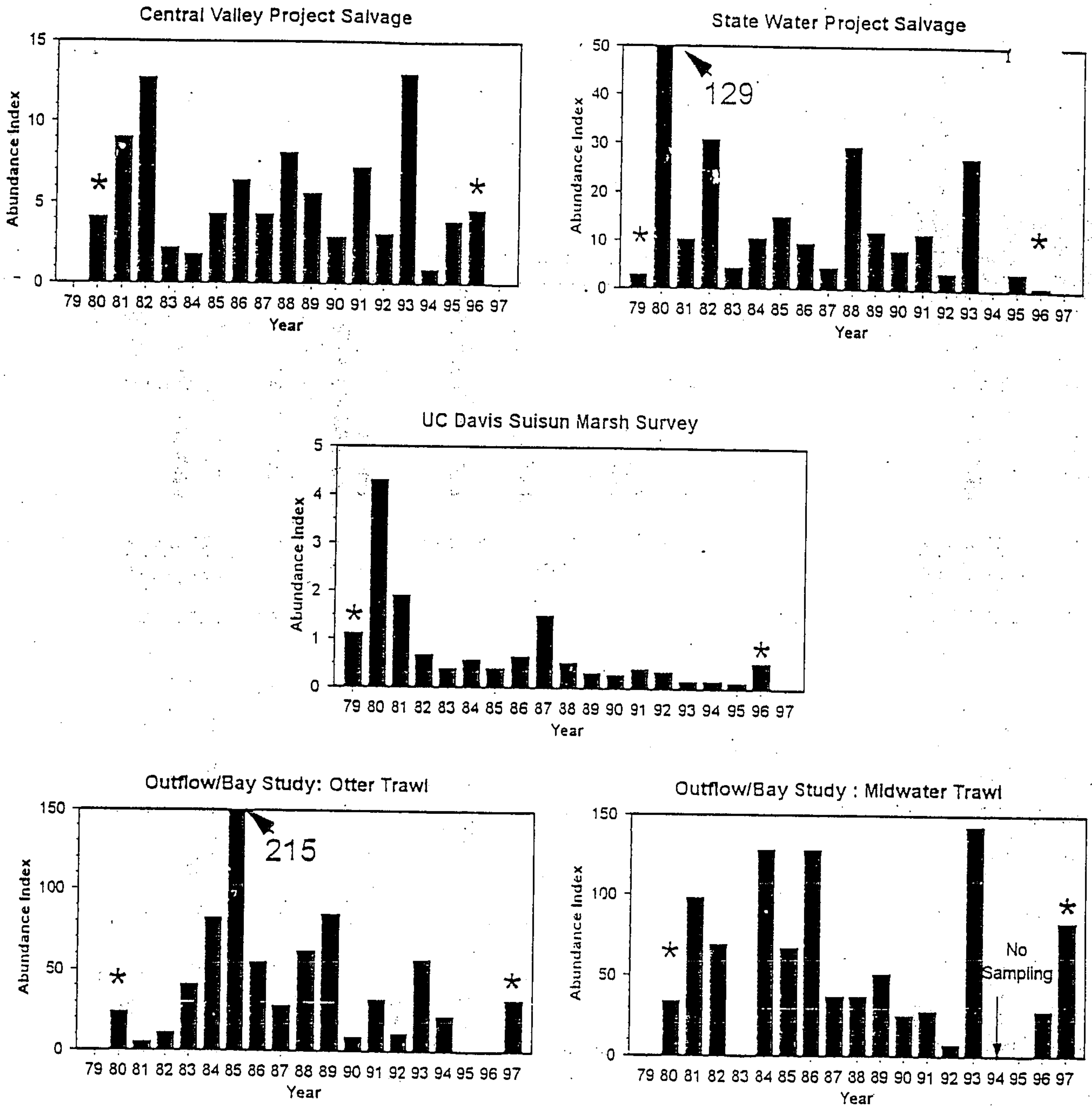

FIGURE D-3. Trends in Adult Splittail Abundance, as Indexed by Five Independent Surveys. Asterisks Inidcate Start of Survey and End of Data Available.

irrored by age-1 abundance the subsequent year.

Both surveys show higher abundance of age-2+ in 1993. A resurgence in adult abundance in 1993 is consistent with relatively higher catches of young-of-the-year in 1991 than in 1987-1990. Age 2+ abundance also appears to reflect young-of-the-year abundance 2 years earlier in other cases. For example, low age-2+ indices in the otter trawl in 1980 and 1985 and high indices in 1982 and 1983 followed similar trends in young-of-the-year 2 years earlier.

