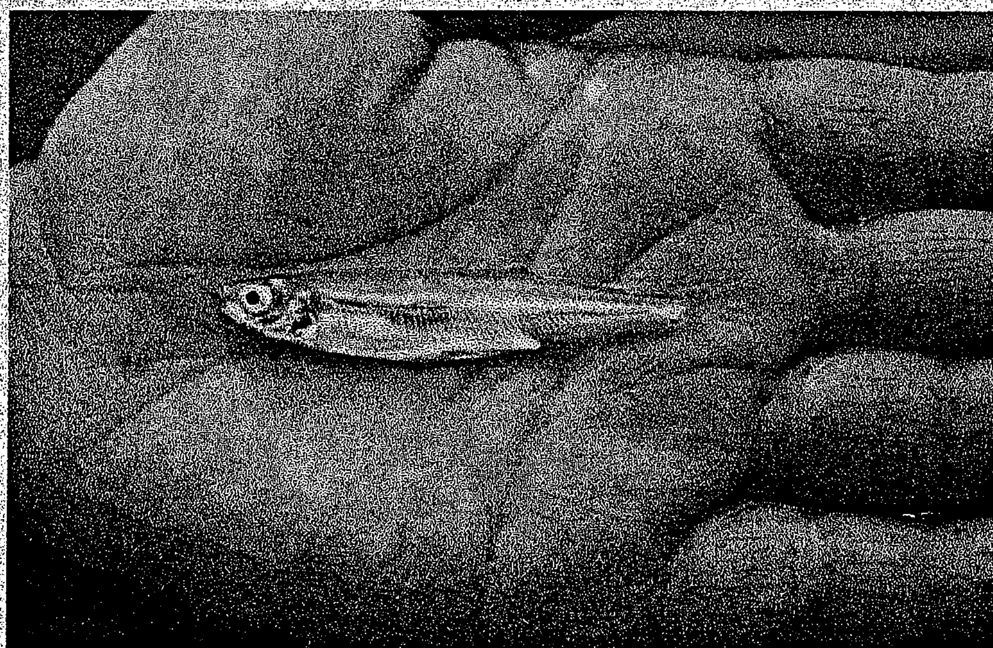
# REPORT TO THE FISH AND GAME COMMISSION:

# A STATUS REVIEW OF THE DELTA SMELT (*HYPOMESUS TRANSPACIFICUS*) IN CALIFORNIA



RESOURCES AGENCY
CALIFORNIA
DEPARTMENT
FISH & GAME

## DEPARTMENT OF FISH AND GAME

STATE OF CALIFORNIA
THE RESOURCES AGENCY

MAY 1993

State of California

# Memorandum

To : Mr. Robert R. Treanor, Executive Director
Fish and Game Commission

Date : April 23, 1993

From : Department of Fish and Game

Subject : Commission Agenda Item for the June 18, 1993 Commission Meeting Re: Transmittal of Pre-Publication of Notice for Amendment to 670.5, Title 14, CCR, Re: Delta Smelt (*Hypomesus transpacificus*).

As a result of the Commission's decision at their April 2, 1993 meeting to accept the Department of Fish and Game's recommendation to list Delta smelt (*Hypomesus transpacificus*) as a threatened species, we are hereby transmitting the subject document and supporting attachments.

Boyd Gibbons
Director

Attachments

bc: Dr. Larry Eng
Environmental Services Division

Mr. Dale Sweetnam
Bay-Delta Division

State of California
The Resources Agency

DEPARTMENT OF FISH AND GAME

# REPORT TO THE FISH AND GAME COMMISSION:

# A STATUS REVIEW OF THE DELTA SMELT (HYPOMESUS TRANSPACIFICUS) IN CALIFORNIA

Prepared by

Dale A. Sweetnam
Associate Marine/Fisheries Biologist

and

Donald E. Stevens
Fisheries Management Supervisor

Approved by

Harold K. Chadwick, Division Chief
Bay-Delta and Special Water Projects Division

Alexander Petrovich Jr., Deputy Director
California Department of Fish and Game

May 1993

Candidate Species Status Report 93-DS

# TABLE OF CONTENTS

**Report to the Fish and Game Commission:**

**A status Review of the**

**Delta Smelt (Hypomesus transpacificus)**

**in California**[1/]

# EXECUTIVE SUMMARY

This report reviews evidence pertaining to a petition presented to the Fish and Game Commission by the Department of Fish and Game to list the delta smelt (Hypomesus transpacificus) as an Endangered Species under the authority of the California Endangered Species Act (Fish and Game Code Sections 2050 et seq.).

On April 2, 1993, pursuant to the Section 2074.2 of the California Endangered Species Act (CESA), the Commission determined that the petition contained sufficient information to indicate that the petitioned action may be warranted. Pursuant to Section 2074.6 of CESA, the Department undertook this review of that petition. Based on the best scientific information available on the delta smelt, the Department has evaluated whether, in fact, the petitioned action should be taken.

## Findings

The delta smelt is a small fish endemic to the Sacramento-San Joaquin Estuary. Delta

1/ *Prepared May 1993.*

smelt are euryhaline and much of the year are typically most abundant in or immediately upstream from the entrapment zone, where incoming saltwater and outflowing freshwater mix. This species feeds exclusively on zooplankton, spawns in freshwater, and usually only lives for one year.

Information from seven different data sets all indicate that the population of delta smelt has declined substantially since the late 1970s or early 1980s. The summer townet survey indicates that the average population since 1982 has been less than one-sixth of the average population level from 1959, when the survey began, to 1981, and the population in 1992 was less than one-eighth of that average. Based on the fall midwater trawl survey, the average population since 1982 has been less than one-third of the average population level from the initial survey in 1967 to 1981, and the population in 1992 was less than one-fifth of that average.

Conclusions

The Department finds that the delta smelt should be listed as a threatened species, based on Section 670.1(b) of Title 14 of the California Code of Regulations and Section 2072.3 of the Fish and Game Code. The Department's findings are based on the following:

1. While the relationship between delta smelt abundance and water diversions is not clear, all life stages of delta smelt are vulnerable to entrainment in these diversions.

Large losses of pre-spawning adult smelt entrained when the major water projects escalate pumping in winters following major droughts (eg. 1977-1978) may be particularly harmful. It is relevant that delta smelt are ecologically similar to young striped bass which have been severely impacted by water diversions. Whether or not water diversions are directly responsible for the delta smelt population decline, their drain on the population may be a significant factor inhibiting recovery.

2. Delta smelt are threatened by habitat modifications which include changes in the character and position of the salinity gradient. An increase in salinity in Suisun Bay caused by increased water diversions, upstream storage, and the extended drought has constricted the delta smelt to only a portion of its former range. Other habitat alterations include changes in food items and the introduction of exotic species.

3. The recent decline in the copepod, Eurytemora affinis, a major diet component of the delta smelt, must be considered as a potential threat to the smelt's recovery unless other food resources such as Pseudodiaptomus forbesi compensate or Eurytemora recovers to its former abundance.

4. A number of exotic fish and invertebrate species have been introduced into the Sacramento-San Joaquin Estuary. Although none of these species can be directly linked to the decline in delta smelt, their presence has led to distinct changes in the biota of the Estuary and may inhibit the smelt's recovery.

5. Low spawning stock levels may inhibit potential for population recovery. The relatively low fecundity of this species and its planktonic larvae, which undoubtedly incur high rates of mortality, indicate that year class success of the delta smelt must depend on reproduction by fairly large numbers of fish.

6. The years of the delta smelt decline are characterized either by outflows that were too low to transport young fish to their optimum habitat in Suisun Bay, or by exceptionally high outflows that may have transported larvae beyond Suisun Bay into the western Estuary.

7. The wakasagi, a closely related species introduced into several reservoirs in the Delta drainage has now been found in the American River below Nimbus Dam. The wakasagi potentially could compete with the delta smelt and/or hybridize with it and dilute its gene pool.

8. Although there is no direct evidence of delta smelt suffering direct mortality or stress from toxic substances, such substances cannot be eliminated as having adverse effects on the population.

9. Diseases and parasites of delta smelt have never been studied; thus, there is no evidence concerning their role in the population decline. After several years of intense study on all aspects of the life history of delta smelt there has been no

evidence that disease or parasites have played a role in the decline of this species. However, should they be found to be important, they could prevent the recovery of delta smelt from current low population levels.

9. Although competition and predation cannot be ruled out as threats to delta smelt, the available evidence suggests that they are not a major threat. In fact, several potential competitors or predators also show signs of population erosion approximately coinciding with or preceding the decline of delta smelt.

10. The delta smelt population trend, certain life history attributes, and environmental threats tend to support listing. However, the Department of Fish and Game believes that the population is not in imminent danger of extinction, thus does not warrant listing as endangered. Based on the best scientific information available (Section 2074.6 CESA), the Department believes that the most prudent action is to list the delta smelt as a threatened species.

Recommendations

Listing:

1. The Commission should find that the delta smelt is a threatened species.

2. The Commission should publish notice of its intent to amend Title 14 CCR 670.5 to add the delta smelt (Hypomesus transpacificus) to its list of Threatened and Endangered Species.

Management and recovery objectives:

1. Modify pumping strategies at the State and Federal Water project diversions to reduce entrainment losses during periods when delta smelt are most vulnerable.

2. Provide spring and summer Delta outflows that will maintain the entrapment zone and major delta smelt nursery in the Suisun Bay region where food supplies are greater than in the Delta and exposure to diversions is minimal. This would increase the amount of suitable habitat available to delta smelt.

3. Evaluate losses to agricultural diversions in the Delta. Screening these diversions probably would reduce entrainment and losses of delta smelt to local crop irrigation.

Relevant studies by the Department of Water Resources began in 1992.

4. Monitor compliance of ship ballast water discharges to the International Maritime Organization's "Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ship's Ballast Water and Sediment Discharges". Such monitoring will provide a basis for judging whether additional regulatory action is warranted to reduce the risk of introducing unwanted freshwater and estuarine organisms.

5. Remove water project diversions from the Delta. Moving the diversion intakes to the Sacramento River upstream from the major smelt nursery area would do this and also provide benefits to delta smelt and other species which formerly made more use of the Delta.

6. Continue to develop pond culture techniques for the purpose of creating "refuge" populations.

Public Responses

Comments were invited in response to the current petition in a Public Notice dated, April 2, 1993 (Appendix A-1). Comments received are in Appendix A-2. Scientific comments in response to this current report will be addressed as part of the regulatory proceedings should the Commission find that the petition warrants action.

During the twelve-month review period preceding the 1990 status report (Appendix B), the Department contacted a number of affected and interested parties, invited comment on the petition and our draft status review, and requested any additional scientific information that may be available. A copy of the Public Notice and a list of parties contacted are contained in Appendix A of that report. Also, a summary of comments on the draft status review is in Appendix B of that report.

## LIST OF TABLES

## LIST OF FIGURES

**Report to the Fish and Game Commission:**

**A Status Review of the**
**Delta Smelt (Hypomesus transpacificus)**
**in California**

## INTRODUCTION

Petition History

On June 13, 1989, the California Fish and Game Commission (Commission) received a petition from Dr. Peter B. Moyle of the University of California at Davis, requesting State listing of the delta smelt (Hypomesus transpacificus) as an Endangered Species (Appendix A-3). The California Department of Fish and Game (Department or CDFG) reviewed the petition and recommended to the Commission that they accept it as complete pursuant to Sections 2072.3 and 2073.5 in the California Endangered Species Act (Fish and Game Code Sections 2050 et. seq.) and that the petitioned action may be warranted. On August 29, 1989 the Commission accepted the Department's recommendation and designated the delta smelt as a Candidate Species as provided for in Section 2074.2 of the California Endangered Species Act (CESA). That action initiated a twelve-month review period pursuant to Section 2074.6 of CESA in which the Department reviewed the best scientific evidence available on delta smelt and provided a written status report evaluating whether the petition was warranted. On July 27, 1990, the Department submitted Candidate Species Status Report Number 90-2 entitled: **Report to the Fish and Game Commission: A Status Review of the Delta Smelt (Hypomesus transpacificus) in California** (Appendix B). In this report the Department recommended listing the delta smelt as a Threatened Species (Appendix B, Executive

Summary).

At their August 30, 1990 meeting, the Commission found that pursuant to Section 2075.5 of the Fish and Game Code the delta smelt did not warrant listing as an endangered or threatened species. But in a letter dated September 14, 1990 (Appendix A-4), the Commission did direct the Department to:

> "coordinate with the Department of Water Resources and other related agencies to immediately commence whatever studies are needed to monitor the Delta smelt population and to address the following management and recovery objectives:
>
> a. Improvement of species identification and fish handling procedures at the existing State and Federal Water Project diversions from the Delta to reduce present entrainment losses to these major diversions.
> b. Modification of pumping strategies at the State and Federal Water Project diversions to reduce entrainment losses during periods when Delta smelt are most abundant.
> c. Increase of spring and summer Delta outflows to maintain the entrapment zone and major Delta smelt nursery in the Suisun Bay region where food supplies are greater than in the Delta and exposure to diversions is minimal.
> d. Support for regulations restricting ship ballast water discharges to eliminate or minimize new introductions of potentially harmful exotic species.
> e. Evaluation of losses to agricultural diversions in the Delta. Screening these diversions probably would reduce entrainment and losses to local crop irrigation.
> f. Consider the development of pond culture techniques for the purpose of creating "refuge" populations."

In response to the Commission directives, the Department met with representatives from the Department of Water Resources (DWR), U. S. Fish and Wildlife Service (USFWS), U.S. Bureau of Reclamation (USBR), State Water Resources Control Board (SWRCB), University of California researchers (Drs. Moyle and Herbold), and outside contractors. This meeting and a series of "pilot" studies performed in 1991 laid the groundwork for a delta smelt study which was fully implemented in January of 1992. Funding for this work was provided by the DWR and the USBR.

Based on the Department's 1992 annual report on the status of the delta smelt population (Appendix A-5), the Commission decided to review the status of delta smelt during their February 5, 1993 meeting. At this February meeting, the Commission decided not to vote on listing due to a legal issue. They did, however, request the Secretary of Resources to maintain an open dialog with the USFWS (Appendix A-6).

On March 15, 1993, the Department petitioned the Commission to list the delta smelt as a Threatened Species (Appendix A-7). On April 2, 1993 the Commission accepted the Department's petition and once again designated the delta smelt as a Candidate Species as provided for in Section 2074.2 of CESA. That action initiated a review period pursuant to Section 2074.6, within which the Department must review the best scientific information available on the delta smelt and provide a written report indicating whether the petition is warranted.

Department Review

This report contains the results of the Department's review and recommendation to the Commission, based on the best scientific information available, whether the petition action is warranted. It also identifies habitat that may be essential to the continued existence of the species and suggests prudent management activities and other recovery actions. Since much of the Department's 1990 status review is still relevant, a copy of Status Report 90-2 is included as Appendix B and is referenced either as Stevens *et al.* 1990 or Appendix B. The present status report generally follows the format of the 1990 status report. It specifies findings subsequent to the Commission's previous actions and reiterates some significant findings from the previous report.

The Department has contacted affected and interested parties, invited comment on the petition, and requested any additional scientific information that may be available, as required under Section 2074.4, Fish and Game Code (Appendix A-8). A list of the newspapers which published the legal notice are contained in Appendix A-9.

Federal Listing

On June 26, 1990, Dr. Donald C. Erman, the president of the California-Nevada Chapter of the American Fisheries Society, filed a petition with the USFWS to list the delta smelt as a Federal Endangered Species. Findings of the petition were listed in the **Federal Register** on December 24, 1990. On September, 27, 1991, nearly 3 months past its legal deadline of June 29, 1991, the USFWS officially proposed threatened status for the Delta smelt with critical habitat. The proposal was cited in the **Federal Register**, October 3, 1991. The term "threatened species" is defined in the Endangered Species Act of 1973 (ESA) as any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. Critical habitat is defined in the ESA as areas containing the physical and biological features essential to the conservation of a species.

On March 5, 1993, the USFWS listed the delta smelt as a Threatened Species under the ESA. This rule went into effect on April 5, 1993. In carrying out their responsibilities under the ESA, the USBR and the DWR have conducted a Section 7 conference with the USFWS on the 1993 operation of the Central Valley Project and the State Water Project.

This conference which was initiated by the USBR in September resulted in a formal consultation process after the delta smelt was listed. This consultation is intended to discuss the biology of the delta smelt and water project operational changes and water allocations that would help in its recovery. Upon completion, this consultation will be converted to a Biological Opinion.

The delta smelt already is listed as threatened by the federal government. And although federal listing does afford protection from actions by state or local entities under sections 9 and 10 of the ESA, federal listing does not require CDFG involvement in conferences and consultations required by the ESA. Thus, state management powers are effectively diminished. State listing would restore state management powers by requiring consultations and other protections under provisions of the State Endangered Species Act.

## LIFE HISTORY

Description:

The delta smelt, Hypomesus transpacificus McAllister, 1963, is a small euryhaline fish which reaches adult sizes of about 55-70 mm standard length (Moyle 1976; Moyle et al. 1989) although some may reach lengths near 130 mm (Stevens, *et al.* 1990). It is translucent with a silvery, steel-blue streak along its sides. Other related smelt species found in the Sacramento-San Joaquin Estuary include longfin smelt, Spirinchus thaleichthys, and now the wakasagi, Hypomesus nipponensis (Moyle 1976; California Department of Fish and Game (CDFG), unpublished data). More marine smelt species historically observed in the Estuary include: whitebait smelt, Allosmerus elongatus, surf smelt, Hypomesus pretiosus, and night smelt, Spirinchus starksi (Wang 1986). The marine species generally do not occur where delta smelt have historically been common.

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 descriptive information can be found in Moyle (1976) with larval descriptions 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).

Taxonomy:

Delta smelt were once thought to be a population of the widely distributed pond smelt, Hypomesus olidus. Distribution is said to have ranged from as far south as San Francisco on the North American side of the Pacific, Japan on the Asiatic side of the Pacific (Wales 1962), and into the Arctic Ocean in the north (McAllister, *et al.* 1979). In 1961, Hamada separated the pond smelt into two separate species; H. olidus was used for the present day H. transpacificus, and a new name, H. sakhalinus was designated for the Asiatic species (presumably named after the Island of Sakhalin off the coast of Siberia in the Sea of Okhotsk). McAllister (1963) determined that H. olidus was not present in California waters and described the two fish as subspecies, H. transpacificus transpacificus, the delta smelt, and the H. transpacificus nipponensis, the wakasagi. H. olidus was retained for the pond smelt which ranges from Alaska to Japan in the northern Pacific (McAllister, *et al.* 1979). The two subspecies have since been split into two distinct species, H. transpacificus and H. nipponensis (Moyle *et al.* 1986) with the common names delta smelt and wakasagi (Committee on Names of Fishes 1990). Currently, electrophoretic analyses are underway to genetically evaluate the two species and to determine if genetic dilution through interbreeding may be possible.

Range:

Delta smelt are found only in the Sacramento-San Joaquin Estuary (Stevens, *et al.* 1990; Moyle, *et al.* 1992) (Figure 1). 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

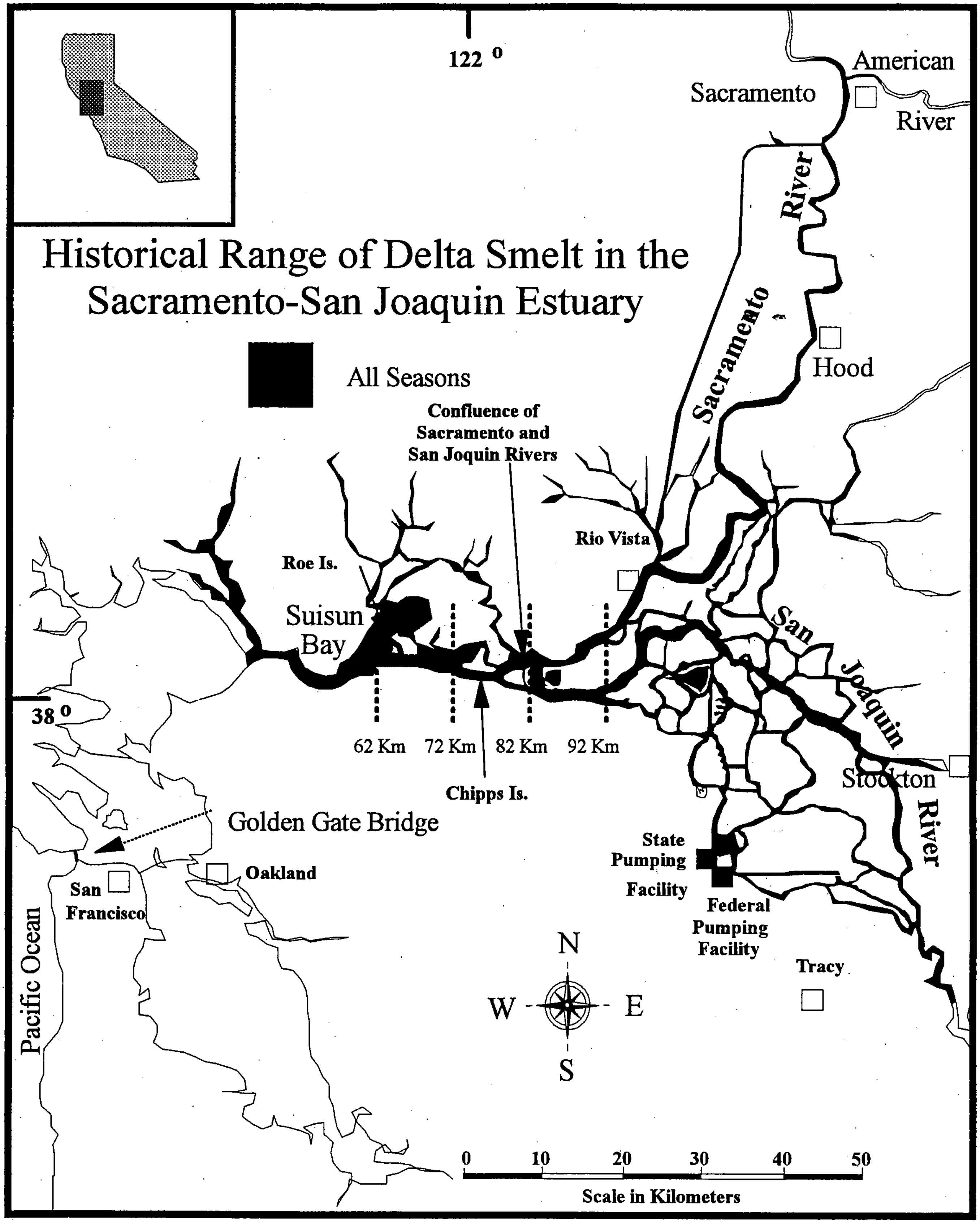



Figure 1. Historical range of delta smelt in the Sacramento-San Joaquin Estuary. Range includes observations from all life history stages and all times of the year. Dashed lines represent distances from the Golden Gate Bridge in Kilometers.

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 and move to freshwater to spawn (Moyle 1976).

In 1959, when the delta smelt and wakasagi were considered to be a single species (H. olidus), CDFG introduced wakasagi into several freshwater reservoirs in the state to supply forage for trout (Wales 1962). H. nipponensis was used because H. transpacificus was difficult to collect (Wales 1962).

Age and Growth:

Delta smelt are fast growing and shortlived (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 wakasagi (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 50-70mm (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). Recent data suggest that normal gonadal development can occur in second year fish (Randy Mager, University of California, pers. comm.). Second year fish can grow to lengths near 130 mm (FL) (Stevens, *et al.* 1990).

Diet:

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).

Reproduction:

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, pers. comm.) 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 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 55-70 mm and fecundity ranges from 1247 to 2590 eggs for females 59 to 70 mm (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). Hatching occurs in 12-14 days based on information from wakasagi. 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 many 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)(Figure 2). Wang hypothesized that delta smelt larvae may also position themselves vertically within the water column as evidenced by the gas bladder which does not develop until the larvae is approximately 16-18 mm (TL). This, in combination with the entrapment zone circulation pattern, would allow the larvae to maintain their position within the Estuary. In comparison, the gas bladder in longfin smelt begins development at 5-6 mm (TL) (Wang 1991). Larval growth is rapid and juveniles may reach lengths of 40-50 mm (FL) by August (Erkkila, *et al.* 1950).

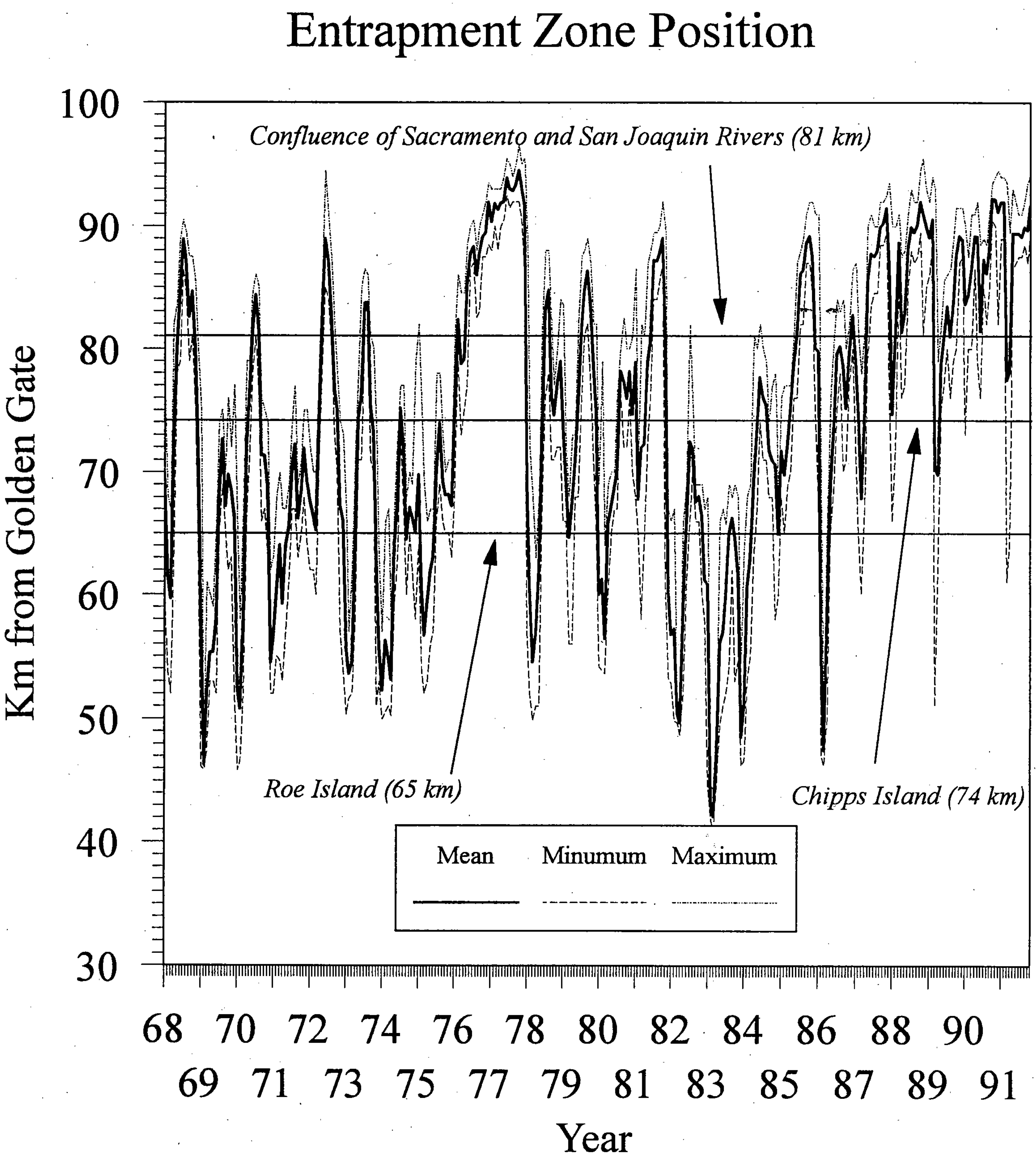



Figure 2. Monthly entrapment zone position in kilometers from the Golden Gate Bridge from January 1968 to November 1991. Data are from Kimmerer, BioSystems Analysis, Inc. (unpub. data).

## HABITAT REQUIREMENTS AND DISTRIBUTION

Delta smelt are found only in the Sacramento-San Joaquin Estuary. 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. 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. Surveys by the Delta Outflow/San Francisco Bay Study, which has sampled fish in the Estuary from South San Francisco Bay and the Golden Gate Bridge to the western Delta since 1980, indicate that delta smelt thin out in San Pablo Bay and are virtually non-existent in San Francisco Bay (Table 1).

Delta smelt usually inhabit the freshwater edge of the salinity gradient close to 2‰ (parts per thousand); they are rarely found at salinities greater than 10‰ (Moyle 1976). Summer townet and fall midwater trawl surveys conducted by the Department indicate that delta smelt are most frequently caught where specific conductance ranges from 500 to 8000 microsiemens (approximately 0.28‰ to 4.59‰ salinity)(Tables 2 and 3). Therefore, much of the year the majority are found at the upper boundary or just upstream of the entrapment zone (Obrebski, unpub. data) which has been depicted as having surface salinities of 1.2-6.0‰ (Arthur and Ball 1979).

Delta outflow affects geographical distribution of delta smelt and probably their survival. As flows increase and saltwater is repelled, more of the population occurs in Suisun and San Pablo bays and less occurs in the Delta (Figures 3 and 4). There is reason to believe that delta smelt benefit from being transported to Suisun Bay, although there is no simple direct relation between delta smelt abundance and outflow. Historically, when delta smelt were more abundant, often a large proportion of the population was found in Suisun Bay and the surrounding areas. In recent years, Suisun Bay has not been suitable for delta smelt because salinities have been outside the optimal ranges for delta smelt (see CDFG (WRINT-DFG-6) 1992 for trends of increasing salinities in Suisun Bay).

Delta smelt live principally in the upper portion of the water column. They tend to school near the surface or in shoal areas (Radtke 1966; Moyle 1976; Moyle, *et al.* 1992; CDFG unpublished data). For example, during a 1963-1964 survey of Delta fish populations, a 10 foot by 10 foot surface trawl captured 1960 delta smelt, while a 15 foot by 5 foot otter trawl only captured 461 delta smelt. These results were obtained despite the otter trawl constituting 60 percent of the survey effort of about 1800 tows.

Delta smelt require freshwater to spawn as they disperse into freshwater in the spring (Radtke 1966; Moyle 1976). They often are found in shallow areas which have adequate flows presumably to aerate the eggs and substrates that will allow proper egg attachment (Wang 1986; 1991).

Table 1. Delta Outflow/San Francisco Bay Study catch of delta smelt by month and area, 1980-1988. Number of sampling sites in parentheses. (Taken from Stevens, et.al., 1990.)

| Area | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| San Francisco Bay (16) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| San Pablo Bay (8) | 4 | 5 | 29 | 1 | 0 | 1 | 0 | 0 | 0 | 54 | 0 | 1 | 95 |
| Carquinez Strait & Western Suisun Bay (6) | 61 | 46 | 86 | 37 | 5 | 55 | 70 | 94 | 71 | 36 | 9 | 38 | 608 |
| Eastern Suisun Bay (3) | 18 | 24 | 15 | 10 | 5 | 8 | 16 | 37 | 54 | 68 | 40 | 12 | 307 |
| Western Delta (2) | 30 | 13 | 15 | 5 | 2 | 20 | 12 | 23 | 55 | 12 | 33 | 32 | 252 |
| Total | 113 | 88 | 145 | 53 | 12 | 84 | 98 | 154 | 180 | 170 | 82 | 83 | 1262 |

Table 2. Summer townet survey catch frequencies for delta smelt by specific conductance (EC) ranges, 1969-1988.[1/]

| EC (microsiemens) | Numbers of Smelt Per Catch | | | | | | | | Total Samples | Number Catches >0 | Percent with smelt |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1-4 | 5-9 | 10-14 | 15-19 | 20-49 | 50-99 | >100 | | | |
| No Data | 9 | 4 | 3 | 1 | 0 | 1 | 1 | 0 | 19 | 10 | 52.6 |
| 1-499 | 541 | 170 | 52 | 17 | 10 | 36 | 16 | 14 | 856 | 315 | 36.8 |
| 500-999 | 105 | 51 | 13 | 16 | 7 | 13 | 14 | 10 | 229 | 124 | 54.1 |
| 1000-1999 | 38 | 31 | 15 | 10 | 8 | 17 | 9 | 10 | 138 | 100 | 72.4 |
| 2000-3999 | 34 | 41 | 15 | 11 | 8 | 22 | 9 | 8 | 148 | 114 | 77.0 |
| 4000-5999 | 31 | 30 | 11 | 6 | 4 | 6 | 8 | 8 | 104 | 73 | 70.0 |
| 6000-7999 | 22 | 21 | 9 | 7 | 3 | 11 | 5 | 1 | 79 | 57 | 72.1 |
| >8000 | 338 | 96 | 32 | 14 | 7 | 17 | 14 | 3 | 521 | 183 | 35.1 |
| Total | 1118 | 444 | 150 | 82 | 47 | 123 | 76 | 54 | 2094 | 976 | 46.6 |

/ EC was not measured prior to 1969 even though the survey started in 1959.

Table 3. Fall midwater trawl frequencies for delta smelt by specific conductance (EC) ranges, 1967-1988.

| EC (microsiemens) | Numbers of Smelt Per Catch 0 | 1-4 | 5-9 | 10-14 | 15-19 | 20-49 | >50 | Total Samples | Number Catches >0 | Percent with smelt |
|---|---|---|---|---|---|---|---|---|---|---|
| No Data | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 |
| 1-499 | 1756 | 604 | 103 | 30 | 16 | 27 | 4 | 2540 | 784 | 30.8 |
| 500-999 | 311 | 137 | 35 | 21 | 7 | 12 | 5 | 528 | 217 | 41.1 |
| 1000-1999 | 224 | 128 | 43 | 18 | 10 | 18 | 2 | 443 | 219 | 49.4 |
| 2000-3999 | 269 | 141 | 44 | 30 | 9 | 14 | 5 | 512 | 243 | 47.4 |
| 4000-5999 | 244 | 97 | 45 | 9 | 10 | 12 | 1 | 418 | 174 | 46.1 |
| 6000-7999 | 202 | 67 | 23 | 10 | 5 | 9 | 1 | 317 | 115 | 36.3 |
| >8000 | 4547 | 173 | 24 | 9 | 9 | 11 | 4 | 4777 | 230 | 4.8 |
| Total | 7562 | 1347 | 317 | 127 | 66 | 103 | 22 | 9544 | 1982 | 20.7 |

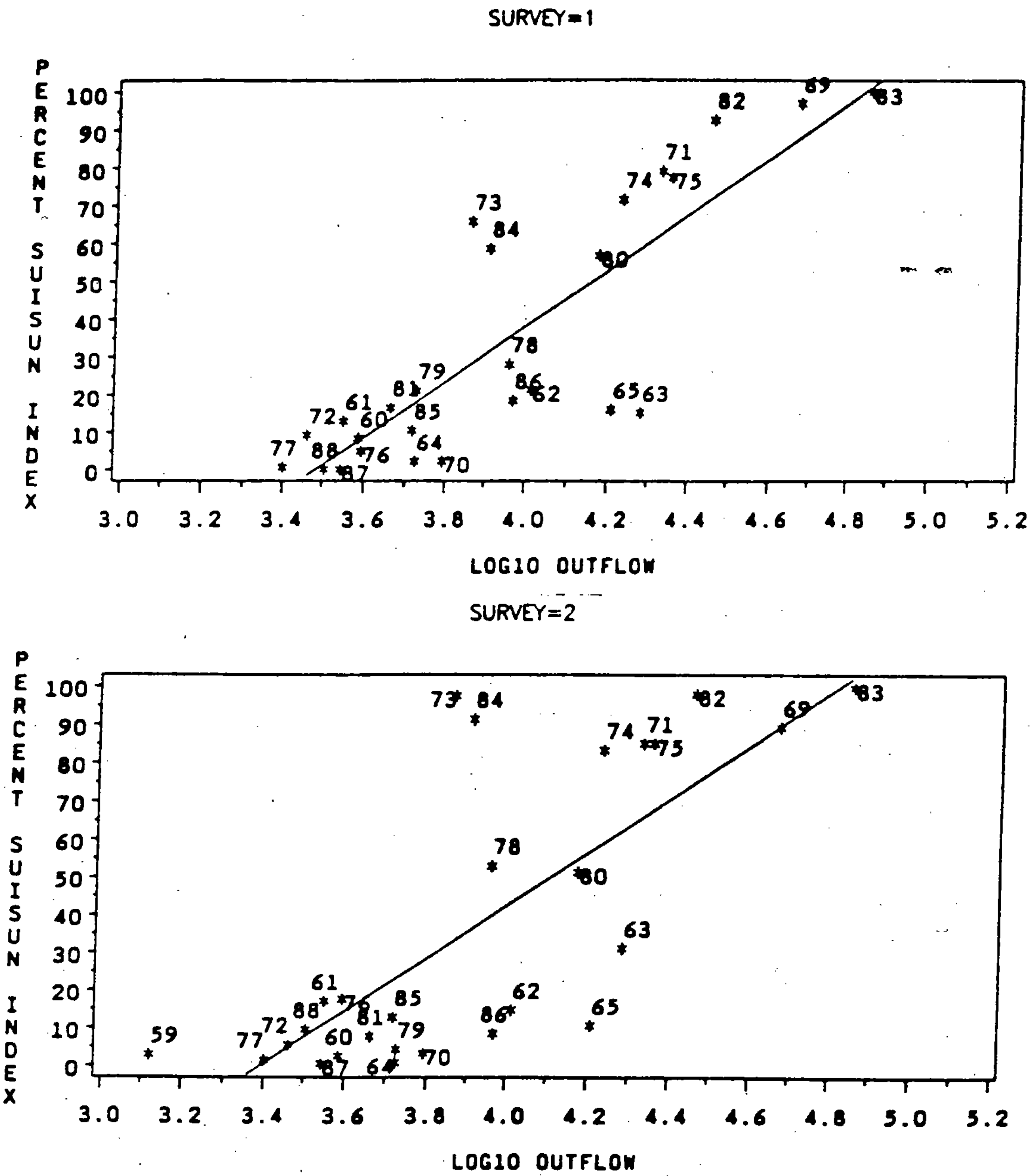



Figure 3. Relationship between the portion of the delta smelt population occurring west of the Delta and log Delta outflow during the survey month. Data are for the summer townet survey (from Stevens, *et al.*, 1990, Figure 1). For arcsine tranformed percentages, $r^2 = 0.74$ for survey 1 and $r^2 = 0.55$ for survey 2.

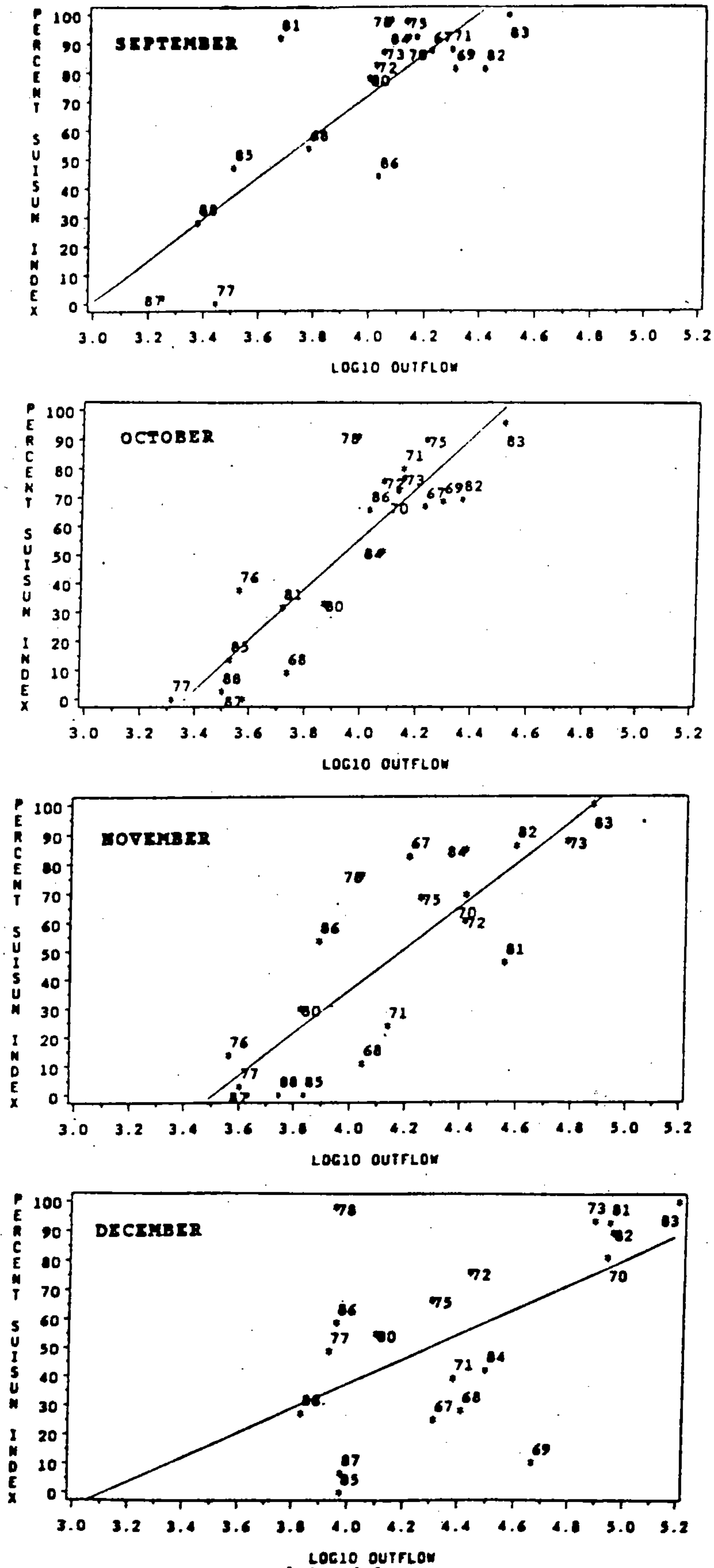



Figure 4. Relationship between the portion of the delta smelt population occurring west of the Delta and log Delta outflow during the survey month. Data are for the fall midwater trawl survey (from Stevens, *et al.*, 1990, Figure 2). For arcsine tranformed percentages, $r^2$ = 0.64 for September, 0.76 for October, 0.71 for November, and 0.34 for December.

## ABUNDANCE

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 abundance index for 1992 is 2.4 (Figure 5). This survey, initiated in 1959, provides one of the two best measures of delta smelt abundance and represents the longest historical record of smelt abundance. For a complete description of the summer townet survey, see Appendix B, pages 17-21. The abundance index indicates that the smelt population has varied dramatically from year to year but declined to low levels in the early 1980s where it has remained 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 has been less than 10 every year.

The fall midwater trawl survey, which covers the entire range of delta smelt distribution, provides the other best measure of smelt abundance. A full description of this survey is on pages 21-23 of Appendix B. The annual fall midwater trawl abundance index for 1992 is 156.8 (Figure 6). This index represents a decline from 689 for 1991 which is an aberration in a series of low abundance years since 1981. The 1992 index is 80% less than the 1967 to 1982 average. The October survey caught only 2 delta smelt in the historical range of the survey. This is the smallest catch in all 24 years of the survey and the second lowest monthly index.