Suisun Marsh Survey

The Suisun Marsh survey is performed monthly by staff and students at UC Davis. The survey has been used by Meng (1993) as an indicator of abundance trends. This survey shows a decline in all age groups between 1979 and 1993 with the strongest year classes being produced in 1979, 1982, and 1986.

Other Surveys

Additional information on splittail abundance is available from shorter-term studies within the range of splittail by PG&E and Suisun Marsh Salinity Control Gate studies.

PG&E

Monthly surveys were conducted in 1978-1979 (PG&E 1981a, 1981b) and 1991-1992 (PG&E 1992b) in Suisun Bay and the lower San Joaquin River using bottom (otter)trawl, gill-net, fyke-net, and beach seine methods. Species composition, based on the percentage of Sacramento splittail within the composite catches is summarized below.

	1978-1979		1991-1992	
Location	% Comp	Rank	% Comp	Rank
Suisun Bay	14	2	12	2
Lower San Joaquin	3	6	4	5

These results suggest that splittail remain a dominant part of the fishery community in Suisun Bay. However, the similarity in percent composition between the surveys is not necessarily representative of the splittail abundance trend. The other surveys provide measures of that trend.

Suisun Marsh Salinity Control Gate Studies

A monitoring program has been conducted at Suisun Marsh Salinity Control Gates since

1987 to address questions about juvenile salmon predation. Although the sampling program is designed primarily to monitor abundance of fish predators in the area, large numbers of splittail also are captured. Sampling is performed during the daytime in spring and summer using stationary and drift gill-nets at sites upstream and downstream of the structure.

Catch-per-unit-effort was calculated based on the total catch of splittail divided by the number of hours sampled at the upstream and downstream site (DFG 1993). Examination of the length data indicated that all splittail captured were in the age-2 + size range.

Splittail were the second most abundant species in most years; in 1988 they were the most abundant species caught. Catch-per-unit-effort data are summarized in Figure D-4. Results indicate that splittail abundance has been variable but has not declined since 1988.

Summary

Except for indices developed for the CVP and the SWP, annual estimates of abundance are based on collection of relatively few splittail. However, some abundance tendencies are evident. There clearly was a decrease in splittail recruitment during 1987-1990. Most of the surveys suggest recruitment improved in 1991 and 1993, although young-of-the-year levels were well below peak levels of the early- to mid-1980s. It also appears that young splittail abundance is highest in wet years such as 1982, 1983, and 1986. In general, the number of adult splittail has been variable since 1979, without a discernible trend. Abundance data for age 2+ after 1991 is limited to the Delta Outflow/San Francisco Bay study, however, both midwater and otter trawl methods indicate that age-2+ abundance was higher in 1993 than in 1991. Independent surveys by PG&E and CFG confirm that adult splittail remain as one of the more common larger fishes in Suisun Bay.

Problems Affecting Sacramento Splittail

Splittail population size and distribution may be influenced by a number of factors including river flow and entrapment zone position, water diversions, predation by and competition with other species, food abundance, spawning stock abundance, and contaminants. Disease and parasites could also pose risks to the splittail population, but no studies are available to address them.

Effects of Flow on Splittail Abundance

Few species in the Estuary respond as dramatically to wet years as splittail. Daniels and Moyle (1983) found a relationship between total Delta outflow and the midwater trawl index of splittail abundance. Regression analyses using the midwater trawl indices through 1993 yield significant relationships with February-May outflow ($r2 = 0.50$). Similar relationships between young-of-the-year splittail abundance and outflow were also reported by Meng (1993) for the Chipps Island and Bay/Outflow surveys.

The benefit of wetter years to splittail is supported using non-parametric statistical methods. If midwater trawl and summer tow-net data are grouped into "dry" (critical-below normal) and "wet" (above normal-wet), differences are statistically significant using a Mann-Whitney U-test (DWR 1994).

One possible explanation for this trend is that strong year classes may only be produced when major storms inundate vegetation in the floodplain, thereby increasing spawning habitat. This hypothesis was initially presented by Caywood (1974) based on observations that ripe splittail were caught in or near areas of flooded terrestrial vegetation. This hypothesis also is consistent with the apparent "bumper crop" of splittail produced in the wet spring of 1995.

In addition, splittail have been observed in two of the major floodplain areas in the basin: Yolo and Sutter bypasses. Caywood (1974) noted that splittail are common in the Yolo Bypass when it floods and occasionally in the Sutter Bypass. Jones and Stokes (1994) also collected adult and juvenile splittail in the Sutter Bypass during 1993.