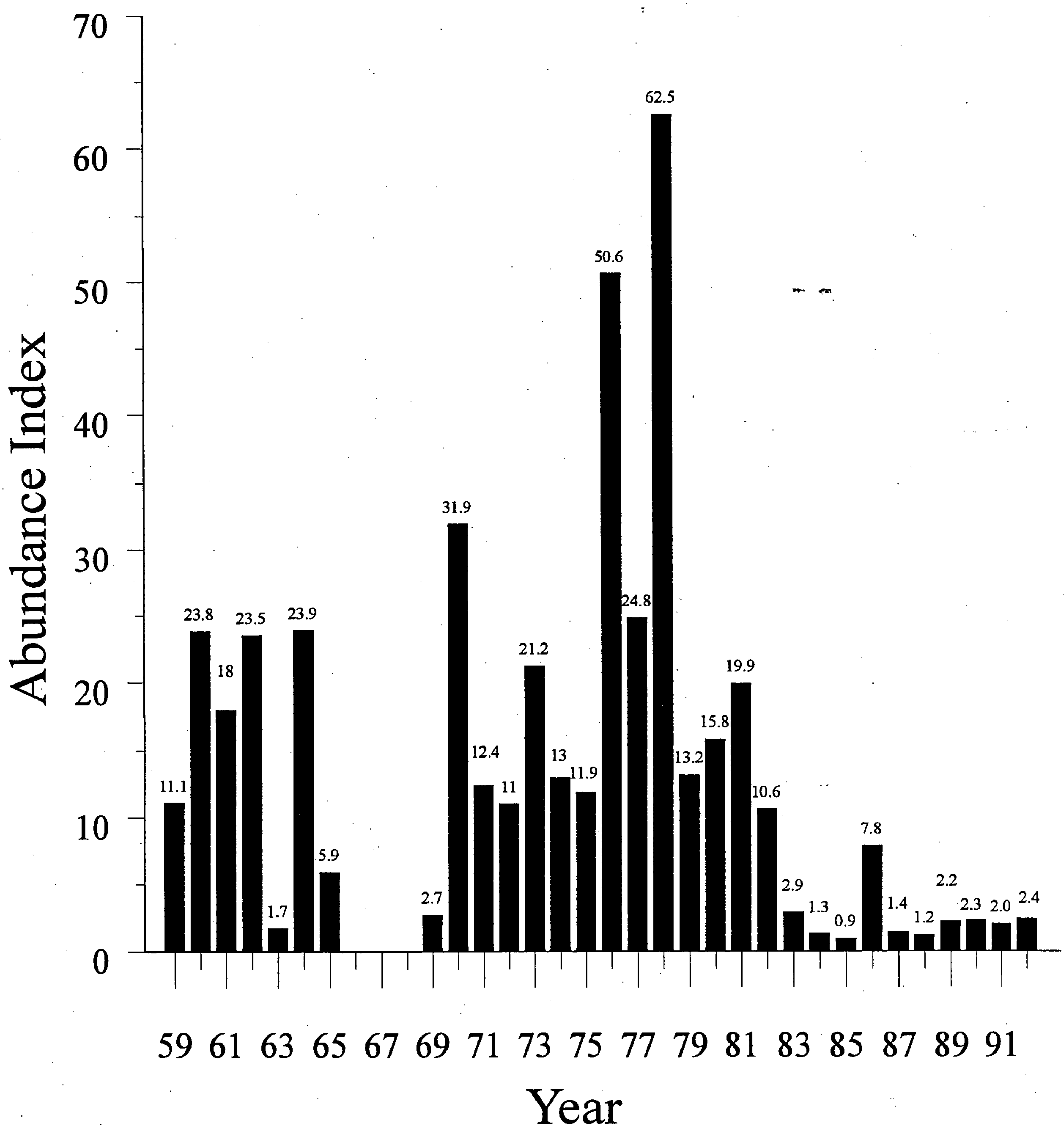



Figure 5. Summer townet abundance index for delta smelt in the Sacramento-San Joaquin Estuary for 1959-1965, 1969-1992. Only surveys 1 and 2 were used.

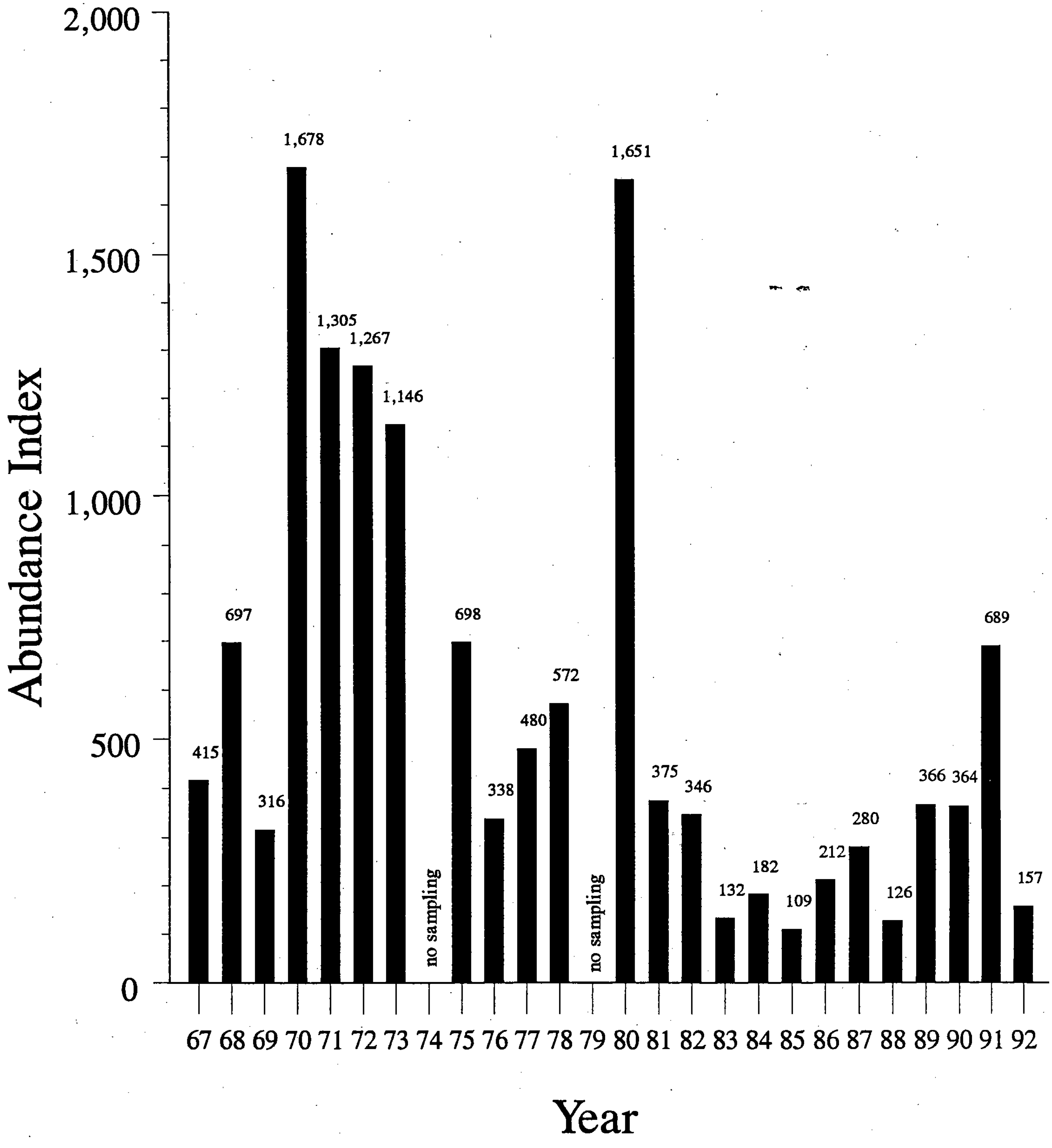



Figure 6. Fall midwater trawl abundance index for delta smelt for the years 1967-1973, 1975-1978, 1980-1991 in the Sacramento-San Joaquin Estuary.

For the past eight years, the remnant delta smelt population has been concentrated inthe lower Sacramento River between Collinsville and Rio Vista (Figure 7). In 1992, 90% of all delta smelt caught in the midwater trawl survey were from this region. 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 the drought and water management, and delta smelt are scarce in the San Joaquin portion of the Delta, perhaps due to losses in water diversions.

Five other independent measures of delta smelt abundance also indicate that the population remains at a low level (Figure 8). 1) The Delta Outflow-Bay Study survey is comprehensive in that it samples monthly throughout the year. A complete description of the Delta Outflow-Bay Study is in Appendix B, pages 23-27. 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 located in 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 20-30 mm have also been taken. A description of these two surveys is given on pages 27-31 of Appendix B.

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 8) 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. For a more complete discussion of SWP and CVP salvage of delta smelt see Appendix B, pages 31-42.

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.

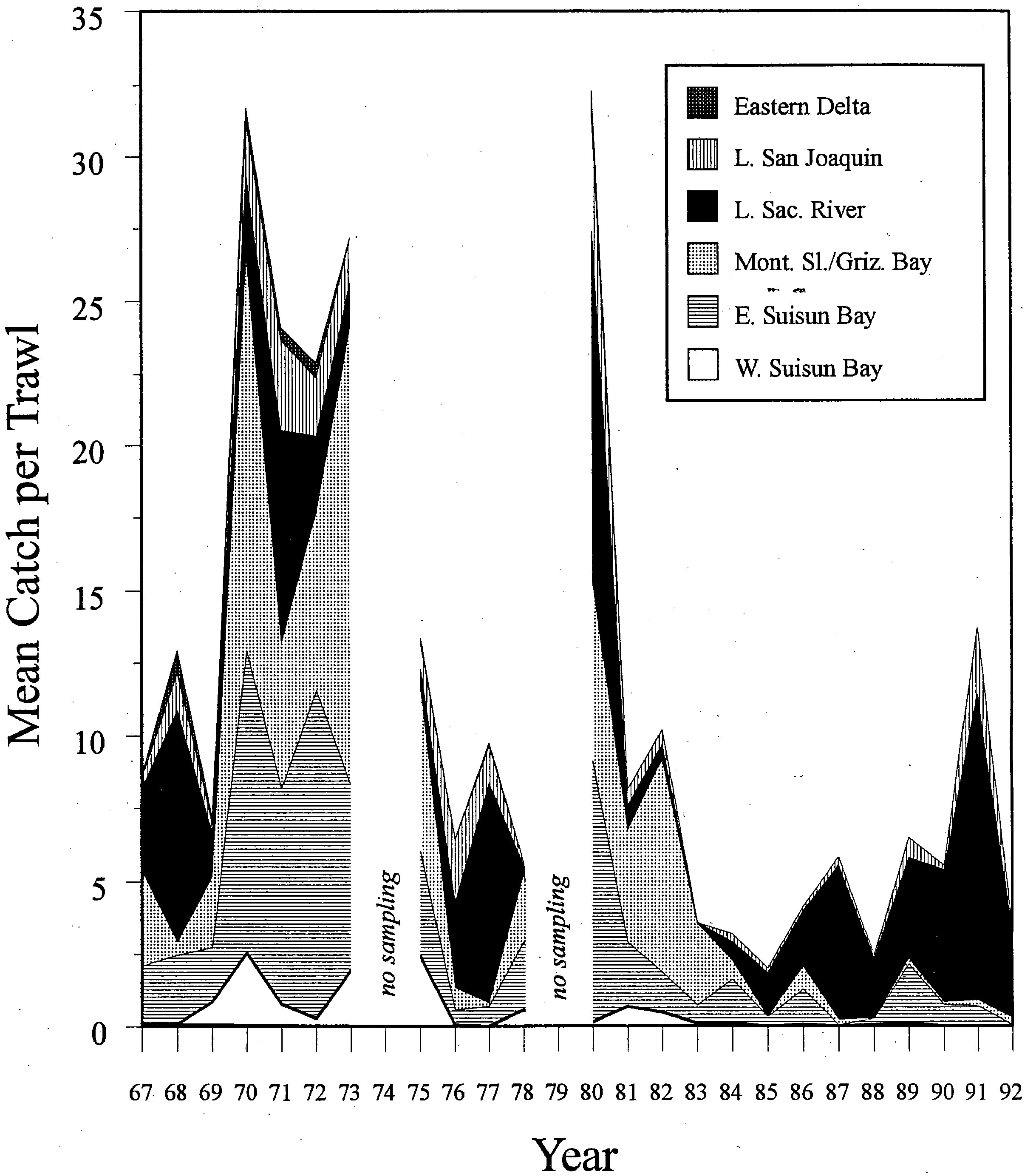



Figure 7. Mean catch-per-trawl from the fall midwater trawl survey for specific areas of the Sacramento-San Joaquin Estuary.

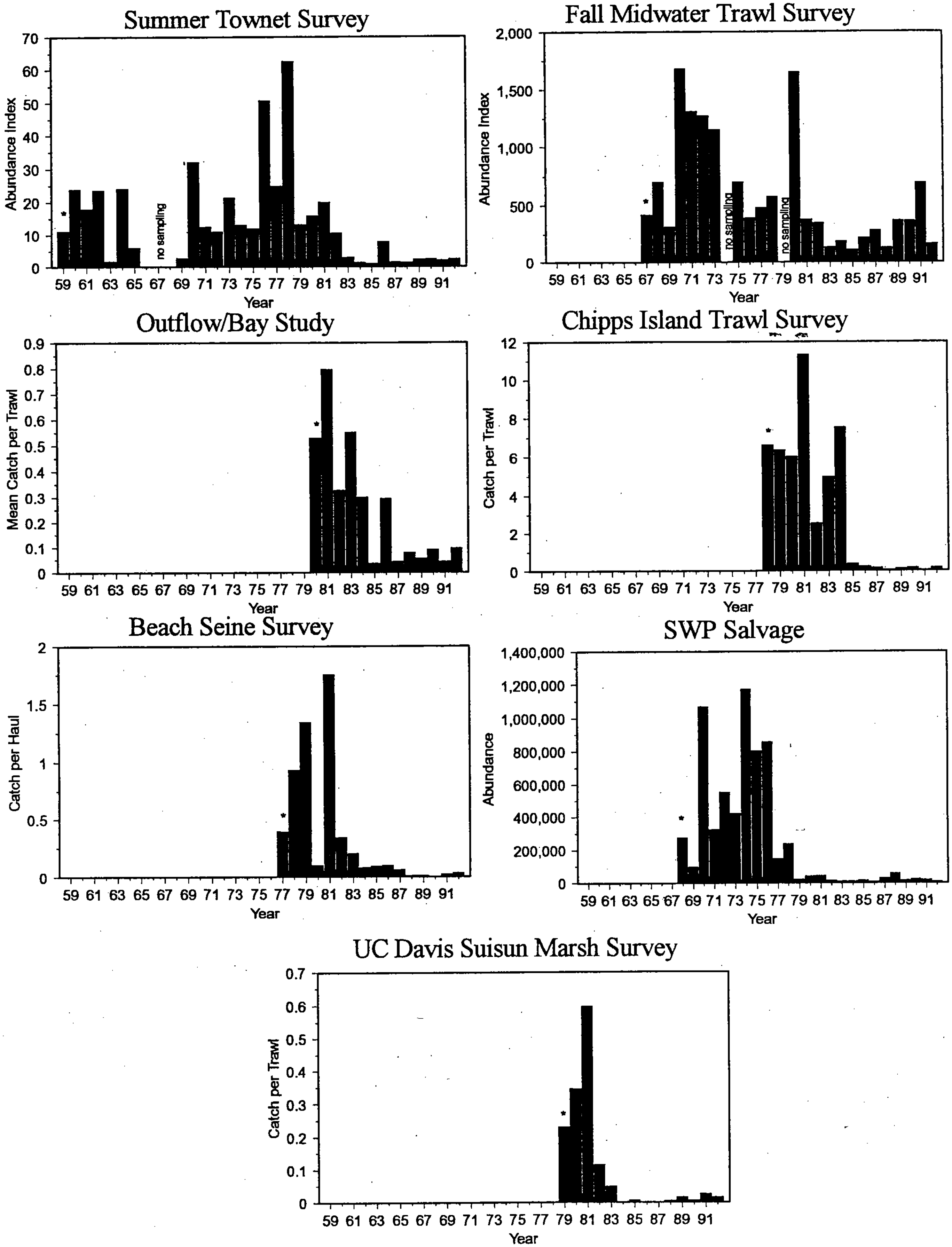



Figure 8. Trends in delta smelt as indexed by seven independent surveys (updated from Stevens, *et al.*, 1990, Figure 4). Asterisks indicate the first year of sampling.

## CONCLUSIONS REGARDING DELTA SMELT ABUNDANCE TRENDS

Although timing of the decline varies with the measure used, all the data sources listed above show a substantial decline of delta smelt in the early 1980s with no subsequent recovery. Looking at the decline by geographical areas (Figures 9 and 10), it is apparent that the delta smelt decline began earlier in the south and east Delta than in the rest of the Estuary. An earlier decline in these areas is consistent with the decline measured by the fish salvage data from the water project diversions in the south Delta.

## POPULATION SIZE

Stevens, et al. (1990) assumed that the standard midwater trawl net had the same catch efficiency for both delta smelt and striped bass and estimated the size of the delta smelt population (Appendix B, pages 48-51) from the difference in ratios of fall midwater trawl indices of delta smelt and striped bass to rough estimates of the young striped bass population derived from life table analyses.

In August, 1991, a net evaluation study of the standard midwater trawl used in the CDFG Fall Midwater Trawl Survey was initiated to test this assumption. A 1/8-inch mesh bobbinnet cover placed over the standard 1/2-inch stretch-mesh codend of the net captured fishes that escaped through the standard codend net. High variances between catches limited the analysis; however, the results suggest that the standard midwater trawl was only 30% as effective at capturing delta smelt and about 80% as effective at capturing striped bass as the bobbinnet cover (Figure 11a,b). There was a difference in the maximum size of escapement between the two species, presumably due to differences in body shape or behavior. Additional sampling in January, 1992 suggested that as the mean size of the delta smelt

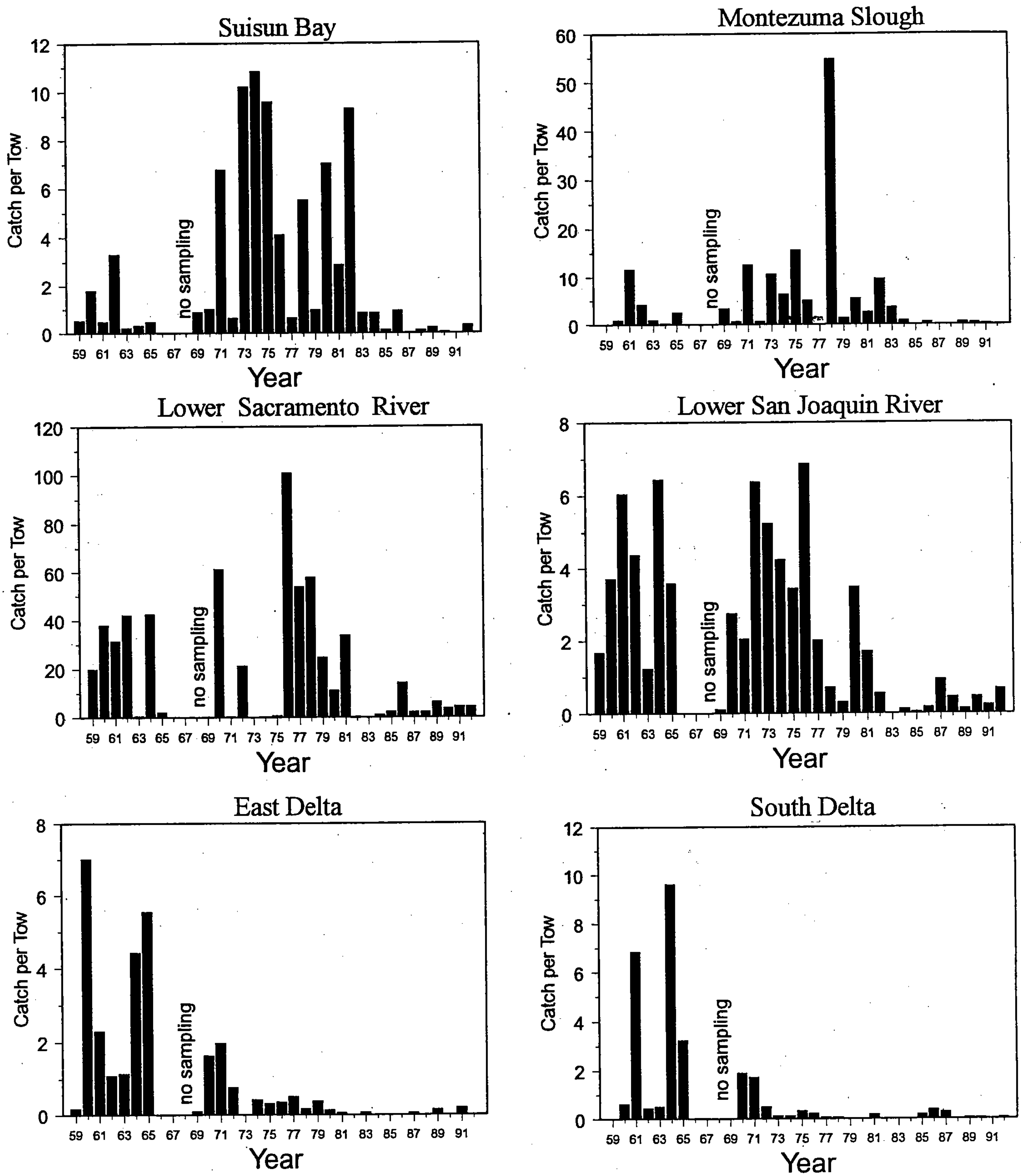



Figure 9. The mean catch-per-tow of delta smelt by area from the summer townet survey. Note differences in the scale used for each area.

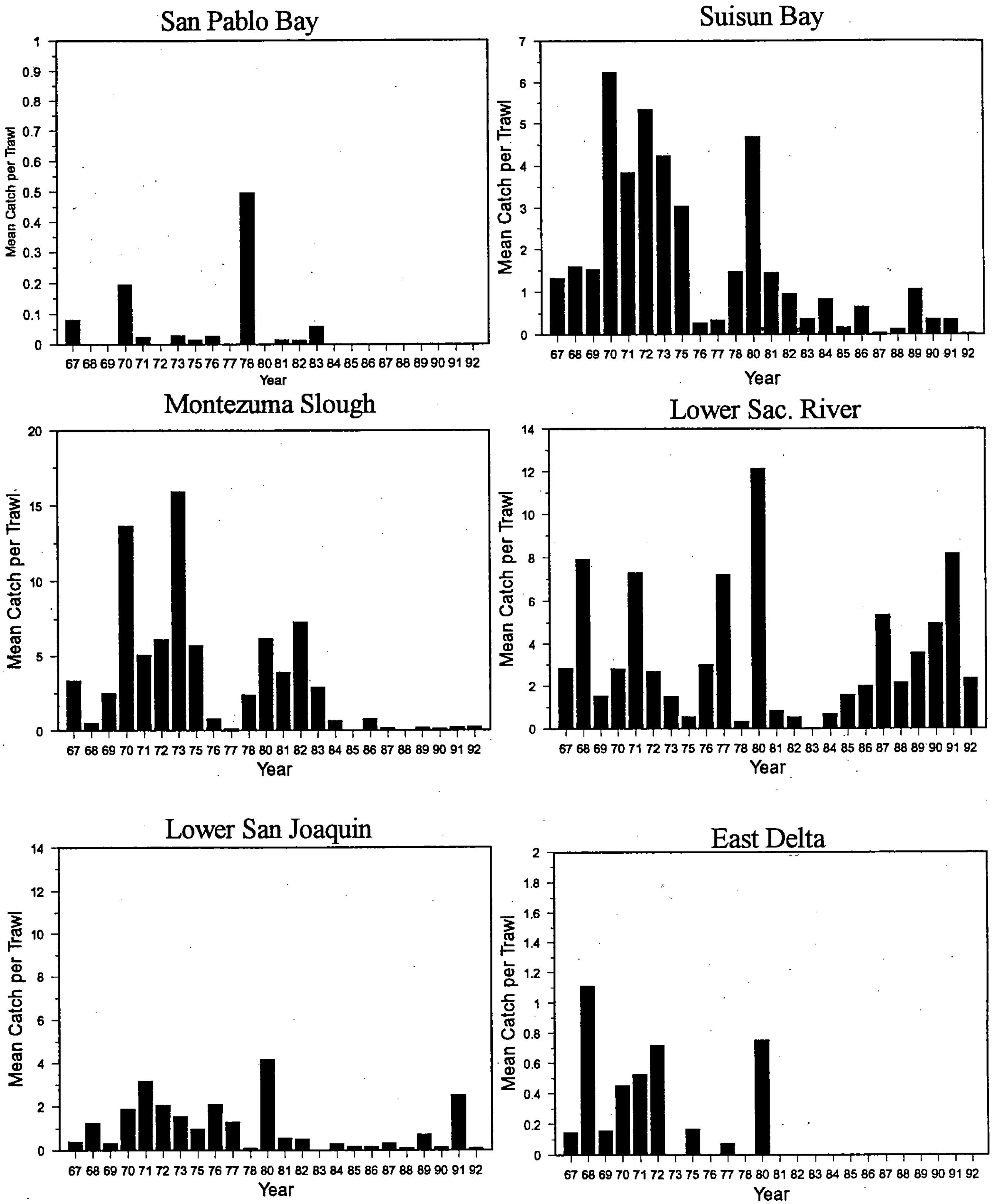
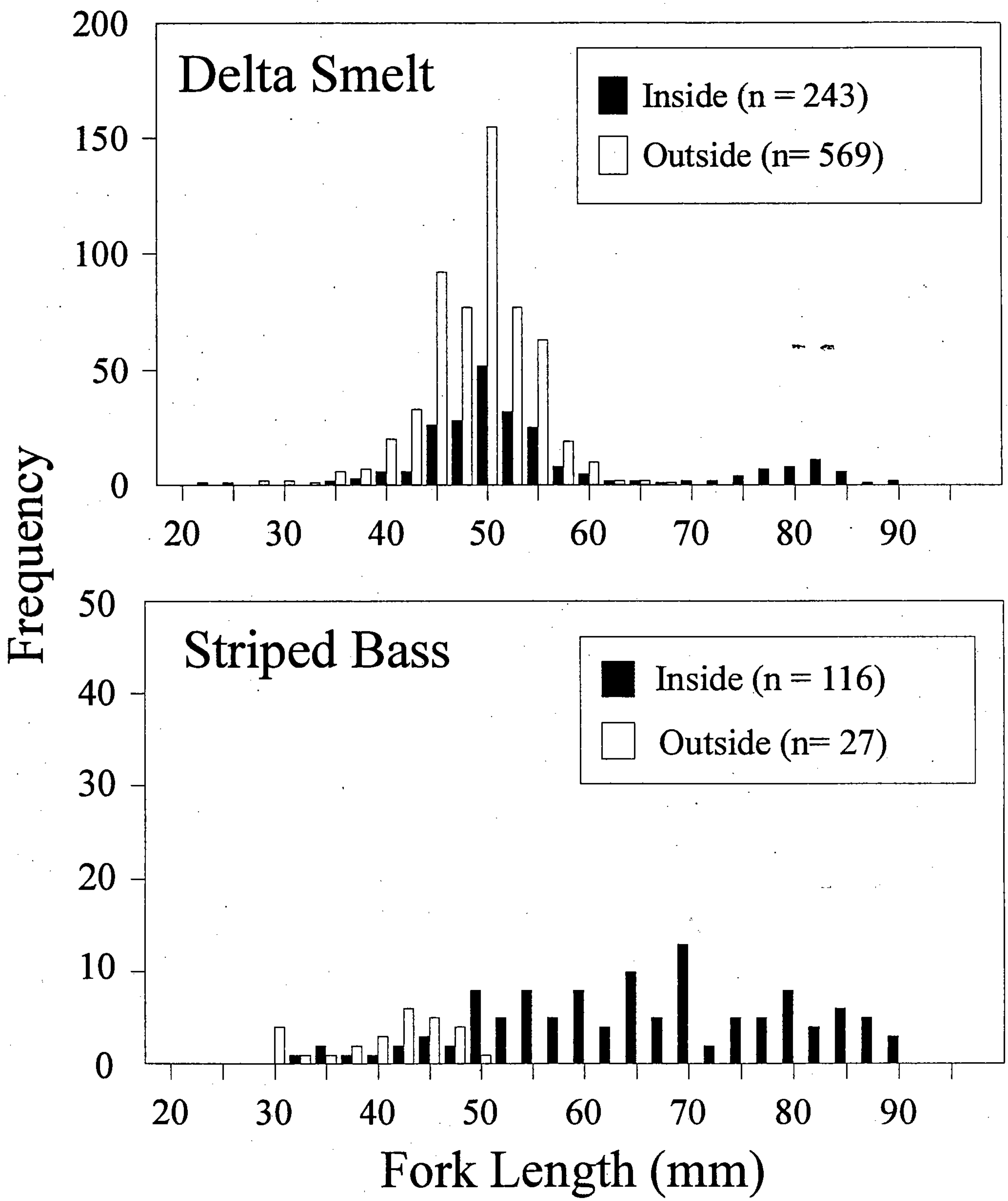



Figure 10. The mean catch-per-trawl of delta smelt by areas from the fall midwater trawl survey. Note differences in the scale used for each area.

captured increases, the efficiency of the standard midwater trawl net also increases (Figure 12). The standard net was about 55% effective at capturing delta smelt (Figure 12b) and 100% effective at capturing striped bass (not shown). Based on these results, the standard midwater trawl was about 2.6 times more effective at capturing striped bass than delta smelt in August, 1991 and about 1.8 times more effective in January, 1992.

Thus, losses of small fish through the mesh of the standard midwater trawl would have affected the initial abundance estimates for delta smelt based on the analysis of ratios by Stevens *et al.* 1990. It must be emphasized, however, that these results do not affect the interpretation of temporal trends in abundance. These results only indicate that the proportion of the delta smelt population caught by the midwater trawl is less than the proportion of the striped bass population caught and that the magnitude of both past and present abundance is greater than suggested by the extrapolations from catches in the standard midwater trawl survey.




August 28-29, 1991

Figure 11. Length-frequency distributions for a.) delta smelt and b.) striped bass in a midwater trawl net evaluation study, August 28-29, 1991. Solid "inside" bars represent fish captured in the standard 1/2 inch midwater trawl codend, open "outside" bars represent fish captured in the 1/8th inch bobbinnet cover. A total of eleven tows were used. Only young-of-the-year striped bass < 100mm FL were used.

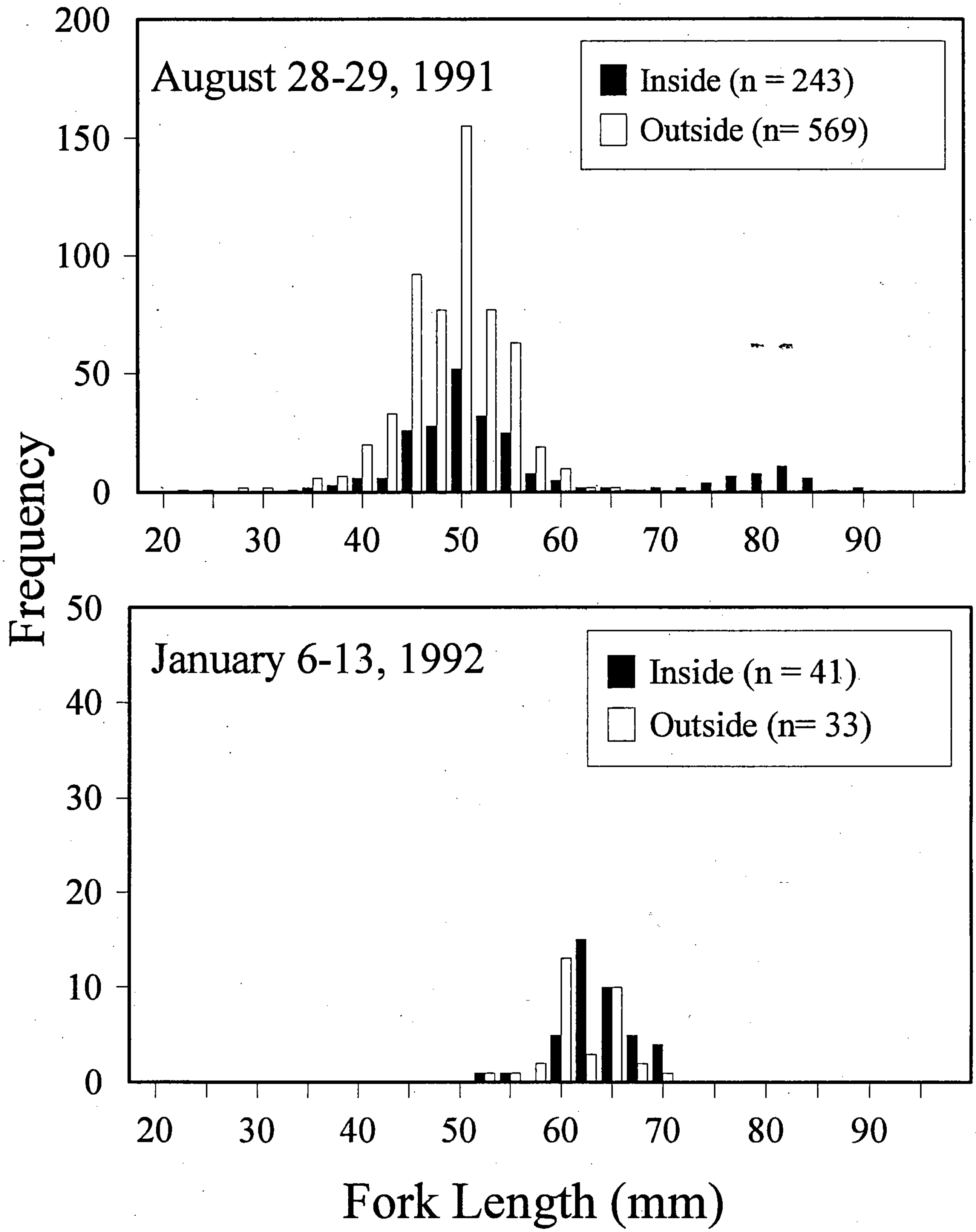



Figure 12. Comparison of length-frequency distributions of delta smelt captured a.) August 28-29, 1991 and b.) January 6-13, 1991. Solid "inside" bars represent smelt captured in the standard 1/2 inch stretch-mesh midwater trawl codend, open "outside" bars represent smelt captured in the 1/8th inch bobbinnet cover. Mean fork lengths (mm): a.) August 28-29, 1991 "inside" = 56.2 ± 12.9 sd, "outside" = 50.1 ± 5.2 sd; b.) January 6-13, 1992 "inside" = 64.9 ± 3.7 sd, "outside" 62.9 ± 3.6 sd.

## FACTORS AFFECTING DELTA SMELT ABUNDANCE

Through regression analyses, Stevens *et al.* (1990) evaluated the impacts of delta outflows, water diversions, food abundance, reverse flows, water temperature, and water transparency on population abundance. This approach did not give a good explanation of the population decline. However, this does not mean that these factors are not important. It is possible that one or more factors were not measured with sufficient reliability for us to detect effects, or that some untested factor acts in concert with the measured factors to drive the smelt population.

Several subsequent analyses have shown relationships between delta smelt abundance and changes in environmental factors within the Estuary:

1) Moyle *et al.* (1992) found a close association of delta smelt abundance with the entrapment zone and increasing reverse flows in the lower San Joaquin River in the spring.

2) A recent analysis of delta smelt abundance and entrapment zone location by Obrebski (DWR draft report) found a significant relationship between delta smelt abundance as measured by the fall midwater trawl survey and entrapment zone position in the Estuary. Entrapment zone position accounted for 16-26% of the amount of variance in the abundance data. His interpretation of these results suggest that the optimal geographical region for delta smelt may be a 15 to 20 kilometer section of the Estuary from western Honker Bay to the confluence of the Sacramento and San Joaquin Rivers. Analysis of the summer townet abundance data found no significant relationship between abundance and entrapment zone location.

3) The 1990 status report indicated that, based on the midwater trawl data, the abundance of spawners accounted for about one quarter of the variability in the abundance of the next year class recruited (Stevens *et al.* 1990). A reanalysis of that relationship (Figure 18C on page 55 of Appendix B) found that two of the data points were erroneous. The relationship, revised with appropriate corrections and the addition of data points for 1989-1991 (Figure 13), still accounts for about one-quarter of the variability in recruitment. Hence, the revised relationship still suggests that environmental factors cause much of the annual variation in delta smelt abundance, but also that losses of adult spawners may have played an important role in the delta smelt decline and inhibit recovery.

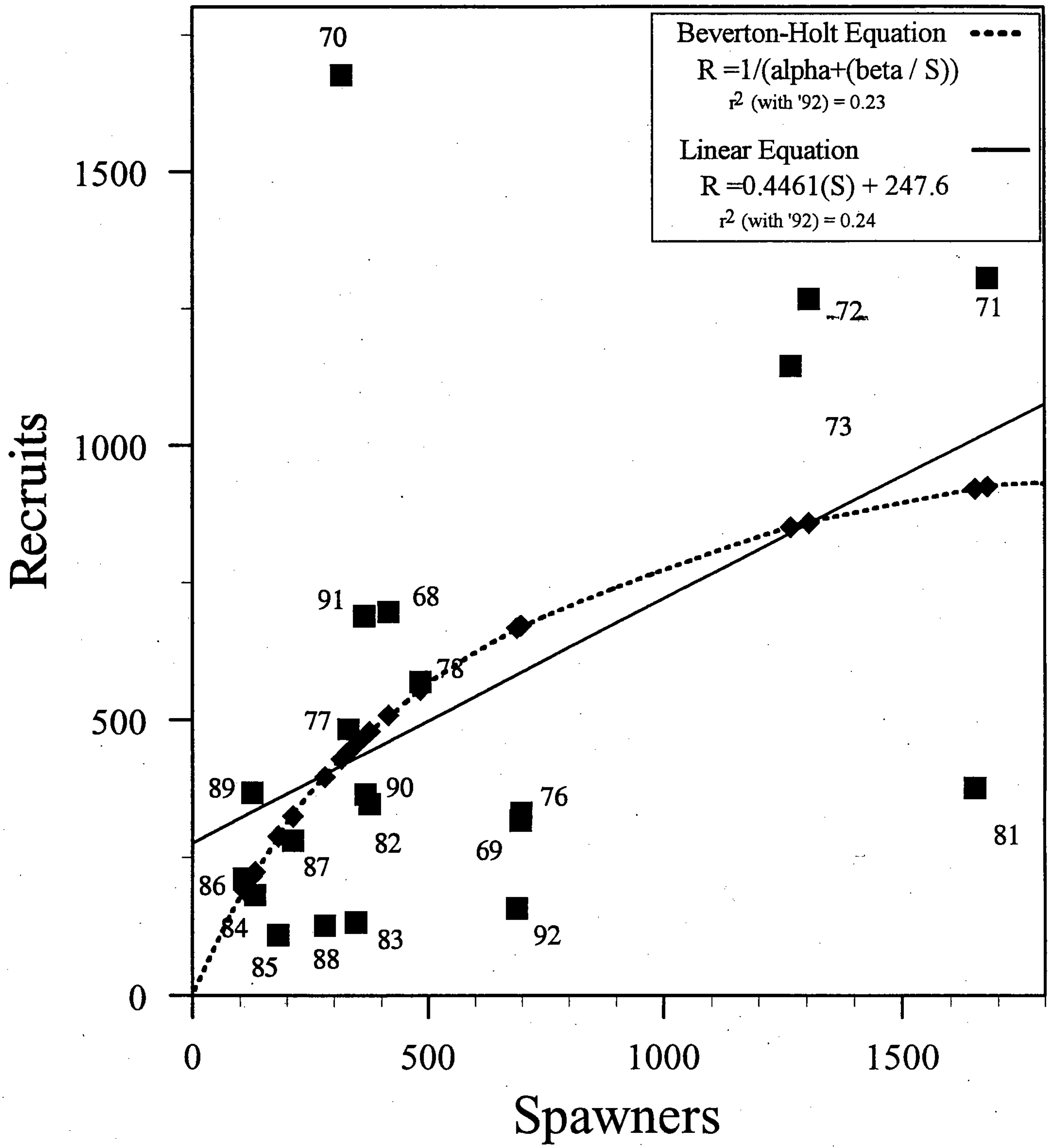



Figure 13. Spawner-recruit relationships for delta smelt based on the fall midwater trawl abundance index. Spawners are represented by the abundance index while recruits are represented by the abundance index for the following year. Dashed line represents fit to Beverton-Holt equation, solid line represents fit to linear equation.

## NATURE AND DEGREE OF THREAT

As indicated in the Department's 1990 status report, the Department has not pinpointed the cause(s) of the Delta smelt population decline. However, inability to explain the decline cannot be considered evidence for an argument against listing a species as threatened or endangered. Subsequent to preparation of the 1990 status report, the Department has participated in three major efforts with agency and "outside" experts, which have attempted to define causes, design appropriate studies and develop potential solutions to the delta smelt decline.

1) The Delta Smelt Study Program, mandated by the California Fish and Game Commission on August 30, 1990, obtained substantial external input into study design. Advice was provided by representatives of the Department, DWR, USBR, USFWS, SWRCB, outside contractors (including the primary biological consultant to the State Water Contractors), and researchers from the UC Davis. The purpose of the study program is to monitor and investigate factors potentially affecting delta smelt population levels in order to insure the long-term survival of delta smelt and to address the management and recovery objectives set forth by the Fish and Game Commission.

2) As part of the consideration for federal listing, a Delta Smelt Working Group was convened by the USFWS in October 1991 to identify possible causes of the decline and to propose possible management measures. This working group consisted of fishery experts from a wide range of agencies and universities. The working group produced a list of 12 actions that would help protect or recover the delta smelt

population. This list was not specifically designed for management purposes, but it was to aid in evaluating water management alternatives that potentially would have precluded federal listing of the species.

3) At the request of the Governor of the State of California, the Resources Agency assembled a Delta and Related System Management Program which included a Delta Smelt and Native Fishes Subcommittee. The goal of this program was to identify problems and design specific near and longer-term management actions which could be taken to improve habitat conditions and hopefully populations of important fish and wildlife in the Delta. The program focused on delta smelt and other declining native estuarine fishes, winter-run salmon, striped bass, and wetland/terrestrial wildlife resources in decline with the expectation that adequately accommodating the needs of these stressed species would strengthen the biological integrity of the entire ecosystem.

Based on the 1990 status review, subsequent Department analyses, and discussions and conclusions of these expert groups, it is believed that the following factors are those most likely inhibiting recovery of the population:

- **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 their 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 of 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. 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).

Entrainment of delta smelt is generally greatest during spring and summer (Figures 14 and 15). This pattern reflects the late winter-spring spawning season and growth and mortality of young-of-the-year fish. During April and May, abundance of young smelt at the SWP and CVP diversions actually is greater than indicated by the salvage data because the smelt are so small that they pass through the screens and are not salvaged for the first month or two of life. It is assumed that the diversion screens are not efficient (0%) at diverting larvae smaller than 20 mm in length. Also, the technicians responsible for sampling of salvaged fish are unable to identify small delta smelt.

The intra-year salvage pattern in 1977-1978 was a notable exception to the usual pattern. Through much of 1977, water exports were reduced, due to a major drought, and a delta smelt peak occurred in July. The greatest entrainment and salvage of the 1977 year class, however, occurred from December 1977 through February 1978 when water exports increased after the drought broke (Table 15, page 72 Appendix B). In fact, the salvage of 134,000 delta smelt at the SWP in January 1978 almost equaled the total for all of 1977 (146,000) and exceeds the annual totals for all subsequent years. Unlike other years when the majority of losses were smaller juvenile fish, the smelt salvaged in 1978 were pre-spawning adults.

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 near 200,000 delta smelt. In January 1993, 3087 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 (Figure 16). This is substantially higher than the May monthly average for the SWP of just under 2,000 delta smelt salvaged (Figure 14). Because the screen efficiency of diverting fish of this size is small (conservatively estimated to be about 20% for a 25mm larvae), the actual loss may be on the order of 200,000 delta smelt.

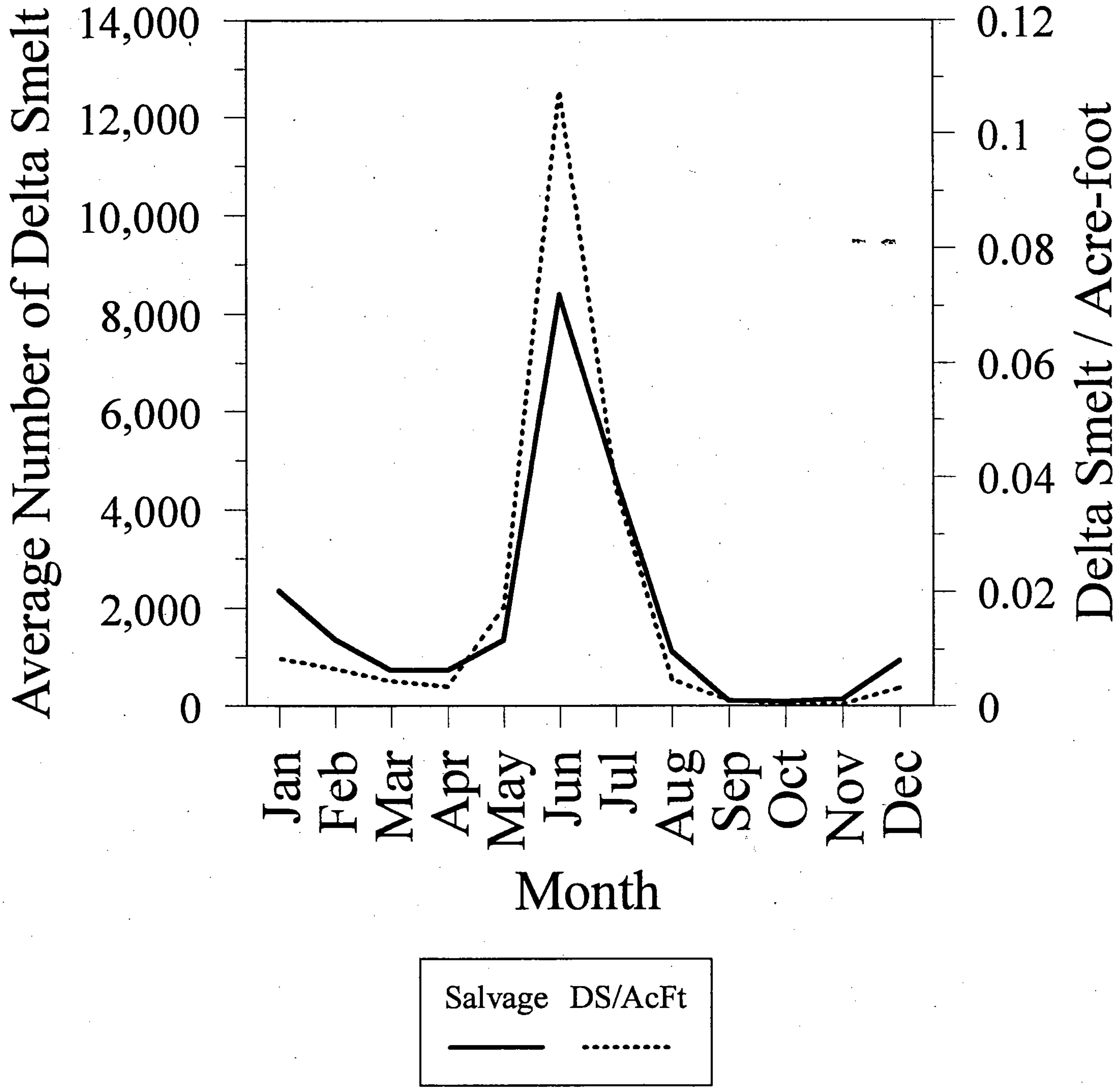



Figure 14. Monthly averages of the estimated delta smelt salvaged and delta smelt/acre-foot exported at the State Water Project diversion from 1980-1991.