The possible importance of Yolo and Sutter bypasses and other floodplain areas is supported by an analysis which shows a significant relationship ($p < 0.01$) between the number of days these areas are flooded in winter and spring and the midwater trawl index. These results do not necessarily indicate that the bypasses are the primary spawning and rearing areas, but they may provide a surrogate for the inundation of floodplains throughout the basin.

Splittail may also benefit from high flows for the same reasons that other fishes benefit from them. High outflows transport young split ail away from the various water diversions which are concentrated in the Delta and rivers upstream and maintain productive habitat in the freshwater/saltwater mixing zone (entrapment zone) of the Estuary in Suisun Bay. Meng (1993) hypothesized that splittail abundance is related to the amount of shallow brackish water habitat in Suisun Bay, and Fox and Britton (1994) found a close relationship between the fall midwater trawl index of splittail abundance and the location of the 2 ppt isohaline (x2) during February-June (r2 = 0.61). USFWS beach seine data from 1993 indicate that many young splittail remain in the Delta and Sacramento River at least through June, however, revealing that even in high flow years the nursery area extends upstream from Suisun Bay.

Regardless of the specific cause, the extended period of drought during the late 1980s and early 1990s has resulted in low flows and produced relatively small year classes of splittail.

Water Diversions

State and Federal water project diversion in the southern delta may affect splittail directly by entraining fish in diverted water or indirectly through environmental modifications caused by using delta channels to convey water from the Sacramento River to the southern Delta.

Entrainment of fish is the most apparent effect of the water projects. Actual losses of juveniles and adults salvaged cannot be calculated with certainty because there is no informatio for splittail pre-screening loss (predation rates) or on efficiency of the louver screens for splittail. Salvage provides a relative index of loss rates between years. However, salvage levels may be influenced by seasonal or annual changes in predation or screening efficiency. Based on the salvage data, it is evident that entrainment occurs throughout the year, with peak levels from February through August.

In general, splittail larvae which are too small to be screened may also be present in the southern Delta from February or March through June, but occurrence may vary within this period from year to year. Entrainment of larval splittail was estimated from the DWR Egg and Larval Entrainment study for 1992 and 1993 and is shown below:

ESTIMATED ENTRAINMENT OF SPLITTAIL LARVAE
1992-1993
(Thousands of Fish)

Year	CVP	SWP	Total
1992	109	0	109
1993	0	194	194
Total	109	194	303

Water project diversions also may impact splittail through the "reverse flow effect". Reverse flow occurs in the Delta when inflow from the San Joaquin River is insufficient to meet exports and agricultural diversions. Water is pulled from the Sacramento River through the delta, and in some channels upstream tidal flow is intensified and causes net upstream flows where they would otherwise not occur.

From 1985 to 1992, reverse flows have characterized the lower San Joaquin River for more than 150 days of the year, and, in every year except 1986, reverse flows have occurred for 15-85 days of the splittail spawning season (February-May). The proposed "threatened" listing for splittail (USFWS 1994) suggests that reverse flow negatively impacts splittail by disorienting larvae and juveniles, leading to mortality at the export facilities.

Recent particle tracking studies by Department of Water Resources, demonstrate that a calculated index of reverse flow, QWEST, is not a good indicator of entrainment risks. Entrainment of tracers occurred despite high positive values of QWEST. The degree to which the simulation is representative of young fish is not known, but the model provides at least an indication of the major physical processes.

An alternative explanation is that there is a "zone of influence" in the interior Delta where entrainment risks are much higher. This region has not been well characterized, but it likely depends on various tributary inflows, export pumping, Delta Cross Channel operations, Clifton Court Forebay operations, and consumptive uses.

Water project operations also may increase risk of splittail loss to diversions because changes in salinity and reverse flow of water associated with project operations have shifted the distribution of individuals upstream, causing the fish to be more vulnerable to State and Federal pumping plants (USFWS 1993).

PG&E Power Plants

Adult and juvenile Sacramento splittail are commonly found in the vicinity of PG&E's Pittsburg and Contra Costa power plants (PG&E 1992a). There is also some evidence that splittail are attracted to thermal discharge, as indicated by higher abundance within the Pittsburg Power Plant thermal plumes (Gritz 1971).

Data on splittail entrainment at PG&E's power plants are limited, except for surveys during 1978 and 1979 (PG&E 1981a, 1981b). Results from April 1978 to April 1979 show that 123,000 splittail were entrained at Contra Costa Power Plant (Ecological Analysts 1981a, 1981b). However, it is possible that not all of these individuals are lost because the diverted water is returned to the Estuary as thermal effluent. It is unknown whether the power plants pose a significant threat to splittail.