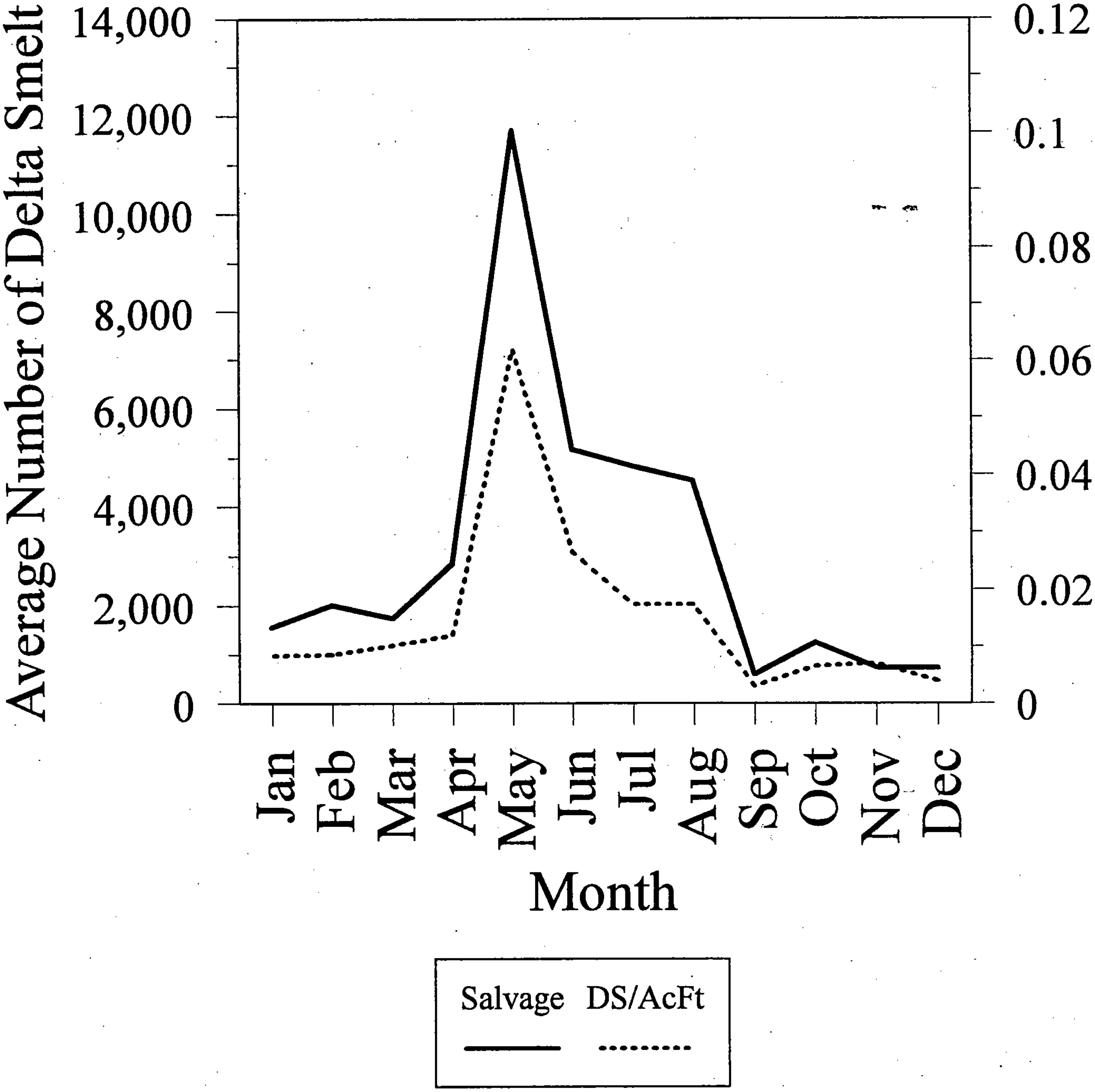



Figure 15. Monthly averages of the estimated delta smelt salvaged and delta smelt/acre-foot exported at the Central Valley Project diversion from 1980-1991.

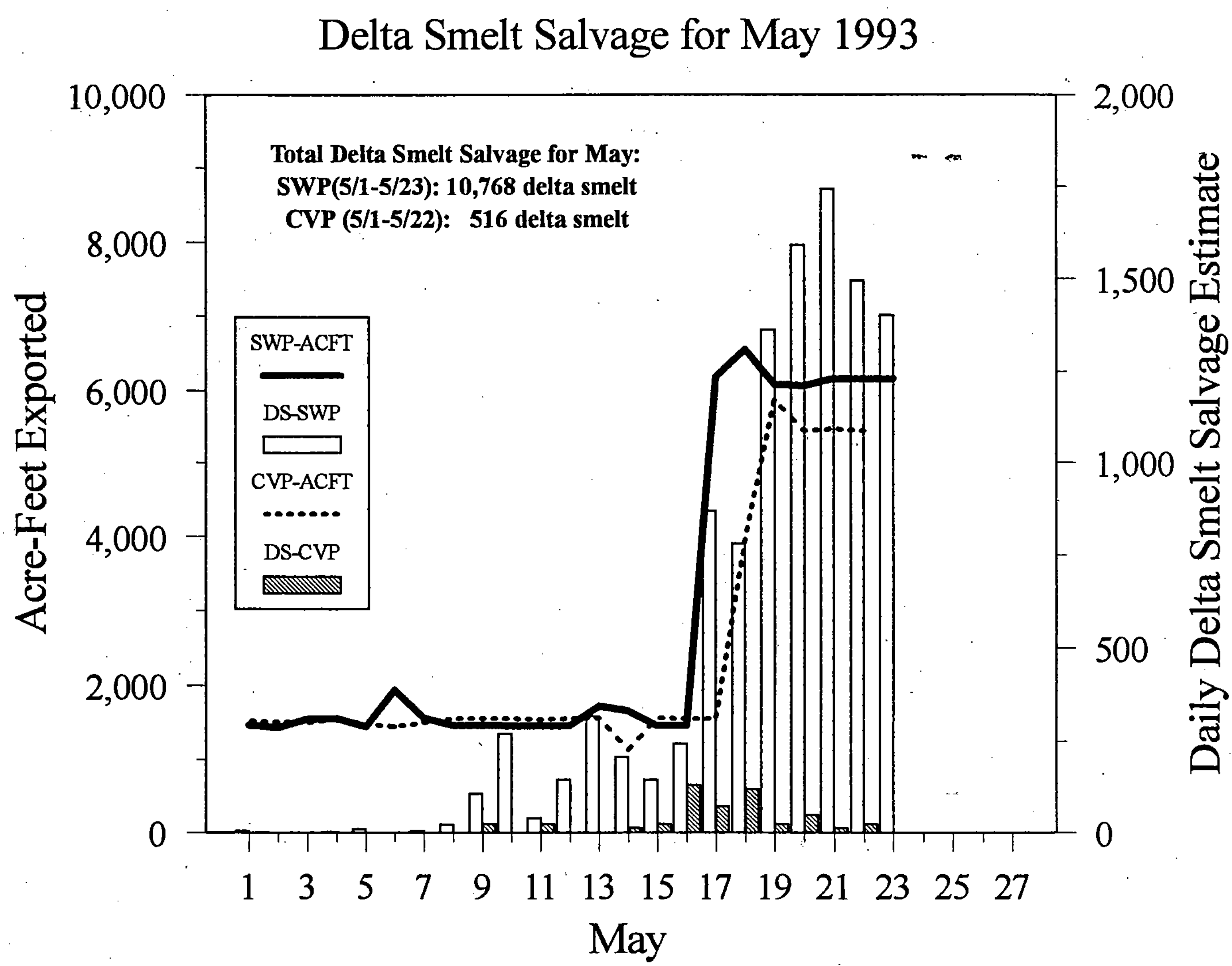



Figure 16. Daily salvage estimates of delta smelt at the SWP and CVP Water Project diversions for May 1993. Total daily exports are in acre-feet.

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 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, estimations of larval entrainment losses of delta smelt to the SWP and CVP were not initiated until 1989. Thus, sampling of larval entrainment losses at both the SWP and CVP has been done by DWR for the past 4 years; however, there was a gap in sampling during the peak spawning period in 1991 (Table 4). 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.

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. There are currently no requirements to report delta smelt losses.

Table 4. 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.

Currently, there are more than 1800 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 time 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. Results are not yet available.

- **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. 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 position was in Suisun Bay.

Recent analyses of summer townet and fall midwater trawl data by Obrebski (DWR draft report) found that entrapment zone position accounted for 16-26% of the amount of variance in the abundance data. These results suggest that the optimal geographical region for delta smelt may be a 15 to 20 kilometer section of the Estuary from western Honker Bay to the confluence of the Sacramento and San Joaquin Rivers. A relationship between outflow and entrapment zone location (Kimmerer and Monismith 1992) indicates maintenance outflows of between 7,000 and 16,200 cfs are required to maintain the zone 71 to 81 kilometers from the Golden Gate Bridge.

The period of the smelt decline included year 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 (Figure 2). These 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.

- **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 amarensis) 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 an unexplained population explosion of the Chameleon goby, Tridentiger trigonocephalus, that occurred in 1990.

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 have only recently become abundant. Furthermore, the subsequent increases in exotic species may inhibit recovery of the delta smelt.

- **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 known 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. Hybridization between delta smelt and wakasagi might be possible if they should coexist. Thus, there is potential for dilution of the delta smelt gene pool and elimination of its existence as a separate species. If hybridization is not possible, increased competition from wakasagi is possible because both fish have similar feeding habits and diets.

- **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.

- **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. The recent appearance and explosion of the chameleon goby, a potential larval competitor and predator, 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 (eat other fish); however, comprehensive striped bass food habit studies in the 1960's 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. At present this issue is moot because, due to concerns regarding predation on young winter-run salmon, the Department of Fish and Game discontinued the stocking of hatchery-produced striped bass into the Estuary in 1992.

## CURRENT MANAGEMENT

There are currently no management measures in place specifically for delta smelt in the Estuary.

As mentioned previously, on March 5, 1993, the USFWS listed the delta smelt as a threatened species under the ESA. This rule went into effect on April 5, 1993. In carrying out their responsibilities under the ESA, the USBR and the DWR have conducted a Section 7 conference with the USFWS on the 1993 operation of the CVP and the SWP. This conference, initiated by the USBR in September 1992, became a formal consultation process after the delta smelt was listed. This consultation is intended to discuss the biology of the delta smelt and water project operational changes and water allocations that would help in smelt recovery. This consultation will culminate in the issuance of a Biological Opinion.

## CONCLUSIONS

We have examined several measures of delta smelt abundance; all indicate that the population has declined since the late 1970s or early 1980s. The best measures are based on the summer townet and fall midwater trawl surveys. The summer townet survey indicates that the average population since 1982 has been less than one-sixth of the average population level from 1959 to 1981 and the population in 1992 was less than one-eighth of that average. Based on the midwater trawl survey, the average population since 1982 has been less than one-third of the average population level from the initial survey in 1967 to 1981, and the population in 1992 was less than one-fifth of that average.

Delta smelt abundance has been highly variable over the period of record. Our evaluation of factors potentially affecting delta smelt abundance did not specify the exact causes(s) of this variability or the sustained population decline. However, we have noted that the years since 1982 are characterized either by outflows that were too low to transport young fish to their optimum habitat in Suisun Bay or by exceptionally high outflows that may have transported larvae beyond Suisun Bay into the western estuary. In any case, inability to identify the specific factors regulating the population does not mean the tested factors are not important. Such failure may simply reflect sampling-associated variability in our measures of delta smelt abundance and/or the environment.

The Fish and Game Commission is guided by the State Endangered Species Act and the guidelines promulgated under this Act in determining whether a species may be properly listed as endangered or threatened. Section 670.1(b) of Title 14 of the California Code of Regulations sets forth the listing criteria. Under this section, the Commission may list a species if it finds that its continued existence is in serious danger, or is threatened by any of the following factors:

- Present or threatened modification or destruction of its habitat;
- overexploitation;
- predation;
- competition;
- disease; or
- other natural occurrences or human-related activities.

To meet the State Endangered Species Act's definition of "endangered", a species must be:

(1) a native species or subspecies;

(2) a bird, mammal, fish, amphibian, reptile or plant;

(3) in serious danger of becoming extinct throughout all, or a significant portion, of its range;

(4) affected by loss of habitat, change in habitat, overexploitation, predation, competition, or disease (Cal. Fish and Game Code Sec. 2062).

A "threatened" species is a species which is "likely to become an endangered species in the foreseeable future" in the absence of the special protection provided by the Act. (Sec. 2067). The Fish and Game Code (Sec. 2072.3) lists additional factors relevant to a determination that a species is threatened or endangered:

- population trend;
- range;
- distribution;

- abundance;
- life history;
- ability to survive and reproduce;
- degree and immediacy of threat;
- existing management efforts;
- type of habitat.

The delta smelt is a native species with a range confined to the upper Sacramento-San Joaquin Estuary. It is vulnerable to extinction because (1) it is short-lived, (2) it has relatively low fecundity, (3) introductions of exotic organisms have altered its food supply, and (4) water projects have adversely modified its habitat, distribution and probably abundance within the Estuary. While our analysis has not determined the specific relationships between these threats and the smelt population, that is not crucial to determining whether delta smelt should be listed as threatened or endangered. Continuing studies may provide the necessary answers in determining these relationships that will provide the basis for management and recovery actions.

Major adverse habitat modifications include changes in the character and position of the salinity gradient and exploitation through entrainment in diversions. Such population threats are likely continue or increase (Table 5). Trends in abundance of other species dependent on estuarine conditions, such as striped bass and longfin smelt, also point toward a general degradation of the delta smelt's habitat. In fact, the State Water Resources Control Board which is responsible for the management of the State's water resources concluded that: "...the public trust resources of the Estuary are in a state of decline." (SWRCB 1992).

Table 5. Probable Trend in Delta Smelt Population Threats.
W = worse, S = Stable.

| Threat | Trend |
|---|---|
| Entrainment Losses | W |
| Delta outflows | W |
| Inadequate Food Supply | S |
| Inadequate spawning stock | S or W |
| Toxicity | ? |
| Genetic dilution | W |
| Exotic introductions | S (if ship ballast discharges are controlled)<br>W (if ship ballast discharges are not controlled) |

Thus, the delta smelt population trend, certain life history attributes, and increasing environmental threats tend to support "listing". The issue, therefore, is whether the population is low enough that it is in danger of extinction. The scientificinformation is insufficient to make that very complicated scientific determination, and no scientific study which we might implement will provide a conclusive answer in the next few years. Meanwhile the population might become extinct.

The Department believes that the relatively stable, albeit low, population is not in imminent danger of extinction. One factor supporting this contention is that the population has historically rebounded quickly from levels nearly as low as present ones. However, we cannot be certain that such rebounds will happen again. Unforeseen or stochastic events may push the species to such a low level as to preclude recovery. The persistent low populations during the last decade, the nature of the delta smelt's life history and distribution, and increasing threats to its habitat lead us to conclude that the delta smelt may well "become an endangered species in the foreseeable future". Hence, based on the best scientific information available (Section 2074.6 CESA), the Department believes that the most prudent action is to list the delta smelt as a Threatened Species.

## RECOMMENDATIONS

Petition Action

1. The Commission should find that the petition action that is warranted is for the status of State Threatened.

2. The Commission should publish notice of its intent to amend Title 14 CCR 670.5 to add the delta smelt (Hypomesus transpacificus) to its list of Threatened and Endangered Species.

Recommended Management/Recovery Measures

The Department's objectives are the protection of a sufficient number of delta smelt to insure their long-term survival and recovery in their native habitat and range. In order to achieve full recovery, the population must be protected, monitored, and shown to be self-sustaining over time. Annual monitoring and evaluation should receive input from interested parties. Recovery goals and reclassification criteria need to be established. When recovery goals have been met, the Department will make recommendations to the Commission regarding delisting this species.

The Department of Fish and Game considers the following actions would benefit delta smelt:

- **Restrict SWP and CVP diversions from the south Delta.** These diversions draft water and smelt from throughout most of the Delta to the export pumps. This harms the smelt population both by 1) killing thousands of adult and juvenile smelt and millions of delta smelt larvae at the pump intakes, and 2) indirectly by preventing smelt from being transported to their primary habitat in Suisun Bay. In addition, more reliable estimates of larval fish losses at these facilities need to be done.

- **Increase Delta outflows.** In most years, increased spring and summer outflows would increase optimum habitat for spawning and rearing, transport more young delta smelt to Suisun Bay, reduce losses to water diversions in the Delta, and likely reduce or displace the population of the Asian clam believed responsible for reducing the zooplankton in that area. Increased outflows would also aid in reversing the trend of increased habitat degradation in Suisun Bay.

- **Restrict entrainment losses at Pacific Gas and Electric Company's Pittsburg and Contra Costa power plants.** Entrainment losses of delta smelt are a potential drain on the population. Recent lower entrainment losses due to the reduced population and upstream location of the entrapment zone will increase if efforts to move the delta smelt population to Suisun Bay are put in effect.

- **Screen, restrict, or consolidate the agricultural diversions in the Delta when larvae are present.** Losses to local agricultural diversions are a potential drain on the delta smelt population.

- **Screen the Contra Costa Water District's water diversion at Rock Slough.** The Central Valley Project Improvement Act (PL 102-575) provides for this diversion to be screened. Meanwhile, the Department of Fish and Game is advocating that it be screened as a condition for Contra Costa Water District proceeding with the Los Vaqueros Project.

- **Reduce diversion to the North Bay Aqueduct during Delta smelt spawning season.** Based on sampling during 1992, the vicinity of the North Bay Aqueduct intake appears to be important for delta smelt spawning.

- **Move major water project diversions from the southern Delta to the Sacramento River above the Delta.** Such action would essentially eliminate entrainment losses of young delta smelt by the SWP/CVP. This will be an alternative considered in the comprehensive water planning effort initiated by the Governor.

- **Restrict ship ballast water discharges in the Estuary to eliminate or reduce introductions of potentially harmful exotic species.** Assembly Bill 3207 which was enacted into law effective January 1, 1993 requires the Department of Fish and Game to adopt the International Maritime Organization's "Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ship's Ballast Water and Sediment Discharges", and to develop a ballast water control report form to monitor compliance with these guidelines. The guidelines encourage, but do not mandate, ballast exchange at sea to reduce the risk of introducing unwanted freshwater and estuarine organisms. Monitoring compliance is intended to provide information on the proportion of ships which actually exchange ballast at sea, thus, providing a basis for judging whether additional regulatory action is warranted.

- **Research on creating a refuge population and refining hatchery and production techniques.** Such research was implemented in 1992 through contracts between the Department of Water Resources and aquaculture experts at the University of California, Davis and a private consulting company. Delta smelt were successfully spawned by these experts, but production was limited by the smelt's low fecundity and excessive larval mortality. Further work is planned for 1993.

- **Reduce input of toxicants into the Estuary.** While evidence on the effects of toxicants on delta smelt is lacking, evidence of adverse effects on other species exists. Vigorous pursuit of evidence on toxic effects and implementation of measures to correct any identified effects is appropriate.

While there are good reasons for concluding that management actions in each of the above areas would improve conditions for delta smelt, no quantitative basis exists for estimating the benefits of any given set of measures. Thus, we are unable to select management measures that will assure the delta smelt's recovery to any specific abundance target. Rather smelt recovery will involve selecting management measures to implement and evaluating their success empirically.

Furthermore, the experience of the 1977 drought indicates that substantial recovery of smelt may not occur in the near future. Given the present physical configuration of the water delivery system, it appears that very low water exports caused by drought, not regulatory action, caused good survival of smelt in the Delta in 1977, only to have large losses occur when high water export rates resumed. Those losses occurred despite large increases in freshwater outflows. That experience indicates that comprehensive water planning, such as recently reinitiated by the Governor, may be crucial to recovery of the delta smelt.

Alternatives to the Petitioned Action

If the Commission should choose not to list the delta smelt, it is our opinion that this fish would be deprived of protection provided through recognition and formal consultation available to a listed species. When a species is listed as Threatened or Endangered, a higher degree of urgency is mandated, and protection and recovery receives more attention from the Department and other agencies than does a non-listed species. It also would receive protection from unauthorized take under sections 2080 and 2091 for private individuals and state agencies.

In the absence of listing, it still would be possible to devise a management plan for this species. However, this Departmental status review indicates that the future existence of this species is already seriously threatened. Despite good intentions on the part of the Department and the Commission, promises of management and protection for a non-listed species do not have the weight of law behind them, and thus seldom receive high priority in the eyes of other agencies. Without the benefits of listing and the cooperation of other agencies in preservation and recovery actions, the species could decline further until the population is no longer viable, and is no longer able to exist in perpetuity. Eventually, extinction could occur.

The Department has made the recommendation to list this fish as Threatened. With this status, the delta smelt would receive the same special consideration and protection under CESA and the California Environmental Quality Act (CEQA) as if it were listed as Endangered. This Departmental status review indicates that the continued existence of the delta smelt is seriously threatened throughout its range, and that this alternative is appropriate.

The delta smelt already is listed as Threatened by the federal government. Federal listing, however, does not require CDFG involvement in conferences and consultations required by the Federal Endangered Species Act. Thus, state management powers are effectively diminished. State listing would restore state management powers by requiring consultations and other protections under provisions of the State Endangered Species Act.

## PROTECTION AFFORDED BY LISTING

If listed, the delta smelt will receive protection from take during development activities subject to CEQA and will be subject to formal State lead agency consultation requirements under CESA. The species will also be eligible for the allocation of resources by government agencies to provide protection and recovery. During the CEQA environmental review process, listed species receive special consideration, and protection and mitigation measures can be implemented as terms of project approval. Species that are not listed do not readily receive protection. The status of listing provides a species with recognition by lead agencies and the public, and significantly greater consideration is given to the Department's recommendations resulting from project environmental review.

Listing this species increases the likelihood that State and Federal land and resource management agencies will allocate funds and personnel for protection and recovery actions that benefit the delta smelt. With limited funding and a growing list of Threatened and Endangered species, priority has been and will continue to be given to species that are listed. Those that are not listed, although considered to be of concern, are rarely given serious consideration under these circumstances.

## ECONOMIC CONSIDERATION

The Department is not required to prepare an analysis of economic impacts per CESA Section 2074.6. The Department is to provide a report to the Commission "based upon the best scientific information available to the Department, which indicates whether the petitioned action is warranted, which includes a preliminary identification of the habitat that may be essential to continued existence of the species, and which recommends management activities and other recommendations for recovery of the species".

## REFERENCES

Arthur, J. F. and M.D. Ball. 1979. Factors influencing the entrapment of suspended material in the San Francisco Bay-Delta Estuary. Pages 143-174 in T.J. Conomos, ed. San Francisco Bay, the urbanized Estuary. Pacific Division, American Association for the Advancement of Science, San Francisco.

Brown, R.L. 1982. Screening agricultural diversions in the Sacramento-San Joaquin Delta. Department of Water Resources, internal report. Sacramento.

California Department of Fish and Game (WRINT-DFG-6). 1992. Estuary dependent species. Exhibit WRINT-DFG-Exhibit #6 entered by the California Department of Fish and Game to the State Water Resources Control Board 1992 Water Quality/Water Rights Proceedings on the San Francisco Bay/Sacramento-San Joaquin Delta. Sacramento, California.

Committee on Names of Fishes. 1990. Common and scientific names of fishes from the United States and Canada. Fifth ed. American Fisheries Society Special Publication 20. Bethesda, MD.

Doroshov, Serge, University of California at Davis. Primary Investigator which has a contract (1992, 1993) with the Department of Water Resources to culture delta smelt in the laboratory and to study gametogenesis and reproductive development of delta smelt.

Erkkila, L.F., J.W. Moffet, O.B. Cope, B.R. Smith, and R.S. Nelson. 1950. Sacramento-San Joaquin Delta fishery resources: Effects of Tracy Pumping Plant and the Delta Cross channel. U.S. Fish and Wildlife Service Special Scientific Report 56:1-109.

Fry, D.H. 1973. Anadromous fishes of California. California Department of Fish and Game. 112pp.

Jassby, A.D. 1993. Isohaline position as a habitat indicator for estuarine resources: San Francisco Estuary. in J.R. Schubel (ed.) Managing freshwater discharge to the San Francisco Bay/Sacramento-San Joaquin Estuary: the scientific basis for an estuarine standard. Final Report from the technical workshop on salinities, flows, and living resources of the Bay/Delta Estuary. San Francisco Estuary Project. San Francisco, California.

Jung, M., J.A. Whipple, and M. Moser. 1984. Summary report of the Cooperative Striped Bass Study. Institute for Aquatic Resources. Santa Cruz, California. 117p.

Kimmerer, W. 1992. An evaluation of existing data in the entrapment zone of the San Francisco Bay Estuary. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 33. Sacramento, California.

Kimmerer, W. and S. Monismith. 1992. An estimate of the historical position of the 2ppt salinity in the San Francisco Bay Estuary. Report Submitted to the San Francisco Estuary Project. San Francisco, California.

Mager, Randy, University of California at Davis. Researcher under P.I. Serge Doroshov which has a contract (1992, 1993) with the Department of Water Resources to culture delta smelt in the laboratory and to study gametogenesis and reproductive development of delta smelt.

McAllister, D.E. 1963. A revision of the smelt family, Osmeridae. Bulletin National Museum of Canada. 191. 53pp.

McAllister, D.E., R. Boyle, and B. Parker. 1979. Pond Smelt. Page 121 in D.S. Lee, *et al.*,(eds.) Atlas of North American freshwater fishes. North Carolina Museum of Natural History, Raleigh, NC.

Moyle, P.B. 1976. Inland fishes of California. University of California Press, Berkeley. 405pp.

Moyle, P.B., R.A. Daniels, B. Herbold, and D.M. Baltz. 1986. Patterns in distribution and abundance of a noncoevolved assemblage of estuarine fishes in California. Fishery Bulletin. 84(1): 105-118.

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

Moyle, P.B., J.K. Wilkens, and E.D. Wikramanayake. 1989. Fish species of special concern of California. Final Report to California department of Fish and Game. Department of Wildlife and Fisheries Biology, University of California, Davis. 77-83.

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

Obrebski, S. 1993. Relationship between delta smelt abundance and entrapment zone position. in Factors affecting the distribution and abundance of delta smelt in the Sacramento-San Joaquin Estuary. Draft Report. Department of Water Resources. Sacramento, California.

Odenweller, D. 1990. Delta Fish Facilities Study. Chapter 8 in P.L. Herrgesell, (compiler), 1989 Annual Report, Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Sacramento, California.

Orsi, J.J. and A.C. Knutson, Jr. 1979. The role of mysid shrimp in the Sacramento-San Joaquin estuary and factors affecting their abundance and distribution. Pages 401-408 in T.J. Conomos, ed. San Francisco Bay, the urbanized Estuary. Pacific Division, American Association for the Advancement of Science, San Francisco, California.

PGE (Pacific Gas and Electric Company). 1981a. Contra Costa Power Plant cooling water intake structures 316(b) demonstration. PGE. San Francisco, California.

PGE (Pacific Gas and Electric Company). 1981b. Pittsburg Power Plant cooling water structures 316(b) demonstration. PGE. San Francisco, California.

Radtke, L.D. 1966. Distribution of smelt, juvenile sturgeon, and starry flounder in the Sacramento-San Joaquin Delta with observations on food of sturgeon. In J.L. Turner and D.W. Kelley (eds), *Ecological Studies of the Sacramento-San Joaquin Delta.* California Department of Fish and Game, Fish Bulletin 136:115-129.

State Water Resources Control Board. 1992. Draft Water Right Decision 1630: Decision establishing terms and conditions for interim protection of public trust uses of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. Sacramento, California.

Stevens, D.E. and L.W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin river system. North American Journal of Fisheries Management. 3:425-437.

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

Stevens, D.E., L.W. Miller, and B.C. Bolster. 1990. A status review of the delta smelt, (Hypomesus transpacificus) in California. California Department of Fish and Game. Candidate Status Report 90-2.

Wales, J.H. 1962. Introduction of pond smelt from Japan into California. California Fish and Game. 48(2):141-142.

Wang, J.C.S. 1986. Fishes of the Sacramento-San Joaquin Estuary and adjacent waters, California: A guide to the early life histories. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 9. Sacramento, California.

Wang, J.C.S. 1991. Early life stages and early life history of the delta smelt, Hypomesus transpacificus, in the Sacramento-San Joaquin Estuary, with comparison of early life stages of the longfin smelt, Spirinchus thaleichthys. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary. Technical Report 28. 52pp.

# APPENDIX A

## APPENDIX A

Following receipt of the Department's report, the Commission will allow a 45-day public comment period prior to taking any action on the Department's recommendation.

**NOTICE IS FURTHER GIVEN** that any species above, proposed to be added to the State list as endangered or threatened, is a "candidate species" pursuant to Section 2074.2, FGC, and pursuant to Section 2085, FGC, may not be taken or possessed except as provided by Section 2080, et seq., of the Fish and Game Code, or other applicable statutes.

Sincerely,

Felix L Arteaga

for Susan A. Cochrane, Chief
Natural Heritage Division

# The Bay Institute
*of San Francisco*



Post-it™ brand fax transmittal memo 7671 | # of pages ▸ 3
To DALE SWEETNAM | From GARY BOBKER
Co. | Co.
Dept. | Phone # 415/331-2303
Fax # 209/946-6355 | Fax #

April 13, 1993

Celeste Cushman
Natural Heritage Division
California Department of Fish and Game
1416 Ninth Street
Sacramento, Ca. 95814

<u>Re: Comments of the Bay institute of San Francisco on the Proposed Listing of the Delta Smelt by the State Fish and Game Commission</u>

Dear Ms. Cushman,

This letter is submitted as the comments of the Bay Institute of San Francisco on the proposed listing of the Delta smelt under the California Endangered Species Act by the State Fish and Game Commission.

The Bay Institute supports listing of the Delta smelt as a threatened species under the California Endangered Species Act. The preponderance of scientific evidence on the precipitous decline and tenuous hold of this species resulted in federal listing of the smelt, and state action to protect the fish is long overdue. If the state is to play a role in management efforts to protect and restore smelt populations, it must begin by according the species full protection under state law.

**1. The Commission should accept and act upon the findings of CDF&G biologists.**

The listing of the Delta smelt as a threatened species under the federal Endangered Species Act by the U.S. Fish and Wildlife Service was based in large part on the scientific evidence generated by the California Department of Fish and Game. The Commission should accept the findings of CDFG without further consideration and initiate actions to protect the species. Among these actions should be close coordination with and assistance to the Service in federal listing implementation activities.

**2. Use state authority to account for entrainment losses unreachable by federal authority due to statutory limitations of the federal Endangered Species Act.**

CDFG documents conclude that mortality due to entrainment at multiple delta pumping stations is a major inhibitor to recovery of the population. Agency biologists have indicated that *all* entrainment losses must be accounted for and subsequently minimized to bring about long-term recovery. Where federal protective authority may not address impacts of state and private actions affecting the smelt, the state's authority under the California Endangered Species Act should be applied to regulation of non-federal pumping sites.

**3. Adopt the protections proposed in draft Water Right Decision 1630, pertaining to the elimination of reverse flows in the lower San Joaquin river from February 1 to June 30, the restriction of reverse flows from July 1 to January 31, the initiation of pulse flows, and the limitation of SWP project exports in April and in dry and critical years.**

Draft Water Right Decision 1630 provides an adequate foundation for basing operational requirements to help protect the Delta smelt, independent of whatever the final disposition of the plan is before the State Water Resources Control Board. D1630's estimated beneficial effects were quantified by CDFG to the fullest extent possible and were included in the most recent petition to the Commision. This was an appropriate approach, as the infrastructure of its implementation are highly transportable to other management processes. This is a more reasonable and more practical approach to decreasing entrainment losses than the relocation of water project diversion points proposed in the "Recommended Management/Recovery Measures" section in the most recent listing petition.

**4. Concentrate recovery efforts on increasing Delta outflows.**

The operational requirements contained in D-1630, however, will not in themeselves provide adequate levels of protection for the Delta smelt. Increased Delta outflow requirements to ensure low-salinity habitat in Suisun Bay are a primary component of the recovery program for Delta smelt.

**5. Coordinate state listing actions with the U.S. Environmental Protection Agency.**

EPA is deeply involved in the implementation of plans for delta smelt recovery, both as a member of the federally-sanctioned delta smelt recovery team and in the rulemaking procedure to establish water quality standards for the Bay/Delta estuary that are protective of overall estuarine habitat. The State Fish and Game Commission and CDFG must therefore coordinate their efforts with those of EPA, as well as USFWS.

Please contact me at 415/331-2303 if you have any questions regarding our comments in this matter.

Sincerely,

David Behar
Executive Director

# state water contractors

APR 2 1 1993

Directors

David B. Okita

Duane L. Georgeson

Thomas N. Clark

April 12, 1993

Rec'd NHD APR 14 1993

Ms. Susan A. Cochrane, Chief
National Heritage Division
California Department of Fish & Game
1416 Ninth Street
Sacramento, CA 95814

**RE: LISTING OF DELTA SMELT AS ENDANGERED SPECIES**

Dear Ms. Cochrane:

The State Water Contractors ("SWC") is a non-profit organization formed in 1982 for the purpose of representing the common interests of 27 public agencies that have contracts with the California Department of Water Resources to receive and deliver virtually all of the water supply from the State Water Project. Collectively, two-thirds of California's population (21 million people) in northern, central, and southern California receive all or a portion of their water supply from member agencies of our organization. In addition, hundreds of thousands of acres of California's finest irrigated agriculture is served by the State Water Project.

The SWC have been involved for some time in the Department of Fish and Game's and the California Fish and Game Commission's ("Commission") proposals to list the Delta smelt as a threatened species under the California Endangered Species Act. The SWC have received the public notice dated April 2, 1993, requesting comments on the status, ecology, biology, life history, management recommendations and other issues related to the Department's listing recommendation. Due to the short deadline for submitting comments, we are not able to provide you with ecological or biological recommendations. However, in this regard, we would like the Department to consider the materials previously submitted by the SWC during the previous listing process.

The SWC do, however, have the following recommendation with respect to the procedure which should be followed in determining whether or not the Delta smelt should be listed as a threatened species. The recent federal listing makes action on the

State petition less critical from a time standpoint. The biological opinion and the reasonable and prudent alternative established by the Fish and Wildlife Service will protect the species' habitat during 1993. Therefore, the SWC recommend that the Department of Fish and Game defer issuing its final recommendation to the Commission until the results of 1993 summer tow-net survey and the fall mid-water trawl survey are available. This will enable interested parties to ascertain if the end of the six-year drought has positively impacted smelt populations. This data could be critical to a listing decision and, as noted above, deferring a decision until the data is available will in no way jeopardize the continued existence of the species.

We urge your consideration of this recommendation and look forward to continuing our participation in the listing process.

Sincerely,

George R. Baumli
General Manager

cc: Member Agencies
Dave Kennedy, Director, DWR
C. Schulz, KMT&G
G. Wilkinson, BB&K
Charles Hanson, HEI
Randy Brown, DWR

KRONICK, MOSKOVITZ, TIEDEMANN & GIRARD
A PROFESSIONAL CORPORATION
ATTORNEYS AT LAW
770 L STREET, SUITE 1200
SACRAMENTO, CALIFORNIA 95814-3363
TELEPHONE (916) 444-8920

CLIFFORD W. SCHULZ

MAY 17 1993

May 14, 1993

**HAND DELIVERED**

Mr. Robert Treadnor
Executive Director
Fish & Game Commission
1416 9th Street
Sacramento, CA 95814

Re: Proposed Listing of Delta Smelt as Threatened Species

Dear Mr. Treadnor:

This office represents the Kern County Water Agency ("Kern") which directly and through the State Water Contractors has been actively involved in the Commission's Delta Smelt deliberations. The undersigned appeared at your April 1, 1993, meeting to comment on the California Department of Fish & Game's petition to list the Delta Smelt as a threatened species and asked that the Commission insure that its actions were coordinated with those of other state and federal agencies which are attempting to solve Sacramento/San Joaquin Delta fishery problems.

Kern has learned that the Commission may schedule final consideration of the Delta Smelt petition for a meeting in May. Apparently, the Department of Fish & Game has informed you that, by then, it will have completed its review and will have submitted its departmental report for consideration. Fish & Game Code section 2075 requires the Commission to make the Department's report, or copies thereof, available for review upon request. Please consider this letter a request by the Kern County Water Agency and the State Water Contractors that they receive copies of the Department's report as soon as it is available.

It is also our understanding from conversations with legal counsel for the Commission that the Commission's hearing on the departmental report may provide interested parties with their only opportunity to comment on the biological information provided by the Department of Fish & Game. We understand the Commission's position to be that if the it decides that listing is warranted and rulemaking proceedings are initiated, the hearing required by the California Administrative Procedure Act would not include a review of that biological data.

Thus, unless the Department of Fish & Game's report is provided well before the scheduled meeting date, Kern and other interested groups and individuals will have little opportunity to prepare any necessary rebuttal information or to make meaningful biological comments to the Commission at its May meeting. We, therefore, request that the Commission's meeting to consider the biological information not be held earlier than two weeks after the departmental report has been made available to all interested parties. This is the minimum time which we will need to review the data and prepare a meaningful response to the Department's recommendations.

Our concern in this area is heightened by the language of Fish and Game Code Section 2074, which can be interpreted to require the Commission to consider a listing petition at the first meeting after the departmental report is completed. If the departmental report is issued shortly before a scheduled Commission meeting, the public may be denied a reasonable opportunity to review and comment. By a copy of this letter to the Department, we are requesting that the report be distributed to interested parties in draft form before the final version is sent to the Commission. This process could avoid the possible procedural problems created by Fish and game Code Section 2074. Further, given the federal listing of smelt and its candidate status under State law, no damage to the species could result from granting this request.

Given the significance of this proposed listing and the fact that the Delta Smelt has already been listed by a federal agency, we also continue to urge that the Commission defer any final decision on a listing petition until the results of the summer and fall smelt surveys have been completed. This data could be vital to determining whether recent reductions in Delta Smelt populations were primarily related to the drought and whether a significant recovery has occurred because of this year's much improved water supply conditions.

Kern also directs your attention to Government Code section 11346.53 which requires the Commission to determine whether the listing of the Delta Smelt will have the potential for adverse economic impacts on California small business enterprises and individuals. Since the Delta is the hub of California's most important water supply systems, it is undeniable that listing the species as threatened could have enormous economic impacts on farm and business enterprises throughout California. Government Code section 11346.53 requires that the Commission assess those economic impacts "early in the process of initiation and development of proposed regulations." Subsection (a)(2) makes it clear that the Commission, prior to noticing any proposed regulations on the Delta Smelt, (1) must identify the types of small business that would be affected and (2) must include a statement in its notice that the Commission has considered proposed alternatives to the proposed regulations that would lessen any adverse economic impacts and that invites parties to submit additional proposals to lessen economic impacts. The Commission, therefore, should begin considering economic issues immediately so that comprehensive review of all the interrelated issues can be considered prior to final action. Kern also requests a fair opportunity to provide the Commission with information concerning economic impacts of its proposed action.

We look forward to further participation in the Commission's Delta Smelt considerations.

Very truly yours,

Clifford W. Schulz

CLIFFORD W. SCHULZ

cc: Tom Clark
Dan O'Hanlon
David Schuster
William Cunningham

95899.1

UNIVERSITY OF CALIFORNIA, DAVIS

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

COLLEGE OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES
AGRICULTURAL EXPERIMENT STATION
COOPERATIVE EXTENSION

DEPARTMENT OF WILDLIFE AND FISHERIES BIOLOGY
UNIVERSITY OF CALIFORNIA
DAVIS, CALIFORNIA 95616-8270

June 7, 1989

California Fish and Game Commission
1416 Ninth Street
Sacramento, CA 95814

Attention: Harold Cribbs

Dear Mr. Cribbs:

Enclosed is a petition for listing the Delta smelt as an endangered species. I hope this can be acted on quickly, as I believe this species is likely to become extinct in the next few years if something is not done to protect it.

Sincerely,

Peter B. Moyle
Professor

PBM:bc/001:cribbs.091

cc: B. Bolster
J. Krautkramer
R. Spotts
E. Lorentzen
G. Meral

State of California
FGC - 670.1 (1/86)

A PETITION TO THE STATE OF CALIFORNIA FISH AND GAME COMMISSION

for action pursuant to Section 670.1, Title 14, California Administrative Code, and sections 2072 and 2072.3 of the Fish and Game Code, relating to listing and delisting endangered and threatened species of plants and animals.

I. SPECIES BEING PETITIONED:

Common Name: Delta Smelt

Scientific Name: *Hypomesus transpacificus*

II. RECOMMENDED ACTION:

Endangered: X

III. SUMMARY OF REASONS FOR RECOMMENDED ACTION:

The Delta smelt fits the definition of an endangered species as it is in danger of extinction throughout its entire limited range. It is vulnerable to extinction because (1) it is short-lived, (2) it has relatively low fecundity, (3) it is a planktivore throughout its life cycle, and (4) it is confined to the upper Sacramento-San Joaquin estuary.

Delta smelt rarely live more than one year, at the end of which they spawn and die. This makes them exceptionally vulnerable to changes in estuarine conditions because they must reproduce every year (unlike all other native fishes in the estuary). The relatively low fecundity, coupled with their planktonic larvae (which presumably have high mortality rates in the best of conditions) means that this annual reproduction must be accomplished by a fairly large number of fish if the population is to perpetuate itself. Pimm et al. (1988) show that small species with variable populations, like Delta smelt, become increasingly vulnerable to extinction as their populations decrease.

Survival of this species also depends on having copepods available in abundance as copepods are its principal food throughout its life cycle; anything that affects copepod abundance will also affect Delta smelt abundance. Copepods, and hence Delta smelt, are likely to be affected, directly and indirectly, by changes in water quality and productivity patterns in the estuary. There are many changes in the estuary that are now taking place that are threatening the abundance of copepods and the survival of smelt.

Why is the Delta smelt endangered? According to the Federal Endangered Species Act, there are five possible general reasons: "(A) the present, or threatened destruction, modification, or curtailment of its habitat or range, (B) overutilization for commerical, recreational, scientific, or educational purposes, (C) disease or predation, (D) the inadequacy of existing regulatory mechanisms, or (E) other natural or manmade factors affecting its continued existence." Reasons can be found in all areas except (B), as Delta smelt have never been harvested for any reason except scientific study.

Destruction of habitat. The principal habitat of the Delta smelt is the open water of the Delta and Suisun Bay. To provide sufficient food for these fish the water must contain dense populations of zooplankton, especially of copepods. This means a critical habitat requirement is having the entrapment zone located in Suisun Bay during March-midJune, when larval smelt are present. Present regimes of outflow do not allow the entrapment zone to be located there long enough in every year to assure that this annual species can successfully reproduce. Prior to the diversion and regulation of Delta outflows, it is likely that the null zone was frequently located well above Suisun Bay but the Delta smelt was presumably able to persist because there was adequate shallow water habitat upstream in the Delta to create the conditions it needed. This habitat is now gone, as the Delta today consists of a complex of islands separated by dredged channels. Thus the long-term survival of Delta smelt requires that conditions in Suisun Bay in the spring months meet its ecological requirements.