Agricultural Diversions

Some information is available on splittail from 1992 and 1993 sampling for the Delta Agricultural Diversion Evaluation. No splittail have been collected from any of the diversion sites, but larval splittail have been shown to be present in adjacent channels at two sites (Griffin 1993, Spaar 1994).

Although there is no direct evidence of entrainment, splittail are probably most vulnerable to diversions in February-June, during their larval and early juvenile stages. The irrigation season runs generally from late March or early April through September. Potentially, the period of highest losses of splittail to agricultural diversions would be April-June, based on their life stages at this time and timing of the irrigation season.

Predation and Competition

Splittail abundance may also be affected by a number of native and introduced fish and invertebrate species. The exceptionally large number of introduced species have resulted in major modifications to the estuarine ecosystem.

Of the numerous predators in the region, most such as striped bass, catfish, and sunfish were well established in the Estuary more than a century before low recruitment levels of splittail occurred from 1987 to 1994. Several of these species (*e.g.*, striped bass) also declined in abundance over the same period as, or before splittail young-of-the-year abundance and are, therefore, unlikely to be responsible for recent trends. Although recent water transparency increases in the Estuary could have enhanced predation, analyses indicate that this variable is not well correlated with splittail abundance (DWR and USBR 1994).

If predation is responsible for poor splittail recruitment, the most probable explanation is that a recently introduced species is responsible. The most likely species would be inland silversides (introduced in 1975) and the yellowfin goby (introduced in the late 1950s).

Predation studies using large field enclosures stocked with larval striped bass demonstrate that inland silversides will prey on larval fish (Bennett *et al.* 1993). A possible relationship between splittail and inland silverside abundance was examined using data from the midwater trawl survey. Annual catch-per-unit-effort for each species was calculated as the average of the monthly catch for September-December during 1980-1990, when silverside became highly abundant. Regression analyses indicate no significant relationship in CPUE for the two species ($r^2 = 0.19$) (DWR - USBR 1994).

Yellowfin goby have been a common species in the midwater trawl throughout the period of record. However, a comparison of CPUE between yellowfin goby and splittail in the midwater trawl for 1980-1990 also suggests their abundance trends are not related ($r^2 = 0.09$) (USBR, DWR 1994).

Several introduced fish species could also compete with splittail for food. In the Bay/Delta system, low food abundance and changing composition suggest that food could be limiting at juvenile or adult stages (Moyle *et al.* 1992). Inland silverside is a successful competitor with native species in a number of other locations (Li *et al.* 1976). Yellowfin and shimofuri goby are potentially important competitors with splittail, because all appear to be benthic feeders. Nonetheless, the analyses described above provide no evidence that splittail abundance is related to trends in yellowfin goby and inland silverside. Shimofuri goby did not occur in the midwater trawl catch until 1988, the year after a decline in splittail young-of-the-year abundance was noted at the beginning of the 6-year drought. There are insufficient data to determine whether subsequent abundance of these species may be associated.

The introduction of the Asian clam, *Potamocorbula amurensis*, is perhaps the major biological change in the Estuary over the past decade. Recent evidence suggests that *Potamocorbula* is responsible in part for a decline in phytoplankton abundance in the Estuary (Alpine and Cloern 1992) and may directly compete with fish by consuming *Eurytemora affinis* nauplii (Kimmerer, in press), perhaps an important zooplankton food source. Conversely, an increase in abundance of a similar exotic copepod, *Pseudodiaptomus forbesi*, should compensate to some extent for the decline of *Eurytemora*. Studies from 1993 indicate that high freshwater flows did not significantly reduce the range of the clam, so it may continue to be a problem for resident biota.

Adult and juvenile splittail are predominantly benthic foragers with a limited range of prey types, and they feed opportunistically on the benthic food items available within local habitats. Caywood (1974) analyzed stomach contents of splittail from Miller Park on the Sacramento River in 1973 and 1974 and found the most frequent items included detritus and algae (73 to 81%), earthworms (*Lumbricus* spp.) (40 to 64%) and dipterans (up to 46%). The relative abundance of food organisms was dominated by oligochaetes, cladocerans, and dipterans.

Dominant food organisms in splittail stomachs taken near Antioch in the fall of 1973 and analyzed by Caywood (1974) included copepods (86% relative frequency) and dipterans; in October stomachs were gorged with detritus and algae. Juvenile splittail (143 mm mean FL) sampled from Big Break in April 1974 had detritus, clams (*Corbicula manilensis*), amphipods (*Corophium* spp.), and copepods as the dominant food items (Caywood 1974).