Disease, competition, and predation. There is no evidence that these biological interactions have affected Delta smelt populations in the past, despite the abundance of introduced species in the estuary. However, the diseases and parasites of Delta smelt have never been studied. The effects of predation by fishes like the introduced striped bass or of competition from introduced planktivores like threadfin shad and American shad have likewise not been studied in depth. It is quite possible that under the low population levels that now exist for Delta smelt, these factors could become important and prevent recovery. Because the populations of many other fish species as well as Delta smelt appear to be depressed in the upper estuary (Moyle et al. 1985; Moyle and Herbold, unpublished data), a particular problem could be the proposed effort to enhance striped bass populations by producing large numbers of juveniles in hatcheries. The enhanced predator populations, without a concommitant enhancement of prey populations, could result in excessive predation pressure on the remaining prey species, such as Delta smelt.

Inadequacy of regulatory mechanisms. The regulation of Delta outflows, Delta water quality, and flow patterns through the Delta is complex and under the jurisdiction of a number of agencies. The present regulatory system primarily benefits the water exporters at the cost of the fish. Even valuable gamefishes like striped bass and chinook salmon have suffered severe declines in recent years, despite major efforts to sustain them. For example, large numbers of all pelagic species and species with pelagic larvae are entrained in CVP and SWP facilities and current rescue/mitigation efforts do not seem to compensate for the losses. This is particularly true of Delta smelt, which (1) have received little attention from the management agencies, (2) are frequently exposed to entrainment, and (3) are unlikely to survive any rescue attempts that involve handling of fish. In short, the present mechanisms that regulate freshwater flows through the Delta are inadequate to protect Delta smelt.

Other factors. There are a number of other factors that may affect the abundance of Delta smelt; four mentioned previously are the invasions of exotic copepods, the invasion of the exotic clam, the blooms of the inedible diatom *Melosira*, and the presence upstream of populations of a closely related Japanese smelt. A number of other exotic species are also invading the estuary at this time and may directly or indirectly affect the Delta smelt. None of these potential threats is well understood, nor is it understood if the current series of invasions of exotic species is only possible because of altered environmental conditions in the Delta or if they are independent of the changes. The combination of altered conditions and invasions of exotic species, however, may extirpate the Delta smelt.

As a back-up measure, fish culture techniques and facilities should be developed, as the Japanese have done for other smelts. However, if hatchery propagation is to be successful, the fish must be released into an environment which provides ample food, low levels of toxic compounds, and low entrainment losses. Thus water management in the estuary will always be a key factor in smelt survival.

## IV. NATURE AND DEGREE OF THREAT

The causes of the decline of Delta smelt are probably multiple and synergistic but seem to be in the following order of importance:

1. Reduction in outflows. Increased diversion of water from the Sacramento and San Joaquin Rivers and tributaries has reduced the freshwater available to flush through the estuary. In particular, spring (March-June) outflows, created by snowmelt from the Sierras, are usually diminished, so the total amount of outflow is reduced, as is the number of weeks of high outflow. Diversion also creates reverse flows up the San Joaquin River; during drought years, these reverse flows may be almost continuous (see #3). The overall effect of diversions is particularly severe in years when the total water available from runoff is low. For fishes and most other Delta organisms, moderately high spring outflows are

important because they cause the mixing zone (entrapment zone) of the estuary, where outflowing freshwater meets incoming tidal water. The mixing effect allows organisms that do not swim well, such as zooplankton and larval fish, to remain suspended in the mixing area, rather than being flushed out to sea. Suisun Bay is broad and shallow, so when the entrapment zone is located there nutrients and algae can circulate, in sunlit waters, allowing algae to grow and reproduce rapidly. This provides plenty of food for zooplankton, which are food for plankton-feeding fish, including Delta smelt and their larvae. When outflows are low, the mixing zone is located in the deep, narrow channels of the Delta and Sacramento River, where productivity is lower because much of the water is beyond the reach of sunlight, so fewer fish can be supported.

A strong relationship between the abundance of striped bass, American shad, chinook salmon, and longfin smelt and outflows was demonstrated by Stevens (1977) and Stevens and Miller (1983). Stevens and Miller (1983) failed to find this relationship for Delta smelt. However, Moyle and Herbold (1989) show that there nevertheless is a relationship between outflows and smelt abundance, but it is more complex than the one for the other species, as outflows not only affect abundance but also affect distribution patterns. The relationship is also masked by the fact that the index, which was developed for striped bass, needs to be modified to account for peculiarities of smelt ecology. Basically, low outflows produce low smelt populations, but years of higher outflow do not necessarily produce high smelt populations, because other factors may depress smelt populations when outflow conditions are favorable.

The analysis of environmental factors correlated with Delta smelt abundance (Moyle and Herbold 1989) shows that one of the strongest determinants of their abundance is high productivity (as reflected in phytoplankton and zooplankton abundances) in late spring (April-June). This high productivity is associated with establishment of the entrapment zone in the shallow waters of Suisun Bay. When this zone is located there, the abundance of the zooplankton fed upon by the larval smelt is higher than when the zone is located in the deeper channels of the Delta. Presumably, most of the larval smelt starve to death if the food supply is inadequate, as it seems to have been in recent years.

2. <u>High outflows</u>. The years of the major smelt decline have been characterized by not only unusually dry years with exceptionally low outflows (1987, 1988) but also by unusually wet years with exceptionally high outflows (1982, 1986). High outflows have much the same effect biologically as low outflows: they put the entrapment zone in a location (Carquinez Straits, the deeper parts of San Pablo Bay, or San Francisco Bay) where phytoplankton grow and reproduce slowly, disrupting food chains leading to smelt larvae. Exceptionally high outflows may have the additional

effect of flushing adult smelt out of the system, along with much of the zooplankton. This means that not only is the potential spawning stock of smelt reduced, but their food supply is as well. Furthermore, the depletion of the established populations of invertebrates and fish may have made it easier for exotic species of invertebrates and fish (see #4) to colonize the estuary, which may be detrimental to smelt.

3. Entrainment losses to water diversions. This factor is closely tied to the first factor because as diversions increase, there is less fresh water available to establish the entrapment zone in Suisun Bay. Water is pumped out of the system through numerous small diversions for the farms of the Delta and, especially, the large diversions of the federal Central Valley Project (CVP) and the State Water Project (SWP). Water is also pumped through several power plants for cooling. Recent analyses by CDFG (1987) indicate that the entrainment of larvae in these diversions, coupled with the loss of food organisms entrained as well, has been a major cause of the ongoing decline of striped bass. Turner (1987) indicates the diversions are the major cause of striped bass declines. It is likely that this entrainment loss is also a major factor limiting Delta smelt populations, because (1) Delta smelt are ecologically quite similar to larval and juvenile striped bass, (2) low smelt populations are associated with the number of days of reverse flows in the San Joaquin River, and (3) large numbers of smelt larvae are pumped through the CVP and SWP plants, just as striped bass larvae are. Delta smelt are vulnerable to diversions throughout their life cycle because they usually occur in the channels of the Delta from which water is diverted. In recent years, the more upstream location of the entrapment zone may have increased the likelihood of entrainment. Efforts are made to rescue larger fish being entrained at the CVP and SWP plants by trapping them and trucking them back to the Delta. The effectiveness of this procedure has not been well evaluated but it is unlikely that many Delta smelt would survive the handling it involves. Our experience in capturing and handling the fishes of the estuary indicates that Delta smelt are one of the most delicate and most likely to die from handling of any Delta fish.

4. Changes in food organisms. In recent years, three exotic copepods (Sinocalanus doerrii and two species of the genus Pseudodiatomous) have invaded the estuary and increased in numbers while the dominant native euryhaline copepod, Eurytemora affinis, has declined. Whether this decline is caused by competition between the native and introduced species, by selective predation on the native copepod, or by changes in estuarine conditions that favor the introduced species is not known. However, CDFG (1987) studies show that juvenile striped bass do not feed on Sinocalanus as much as its abundance would indicate they should. Apparently, Sinocalanus can swim faster and therefore avoid predation more easily than Eurytemora (J. Orsi, personal communication), although

the *Pseudodiaptomus* species do not appear to have that advantage. Feeding by Delta smelt, especially larvae, is probably affected in ways similar to that of striped bass larvae by this change in zooplankton species. The increased abundance of the exotic copepods may increase the likelihood of larval starvation.

Another potential indirect cause of larval starvation is the recent invasion (ca. 1986-87) of the euryhaline clam, *Potamocorbula*, which is now abundant in Suisun Bay. This clam may be reducing phytoplankton populations in the bay with its high filtration rates and dense populations. This clam has obviously not been responsible for the smelt declines but it may help to keep smelt populations at low levels by reducing the availability of food for the larvae.

Yet another complicating factor is the rise in abundance of the diatom *Melosira* to the point where it has been, on occasion, the most abundant species of phytoplankton. This diatom grows in long chains and is very hard for zooplankton to graze on; thus the change in composition and/or abundance of zooplankton may also be tied to the increased importance of this diatom. The causes of the increase in *Melosira* are not known but it may be related to the increase in water clarity experienced in recent years.

5. Toxic substances. The waters of the estuary receive a variety of toxic substances, including agricultural pesticides, heavy metals, and other products of our urbanized society. The effects of these toxic compounds on larval fishes and their food supply are poorly known (CDFG 1987). Although there is no indication so far that larval fishes are suffering direct mortality or additional stress from low concentrations of toxic substances, this factor has also not been studied very extensively, so cannot be eliminated as a possible factor affecting Delta smelt populations.

6. Loss of genetic integrity. The closely related wagasaki (*Hypomesus nipponensis*), or Japanese smelt, was introduced into Alamanor Reservoir in the Sacramento drainage and has subsequently been collected from downstream areas. It is highly likely that the wagasaki can hybridize with Delta smelt, but whether they have done so is not known, nor is it known if such hybridization could have a negative effect on the fitness of the Delta smelt. Loss of genetic integrity is nevertheless a possible contributing factor to the decline of Delta smelt. It is also possible the wagasaki could displace the Delta smelt completely through introgression or direct competition.

## V. HISTORIC AND CURRENT DISTRIBUTION

Delta smelt are endemic to the upper Sacramento-San Joaquin estuary so their historic and current distribution patterns are similar. They occur primarily below Isleton in the Sacramento River, below

Mossdale in the San Joaquin River, and in Suisun Bay. When outflows from the Sacramento and San Joaquin rivers are high (mainly during March-mid June) the smelt congregate in upper Suisun Bay and Montezuma slough. During high outflow periods, they may be washed into San Pablo Bay, but they do not establish permanent populations there.

Because of the restricted distribution and seasonal movements of the smelt, a range map is not included.

## VI. HISTORIC AND CURRENT ABUNDANCE

The Delta smelt was once one of the most common pelagic fish in the upper Sacramento-San Joaquin estuary, as indicated by its abundance in CDFG trawl catches (Erikkila et al. 1950, Radtke 1966, Stevens and Miller 1983). Smelt populations show considerable natural fluctuations, but since 1982 populations have been consistently low (Figure 1). The numbers of Delta smelt are now at their lowest levels ever recorded. This is shown most dramatically using the annual index of abundance calculated by the California Department of Fish and Game (CDFG), based on catches in their annual midwater trawl survey (Lee Miller, CDFG, personal communication). Details on how the index is calculated are in Stevens and Miller (1983).

The exact numbers of Delta smelt are not known. However, their pelagic life style, short life span, broad-cast spawning habits, and relatively low fecundity indicate that a large population is probably necessary to keep the species from becoming extinct.

The center of Delta smelt abundance is now the northwestern Delta in the channel of the Sacramento River. Previously, it was in the broad and productive expanses of Suisun Bay (Moyle and Herbold 1989). It is now virtually absent from Suisun Marsh, where it was once seasonally common (Moyle et al. 1986). This major change in its distribution is presumably in response to the changes that have occurred in the biological and hydrodynamic characteristics of the estuary.

## VII. SPECIES DESCRIPTION AND BIOLOGY:

### A. Description

Delta smelt (*Hypomesus transpacificus*) are slender-bodied fish with a typical adult size of 60-70mm SL, although a few may reach 120 mm SL. The mouth is small, with a maxilla that does not extend past the mid-point of the eye. The eyes are relatively large, with the orbit width contained approximately in the 3.5-4 x the head length. Small, pointed teeth are present on the upper and lower jaws. The gill covers are unmarked. The first gill arch has 27-33 gill rakers and there are 7 branchiostegal rays. The pectoral fins reach less than two thirds of the way to the bases of the pelvic fins. There are 9-10 dorsal fin rays, 8 pelvic fin rays, 10-12 pectoral fin rays, and 15-17 anal fin

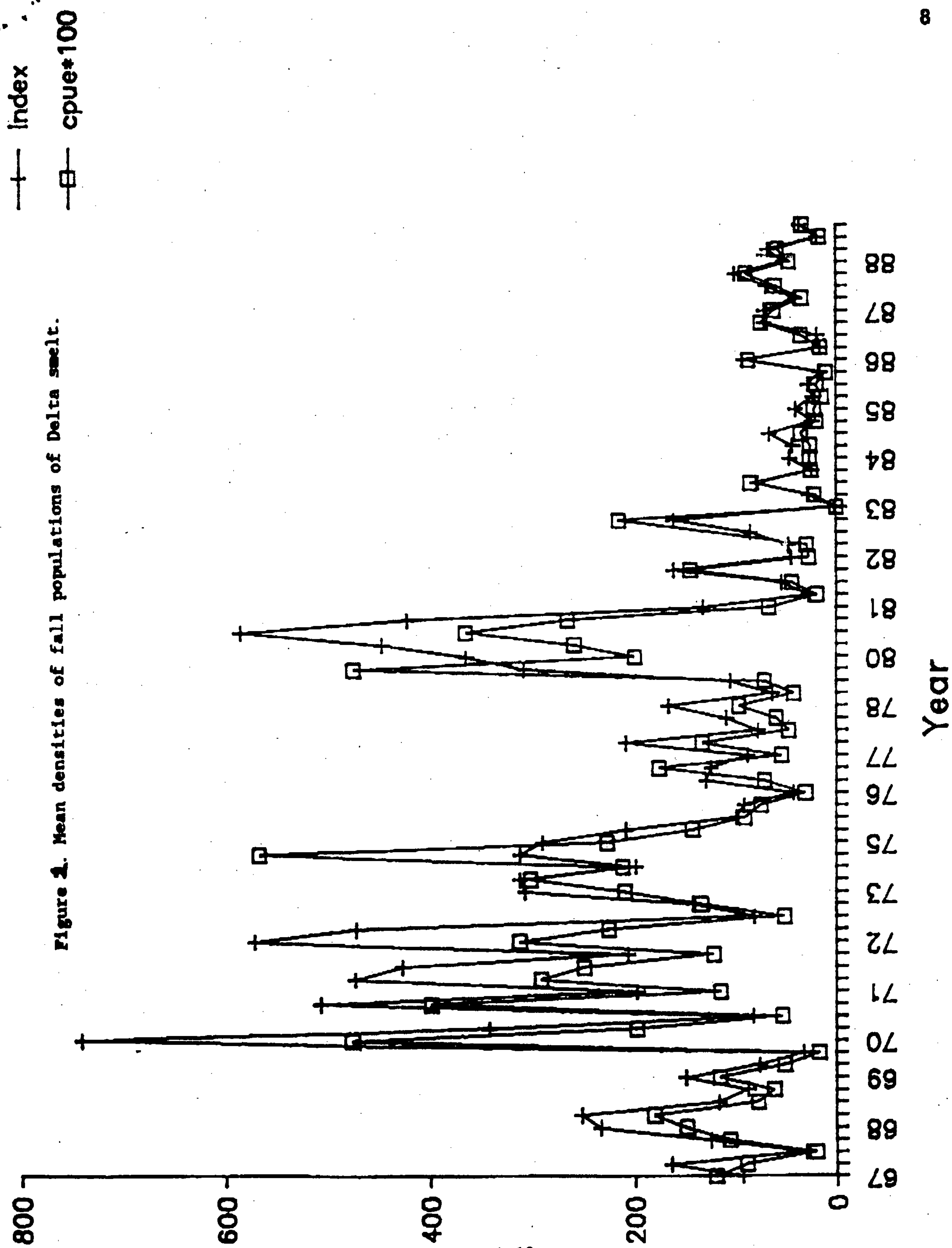



Figure 1. Mean densities of fall populations of Delta smelt.

rays. The lateral line is incomplete and has 53-60 scales along it. There are 4-5 pyloric caeca.

Live fish are nearly translucent and have a steely-blue sheen to their sides. Occasionally there may be one chromatophore between the mandibles, but usually there is none.

B. Taxonomy

The confusing taxonomic history of this species is detailed in Moyle (1976). The Delta smelt was first considered to be a population of the widely distributed pond smelt, *Hypomesus olidus*. Hamada (1961) then recognized the pond smelt and the Delta smelt as being different species and renamed the pond smelt as *H. sakhalinus*, while retaining the name *H. olidus* for the Delta smelt. McAllister (1963) then redescribed the Delta smelt as *H. transpacificus*, but with Japanese and California subspecies, *H. t. nipponensis* and *H. t. transpacificus*, respectively. Subsequent studies have shown that the two widely separated subspecies should be recognized as species, with the Delta smelt being *H. transpacificus* and the Japanese species (wagasaki) being *H. nipponensis* (Moyle 1980). Unfortunately, wagasaki were introduced into California reservoirs on the assumption that they were the same species (*H. olidus*!) as the Delta smelt (Moyle 1976).

C. Habitat Requirements

Delta smelt inhabit the open, surface waters of Delta and Suisun Bay. Spawning takes place between February and June, as inferred from larvae collected during this period (Wang 1986). Apparently, most spawning occurs in the deadend sloughs and shallow edge-waters of the channels in the upper Delta, although it has also been recorded in Montezuma Slough near Suisun Bay (Radtke 1966, Wang 1986). Their eggs are demersal and adhesive so it is likely that Delta smelt spawn over hard substrates such as rock, gravel, tree roots, or submerged branches, although submerged vegetation may also be important (Moyle 1976, Wang 1986). Hatching occurs in 12-14 days, assuming developmental rates are similar to those of the closely related wagasaki (Wales 1962).

After hatching, the bouyant larvae rise to the surface and are washed downstream until they reach the mixing zone. Here currents keep them suspended, circulating with the abundant zooplankton that typically also occur in this zone and provide food for the larvae. Growth is rapid and the juvenile fish are 40-50 mm long by early August (Erkkila et al. 1950, Ganssle 1966, Radtke 1966). The smelt reach adult lengths of 55-70 mm SL by the time they are six to nine months old (Moyle 1976). During the next three months, growth slows considerably (only 3-9 mm total), presumably because most of their energy is being channeled into gonadal development (Erkkila et al. 1950, Radtke 1966). Female smelt produce 1400-2800 eggs, but there is no correlation between size and fecundity (Moyle 1976).

As the summer progresses, adults become increasingly scarce and young-of-year fish dominate the trawl catches by August. The rapid change from a single-age, adult cohort during the spawning runs in spring to a population dominated by juveniles in the summer suggests strongly that most adults die after they spawn (Radtke 1966).

Delta smelt feed primarily on planktonic copepods, cladocerans, amphipods, and to a lesser extent on insect larvae (Moyle 1976) although larger fish may also feed on the opposum shrimp, Neomysis mercedis (Moyle 1976). In the mid-1970's, the most important food organism for all sizes was the euryhaline copepod, Eurytemora affinis (Moyle, unpublished data).

## VIII. HABITAT REQUIREMENTS

Delta smelt are euryhaline fish that rarely occur in water with more than 10-12 ppt salinity (about 1/3 sea water). Spawning takes place in freshwater at temperatures of ca. 7-15 C (Wang 1986). All sizes are found primarily in the main channels of the Delta and Suisun Marsh, and the open waters of Suisun Bay where the waters are well oxygenated and the temperatures relatively cool (usually less than 20-22 C in summer). When not spawning, they are typically most abundant in the entrapment zone, where incoming salt water and outflowing freshwater mix. This area is where primary productivity is highest and where zooplankton populations (on which they feed) are most dense.

## IX. CURRENT AND RECOMMENDED MANAGEMENT

The Delta smelt currently has no special protection or management. The best, and probably the only, way of keeping it from becoming extinct is to maintain high enough freshwater outflows through the Delta to keep the entrapment zone in Suisun Bay during March, April, May, and June for most years. The entrapment zone should not be upstream from Suisun Bay for more than two years in a row.

## X. INFORMATION SOURCES

California Department of Fish and Game. 1987. Factors affecting striped bass abundance in the Sacramento-San Joaquin River System. DFG exhibit 25,State Water Resources Control Board 1987 Water Quality /Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta. 149 pp.

Erkkila, L.F., J.F. Moffett, O.B. Cope, B.R. Smith, and R.S. Nelson. 1950. Sacramento-San Joaquin Delta fishery resources: effects of Tracy pumping plant and delta cross channel. U.S. Fish and Wildlife Serv. Spec. Sci. Rept.-Fish. 56:109pp.

Ganssle, D. 1966. Fishes and decapods of San Pablo and Suisun Bay. pp. 64-94. In: D. W. Kelley, ed., Ecological studies of the Sacramento-San Joaquin Estuary. Pt. 1. Calif. Dept. Fish and Game. Fish. Bull. 133.

Hamada, K. 1961. Taxonomic and ecological studies of the genus Hypomesus of Japan. Mem. Fac. Fish. Hokkaido Univ. 9(1):1-56.

McAllister, D.E. 1963. A revision of the smelt family, Osmeridae. Bull. Natl. Mus. Canada. 191:53pp.

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

Moyle, P.B. 1980. Delta smelt. Page 123 in D.S. Lee et al. Atlas of North American freshwater fishes. North Carolina Museum of Natural History, Raleigh NC.

Moyle, P.B., R.A. Daniels, B. Herbold, and D.M. Baltz. 1985. Patterns in distribution and abundance of a noncoevolved assemblage of estuarine fishes in California. Fishery Bulletin 84: 105-117.

Moyle, P.B. and B. Herbold. 1989. Status of the Delta smelt, Hypomensus transpacificus. Report to the US Fish and Wildlife Service, Office of Endangered Species.

Pimm, S.L., H.L. Jones, and J. Diamond. 1988. On the risk of extinction. American Naturalist 132:757-785.

Radtke, L.D. 1966. Distribution of smelt, juvenile sturgeon and starry flounder in the Sacramento-San Joaquin Delta. pp. 115-119. In: S.L. Turner and D.W. Kelley, eds., Ecological studies of the Sacramento-San Joaquin Estuary. Pt. 2. Calif. Dept. Fish and Game. Fish. Bull. 136.