These findings were similar to results of feeding studies by Daniels and Moyle (1983). Stomach contents of splittail from Suisun Marsh consisted predominantly of detritus in both percent frequency of occurrence (74%) and percent volume (57%). A smaller portion of the stomach contents (41% by volume) consisted of animal matter, dominated by crustaceans (35% by volume). Opossum shrimp (*Neomysis mercedis*) were the dominant crustacean food item (37% by frequency; 59% volume less detritus) both daily and seasonally. Unlike Caywood's results, oligochaetes were not a dominant food item for splittail in the marsh. Other minor prey items included molluscs, insects, and fish.

Feeding and food selection studies conducted by Herbold (1987) suggest that splittail specifically select *Neomysis* as their main prey item in the Estuary. Stomach fullness indices indicate that condition factors of splittail are linked to *Neomysis* abundance. Herbold found that as *Neomysis* densities decline there is concomitant increase in the incident of detritus in stomach contents. Splittail did not switch to alternate and more prevalent food items as was observed for other native resident marsh species. He hypothesized that declines in splittail abundance may be associated with the observed declines in *Neomysis* abundance (pers comm, May 5, 1994). However, the geographic range of splittail extends far beyond the estuarine habitat of *Neomysis*, and Caywood (1974) documented significant feeding on other items, so it is questionable whether this mysid is a required food source. One possibility is that *Neomysis* is indeed the most suitable food within the marsh, but other resources are available in upstream areas.

Recreation Harvest

Splittail are not harvested commercially, but support a small recreational fishery. Harvest of splittail was first evaluated by Caywood (1974), who noted a recreational fishery near Sacramento, at the port of Stockton, and at the Mokelumne-Cosumnes river confluence. Angler surveys were also conducted by PG&E in 1974 to evaluate the fishery near Contra Costa and Pittsburg power plants. Splittail averaged 1.8% of the total catch by anglers from late June through October 1974 near the Pittsburg Power Plant. In some cases, splittail averaged up to 14% of the total (PG&E 1975a). Near Contra Costa Power Plant, splittail comprised 1% of the catch (PG&E 1975b).

The overall status of the recreational fishery has not been measured but it is known to be of small magnitude. Splittail are also sometimes used as bait for striped bass (Moyle *et al* 1993). Although recreational harvest could slightly reduce the number of spawners, it is unlikely to have a major effect on splittail abundance.

Spawning Stock Size and Year-Class Strength

Like many species, splittail abundance could be limited by the number of spawners in the population. If the spawning population is reduced, recruitment may be reduced. However, application of stock-recruitment theory to splittail is complicated by the fact that abundance data for adults are relatively crude, with no separation between age classes. As demonstrated by Daniels and Moyle (1983), fecundity increases with age, length, and weight, indicating that knowledge of the relative contribution of different age classes is necessary for a thorough evaluation of recruitment patterns.

In the absence of detailed size and age data, DWR/USBR (1994) performed analyses with the assumption that the number of age 2+ fish in the population was an adequate measure of the spawning stock. Spawning stock size and year class strength were examined using annual salvage and Delta Outflow/Bay study abundance indices. Abundance indices were analyzed for SWP (1979-1991), CVP (1980-1991), Delta Outflow/Bay study otter and midwater trawl indices (1980-1992) using linear regression and log transformation techniques. They did not find any significant relationships between the number of age-2+ fish and young-of-the-year recruitment.

The salvage and midwater trawl results suggest that environmental factors -- not the number of adults -- are the primary control on splittail recruitment. However, regression analyses indicate that recruitment affects the number of subsequent spawners (DWR/USBR 1994). There are significant relationships ($p < 0.05$) between the number of young-of-the-year and age-1 abundance one year later, and young-of-the-year and age-2+ abundance 2 years later.

Given an association between young-of-the-year indices and the number of adults subsequently observed in the population, it likely that poor recruitment during the recent 6-year drought will lead to a reduced spawning stock. However, recruitment patterns during the past three decades suggesting high resilience of this species are consistent with the apparent rebound of young-of-the-year production in response to improved environmental conditions in spring 1995.

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Toxicity

Toxic contaminants also may affect splittail. Possible pollutants include heavy metals, pesticides, herbicides, and polycyclic aromatic hydrocarbons. No toxicity studies have been conducted to determine the sensitivity of splittail to these compounds. Contaminants in the sediments probably are the greatest threat to splittail, although contaminants in the water column are also a concern. Evidence suggests that toxins in sediments may affect the benthic environment, even at low levels (Elder 1988), but there is no way to evaluate impacts on splittail with present information.

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