Stevens, D.E. and L.W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and Delta smelt in the Sacramento-San Joaquin river system. North American Journal of Fisheries Management 3:425-437.

Turner, J. 1987. Effects of geographic distribution of larval striped bass in determining year class size of striped bass in the Sacramento-San Joaquin estuary. USBR Exhibit 100, SWRCB 1987 Water Quality/Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta. 51 pp.

Wales, J.H. 1962. Introduction of pond smelt from Japan into California. Calif. Fish and Game 48(2):141-142.

Wang, J.C.S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary, Technical Report 9.

XI. AUTHOR OF PETITION:

Peter B. Moyle
Department of Wildlife and Fisheries Biology
University of California, Davis
Davis, CA 95616
(916) 752-6355

Peter B. Moyle

PBM:ss/2/18/88/PBM\Dsmelt

[redacted]

Director

Executive Secretary

September 13, 1990

Adoption of Commission Finding re: Petition to List the Delta Smelt (*Hypomesus transpacificus*) as a Threatened Species.

At the Commission's August 30, 1990 meeting in Sacramento, it made a finding that the Delta smelt (*Hypomesus transpacificus*) does not currently warrant listing as either a threatened or endangered species. The Commission found that the petition did not contain sufficient biological information on which to base its decision. Please refer to the enclosed findings. Therefore, the Commission directed the Department to enter immediately into the studies proposed by the Department of Water Resources to collect the information necessary to make the determination of whether or not the Delta smelt warrants listing. In addition, the Commission requested that the Department monitor the status of this species and, if necessary, bring to its attention any changes in that status for the Commission's consideration to emergency list the Delta smelt.

If you have any questions regarding this matter, please let me know.

COPY Original signed by Robert R. Treanor

Robert R. Treanor

Enclosure

cc: Natural Heritage Division
Inland Fisheries Division
Bay Delta Study
Region 2 and 3

## CALIFORNIA FISH AND GAME COMMISSION
## NOTICE OF FINDINGS

**NOTICE IS HEREBY GIVEN** that, pursuant to the provisions of Section 2075.5 of the Fish and Game Code, the California Fish and Game Commission, at its August 30, 1990 meeting in Sacramento, made a finding that the petitioned action to list the Delta smelt (Hypomesus transpacificus) as an endangered species is not warranted for the following reasons:

1. It was not demonstrated to the Commission that there is sufficient scientific evidence to suggest that the Delta smelt's existence is threatened by overexploitation, predation, competition, disease or other natural occurrences or human-related activities.

   a. The relationship between Delta smelt abundance and water diversions is not clear. There is no convincing evidence that Delta outflow has had major effects on Delta smelt abundance.

   b. There is no direct evidence of Delta smelt suffering direct mortality or stress from toxic substances.

   c. There is no evidence concerning the role of diseases and parasites in current numbers of Delta smelt.

   d. Competition and predation are not considered major threats to the Delta smelt.

2. It was not demonstrated to the Commission that there is sufficient scientific information to determine whether the population is low enough that it is in imminent danger of extinction.

3. The Commission has directed the Department to coordinate with the Department of Water Resources and other related agencies to immediately commence whatever studies are needed to monitor the Delta smelt population and to address the following management and recovery objectives:

   a. Improvement of species identification and fish handling procedures at the existing State and Federal Water Project diversions from the Delta to reduce present entrainment losses to these major diversions.

   b. Modification of pumping strategies at the State and Federal Water project diversions to reduce entrainment losses during periods when Delta smelt are most abundant.

c. Increase of spring and summer Delta outflows to maintain the entrapment zone and major Delta smelt nursery in the Suisun Bay region where food supplies are greater than in the Delta and exposure to diversions is minimal.

d. Support for regulations restricting ship ballast water discharges to eliminate or minimize new introductions of potentially harmful exotic species.

e. Evaluation of losses to agricultural diversions in the Delta. Screening these diversions probably would reduce entrainment and losses to local crop irrigation.

f. Consider the development of pond culture techniques for the purpose of creating "refuge" populations.

FISH AND GAME COMMISSION

Robert R. Treanor

Robert R. Treanor
Executive Secretary

Dated: September 14, 1990

State of California

DEC 2 1992

# Memorandum

To : Fish and Game Commission

Date : NOV 30 1992

From : Department of Fish and Game

Subject : Delta Smelt Study Progress Report

Attached is a progress report for the Delta smelt study. I am submitting this for your information at your December Commission Meeting.

COPY Original signed by
for A. Petrovich, Jr.
Boyd Gibbons
Director

Attachment

BG/H.K. Chadwick/cc

File: Dir, Ex-File, BDD, Chadwick-BDD

HK92C367.cc

Delta Smelt Project
Project Update for the Fish and Game Commission
December 1992

The 1992 summer townet survey was completed June 29. The delta smelt abundance index, which is the mean of the first two surveys is 2.4. This number is slightly higher than last year's value of 2.0, but is consistent with the low values since 1987.

The fall midwater trawl survey started September 9th and will run monthly through mid-December. The abundance index produced from this survey, along with the index produced from the townet survey in June, will give us the best measures of the status of the 1992 year class of delta smelt. The abundance index for September is 71.5. This index represents a total of 61 delta smelt captured with 89% of these fish caught in the lower Sacramento River. This monthly index is down from 126 for September of 1991. The October index is 3.5 which represents a total of 2 smelt captured! This is the lowest index ever for October and the second lowest index for any month. The November index is 57.5 which represents 48 delta smelt captured. Ninety eight percent of these fish were captured in the Lower Sacramento River. The annual abundance index will be set on December 16th; it is the sum of all the monthly surveys. We are expecting the annual abundance index to be around 170 which would make it the fourth lowest annual index in the 24 years of record.

Larval delta smelt sampling, which was run in conjunction with the striped bass egg and larval survey, was completed on July 13th. A total of 2650 samples were taken from over 80 different locations in the Estuary from February 12th through July 13th. Delta smelt larvae were first observed in the Estuary on February 24th in Cache Slough and in the South Delta at Old River on February 25th. It appears that the majority of spawning took place in April and May. Sorting and larval identification are continuing and should be completed by December 31st if ethanol ventilation problems in our new building can be overcome. Gut analysis of larval delta smelt and zooplankton identification work is also continuing.

Otolith (ear bone) extraction from larval and juvenile delta smelt has begun and analysis was started in September when our new image analysis system became totally operational. The purpose of this project is to aid in the determination of when and where the majority of the population was produced. Otoliths are currently being extracted from larval delta smelt of known age which were hatched in the laboratory in order to age-verify deposition of circuli (daily growth rings).

The artificial substrate/aquatic vegetation survey began April 9th and was completed June 1st. This survey, which was concentrated in the Cache Slough area, attempted to collect delta smelt eggs in the field in order to identify specific spawning habitat requirements (e.g., aquatic vegetation, surface vegetation, type of substrate, depth, flow, etc.). No delta smelt eggs were collected. The procedures used have been evaluated and are being modified for next year.

The weekly beach seine survey which was run in conjunction with the Interagency Ecological Study Program Salmon Fry Study began in December was completed in June. The data is currently being keypunched and will soon be analyzed.

After limited success at capturing and keeping adult delta smelt alive in the laboratory, a modified purse seine capture technique proved to be quite successful. A total of 488 smelt were captured in this manner with a 48 hour survival rate of greater than 64%. Most of these smelt were captured in the Cache Slough area of the Estuary and were found in shallow areas where tidal flows were moderate. A total of 107 additional delta smelt were collected from the Skinner Fish Protection Facility with a survival rate of 53%. Two culture sites were designed specifically to culture delta smelt, one at U.C. Davis and one at the now closed Central Valley Hatchery. Both culture sites reported successful delta smelt spawning and hatching in captivity. Over 7000 eggs were produced with a wide range of viability (0-84%) and hatching success ranged from 0-90%. Larvae survived up to 36 days. Laboratory observations suggest that delta smelt are broadcast spawners, spawning occurs either at dusk or in the evening, hatching occurs between 8 and 14 days post spawn, feeding began at 4-5 days post hatch when 2/3 of the yolk is absorbed, and larvae will accept a wide range of both natural and artificial diets. We have already started collecting adults this fall for the second year of culture work and research on the reproductive cycle and gametogenesis of delta smelt. There are currently about 60 individuals alive and well at the culture site at U.C. Davis.

An agricultural diversion study was initiated in May. The purpose of the study is to determine the magnitude of larval fish losses to agricultural diversions in the Delta. Sampling has been conducted by the Department of Water Resources at five sites throughout the Delta. There are plans to expand the study next year.

Collection of adult delta smelt from the Estuary and wakasagi from Folsom Reservoir for electrophoretic analyses has been completed. The purpose of this analysis is to determine if electrophoresis can be used to distinguish delta smelt from the closely related wakasagi.

So far as mentioned above, results from this year's townet survey have not been encouraging. They suggest that 1992 production of delta smelt has not increased significantly and has remained consistently low since 1987. The fall midwater trawl survey on the other hand has shown an increase in the past couple of years with a large increase in 1991, although the 1992 index will once again be at a low level. It is thought that the increase in 1991 may be due to greater survival of young delta smelt from the time of the townet survey in the June and July to September through December when the midwater trawl survey is done. Two possible explanations for this increase are that both State and Federal exports in the summer of 1991 were at their lowest level since 1976, and agricultural diversions in the Delta were reduced due to the drought and State's water banking program.

FEB 2 4 1993

February 22, 1993

Douglas P. Wheeler
Secretary for Water Resources

Executive Director

Delta Smelt

The Commission, at its February 5, 1993 meeting in Long Beach, discussed the reconsideration of the petition to list the delta smelt (Hypomesus transpacificus) as a threatened species. The Commission encourages you to contact the Director of the U.S. Fish and Wildlife Service to provide a coordinated effort for protection of the delta smelt even though the delta smelt is not a State listed threatened or endangered species at this time. A copy of the Commission's motion for that action has already been transmitted to your office.

If you have any questions concerning this matter, please contact me.

COPY Original signed by Robert R. Treanor

Robert R. Treanor

cc: All Commissioners
Director Boyd Gibbons
Bay-Delta Division

**PETITION TO THE STATE OF CALIFORNIA FISH AND GAME COMMISSION**

**For action pursuant to Section 670.1 Title 14, California Code of Regulations (CCR), and Sections 2072, 2072.3, 2072.7, and 2073 of the Fish and Game Code, relating to the listing and delisting endangered and threatened species of plants and animals.**

I. SPECIES BEING PETITIONED

Common Name: delta smelt

Scientific Name: Hypomesus transpacificus

II. RECOMMENDED ACTION:
(Check appropriate categories)

_X_ List

___ as Endangered

_X_ as Threatened

___ Change Status

from ____

to ____

III. AUTHOR OF PETITION:

Name: Harold K. Chadwick

Address: California Department of Fish and Game
Bay-Delta and Special Water Projects Division
4001 North Wilson Way
Stockton, CA 95205

Telephone Number: (209) 948-7800

**I hereby certify that, to the best of my knowledge, all statements made in this petition are true and complete.**

Signature: Harold K. Chadwick

Date: 3/15/93

# PETITION TO THE STATE OF CALIFORNIA FISH AND GAME COMMISSION

## SUPPORTING INFORMATION FOR

| delta smelt | *Hypomesus transpacificus* |
|---|---|
| Common Name | Scientific Name |

1. EXECUTIVE SUMMARY

The current status of the delta smelt population is poor. Information from seven independent data sets indicates that the Delta smelt population was consistently at or near historic low levels since at least the mid-1980s through 1990. Some hope of improvement was provided in 1991 by an increase in the midwater trawl index, which measures abundance in fall, and because of its extensive geographical coverage and long-term record, should be one of the best abundance measures. However, all other population measures remained low in 1991, and in 1992 the midwater trawl index again sunk to a very low level. The townet index which measures abundance in summer, and like the midwater trawl survey has extensive geographical coverage and a long-term base, also remained at a near record low in 1992. The other indices are probably less reliable because they do not adequately sample the entire range of the population, but they also provide no expectation of substantial improvement.

In order for a species to be listed, any one or a combination of the following factors must be considered (section 670.1, Title 14, California Code of Regulations): 1) present or threatened modification or destruction of its habitat, 2) overexploitation, 3) predation, 4) competition, 5) disease, or 6) other natural occurrences or human-related activities.

**1) Present or threatened modification or destruction of habitat**: The delta smelt historically was one of the most abundant fishes in the Estuary and ranged from Suisun Bay on the west through the Delta to Mossdale on the San Joaquin River and Sacramento on the Sacramento River. For the past several years there has been a constriction in its historical range with the major concentration in the lower Sacramento River from Collinsville to Rio Vista. The delta smelt is a pelagic fish which depends solely on pelagic zooplankton for its nutrition. Recent introductions of exotic microzooplankton and an Asian clam through the discharge of ship ballast water threaten the delta smelt's food chain.

**2) Overexploitation for commercial, recreational, scientific or educational purposes**: There has never been a commercial fishery for delta smelt although they may be a small by-catch of the commercial shrimp fishery which operates in the western Estuary, sometimes in Suisun Bay. Some scientific collecting is done but these activities do not measurably reduce the population. There are no educational or recreational uses of delta smelt.

**3) Predation**: There has not been an increase in the abundance of any potential predator that would account for the decline in delta smelt. In fact, striped bass, the most abundant predator of adult delta smelt, also has declined substantially.

**4) Competition**: Increased competition for food may be occurring due to population explosions of accidentally-introduced exotic organisms such as the Asian clam, Potamocorbula amurensis, in the late 1980s and the Chameleon goby, Tridentiger trigonocephalus, that occurred in 1990. Although the introductions of these species occurred after the decline of delta smelt, they may hinder recovery of the population.
**5) Disease**: After one year of intensive study on all aspects of the life history of delta smelt there has been no evidence that disease has played a role in the decline of this species or that it is inhibiting recovery of the species.
**6) Other natural occurrences or human-related activities**: All life stages of delta smelt are vulnerable to entrainment in water diversions of the Central Valley Project (CVP), State Water Project (SWP), Delta agriculture, the Pacific Gas and Electric Company's power generating stations, and other industries using water in the Estuary. Delta smelt are affected by diversions in two ways: A) direct entrainment of larvae, juveniles and adults; and B) altered flow patterns which move younger stages to suboptimum habitats. Inadequate outflows restrict delta smelt to the upper portion of the Estuary by reducing the western transport of larvae and increasing salinities in Suisun Bay. The possibility of genetic dilution of the delta smelt by the closely-related wakasagi (Hypomesus nipponensis) has increased due to the immigration of wakasagi from central valley reservoirs to the Estuary.

The most meaningful near term actions that could be implemented tc restore the delta smelt population probably consist of restricting water exports and increasing Delta outflows.

## 2. SPECIES DESCRIPTION, BIOLOGY, AND ECOLOGY

**Description:**

The delta smelt, Hypomesus transpacificus, is a small euryhaline fish which reaches adult sizes of about 55-70 mm standard length (Moyle 1976) although some may reach lengths near 130 mm (Stevens, *et al.* 1990). It is translucent with a silvery, steel-blue streak along its sides. Other related smelt species found in the Sacramento-San Joaquin Estuary include longfin smelt, Spirinchus thaleichthys, and now the wakasagi, Hypomesus nipponensis (Moyle 1976; California Department of Fish and Game (CDFG), unpublished data). More marine smelt species historically observed in the Estuary include: whitebait smelt, Allosmerus elongatus, surf smelt, Hypomesus pretiosus, and night smelt, Spirinchus starksi (Wang 1986). None of the marine species occur in the areas of the estuary where delta smelt are common.

Delta smelt can be identified from other osmerids 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 descriptive information can be found in Moyle (1976) with larval descriptive information in Wang (1986; 1991).

Although other smelt species are highly prized for their flavor, Delta smelt have no sport or commercial value (Wang 1986). They do, like some other smelts, have a distinct odor of cucumbers (Moyle 1976; Wang 1986).

**Taxonomy:**

Delta smelt were at one time thought to be a widely distributed population of the pond smelt, Hypomesus olidus. Distribution is said to have ranged from as far south as San Francisco on the North American side of the Pacific, as far south as Japan on the Asiatic side of the Pacific (Wales 1962), and into the Arctic Ocean in the north (McAllister, *et al.* 1979). In 1961, Hamada separated the pond smelt into two separate species; H. olidus was used for the present day H. transpacificus, and a new name, H. sakhalinus was designated for the Asiatic species (presumably named after the Island of Sakhalin off the coast of Siberia in the Sea of Okhotsk). McAllister (1963) determined that H. olidus was not present in California waters and described the two fish as subspecies, H. transpacificus transpacificus, the delta smelt, and the H. transpacificus nipponensis, the wakasagi. H. olidus was retained for the pond smelt which ranges from Alaska to Japan in the northern Pacific (McAllister, *et al.* 1979). The two subspecies have since been split into two distinct species H. transpacificus and H. nipponensis (Moyle 1986) with the common names delta smelt and wakasagi (Committee on Names of Fishes 1990). Currently, electrophoretic analyses are underway to genetically evaluate the two species and to determine if genetic dilution through interbreeding is possible.

**Distribution:**

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 usually inhabit salinity ranges of less than 2‰ (parts per thousand). They are rarely found at salinities greater than 10‰ (Moyle 1976). Much of the year the majority are found in the entrapment zone where salt and freshwater meet (Arthur and Ball, 1979). They tend to school near the surface or in shoal areas (Radtke 1966; Moyle 1976; Moyle, *et al.* 1992; CDFG unpublished data). Delta smelt move to freshwater to spawn in the spring (Radtke 1966; Moyle 1976).

In 1959, when the delta smelt and wakasagi were considered to be a single species (H. olidus), CDFG introduced wakasagi into several freshwater reservoirs in the state to supply forage for trout (Wales 1962). H. nipponensis was used because H. transpacificus was difficult to collect (Wales 1962). The six original reservoirs in which wakasagi were planted include: Dodge Reservoir, Lassen County; Dwinnell Reservoir (also known 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). The original plan was for "experimental introduction" into these six reservoirs and if they became established they could be transferred elsewhere. If the fish were determined to be undesirable, they were to have been chemically treated (Wales 1962). Currently, known "escape" populations occur in Oroville Reservoir, Folsom Reservoir, and the American River below Lake Natomas.

**Age and Growth:**

Delta smelt are fast growing and shortlived (Moyle 1976), and until recently, little was known about their early development with most of the information being derived from other closely related species such as wakasagi (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 50-70mm (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 early spring (Radtke, 1966) although a few survive to a second year (Moyle 1976; Stevens, *et al.* 1990; CDFG unpublished data). Recent data suggest that normal gonadal development can occur in second year fish (Randy Mager, University of California, pers. comm.). Delta smelt can grow to lengths near 130 mm (FL) (Stevens, *et al.* 1990).

**Diet:**

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 (in 1980, 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 samples, Pseudodiaptomus forbesi, an exotic copepod first observed in 1987, was the dominant prey item (Stevens, *et al.* 1990; Moyle, *et al.* 1992). Other prey items observed in gut samples include: Sinocalanus doerii (Moyle, *et al.* 1992), the amphipod, Corophium sp., and the cladocerans Bosmina sp. and Daphnia sp. (Stevens, *et al.* 1990).

**Reproduction:**

Spawning may occur from late winter to early summer. Moyle (1976) found that ripe females can be collected 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 that different individuals mature at different times of the year to ensure better chances of survival. Recent histological analyses, however, do not support the fractional spawning theory because all of the eggs develop synchronously (Serge Doroshov, University of California, pers. comm.) There is also evidence that nearly complete spawning failure might occur (Erkkila, *et al.* 1950).

Delta smelt spawn in freshwater (Moyle, *et al.* 1992) or in slightly brackish water in or above the entrapment zone (Wang 1991). Possible spawning locations are reported to include dead-end sloughs (Radtke 1966), close to inshore 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, 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 55-70 mm and fecundity ranges from 1247 to 2590 eggs for females 59 to 70 mm (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). Hatching occurs in 12-14 days based on information from wakasagi (H. nipponensis)(Wales 1962). Delta smelt hatched in 9-14 days at temperatures ranging 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, University of California, pers. comm.).

After hatching, the larvae float to the surface and drift with the currents downstream to the entrapment zone (Stevens, *et al.* 1990; Moyle, *et al.* 1992) which in most springs is in Suisun Bay or to other areas of the Estuary depending on flow conditions (e.g., outflow, exports, Delta cross-channel open, etc.). In the entrapment zone, the mixing effect allows the larvae to remain instead of being swept into salt water (Stevens, *et al.* 1990). This zone also traps large numbers of zooplankton on which they are able to feed (Orsi and Knutson 1979; Arthur and Ball 1979), and its location is important to the young of many fish species, hence the term "nursery area" (Stevens, *et al.* 1985; Appendix A-3). 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). Wang hypothesized that delta smelt larvae position themselves at specific locations within the water column as evidenced by the gas bladder which does not develop until the larvae is approximately 16-18 mm (TL). In comparison, the gas bladder in longfin smelt begins development at 5-6 mm (TL) (Wang 1991). Larval growth is rapid and juveniles may reach lengths of 40-50 mm (FL) by August (Erkkila, *et al.* 1950).

## 3. HABITAT REQUIREMENTS

Delta smelt usually inhabit salinity ranges of less than 2‰ (parts per thousand); they are rarely found at salinities greater than 10‰ (Moyle 1976).

Summer townet and fall midwater trawl surveys conducted by the Department indicate that delta smelt are most frequently caught where specific conductance ranges from 500 to 8000 microsiemens (approximately 0.28‰ to 4.59‰ salinity)(Tables 1 and 2). Delta outflow affects geographical distribution of delta smelt and probably their survival. As flows increase and saltwater is repelled, more of the population occurs in Suisun and San Pablo bays and less occurs in the Delta (Figures 1 and 2). There is reason to believe that delta smelt benefit from being transported to Suisun Bay. Historically, when delta smelt were more abundant a large proportion of the population was found in Suisun Bay and the surrounding areas. Much of the year the majority are found in (or just above) the entrapment zone where salt and freshwater meet (Arthur and Ball 1979). They tend to school near the surface or in shoal areas (Radtke 1966; Moyle 1976; Moyle, *et al.* 1992; CDFG unpublished data).

Delta smelt apparently require freshwater to spawn as they disperse into freshwater in the spring (Radtke 1966; Moyle 1976). They often are found in shallow spawning areas which have adequate flows presumably to aerate the eggs and substrates that will allow proper egg attachment (Wang 1986; 1991).

## 4. DISTRIBUTION

Delta smelt are found only in the Sacramento-San Joaquin Estuary. 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. 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. Surveys by the Delta Outflow/San Francisco Bay Study, which has sampled fish in the Estuary from South Bay and the Golden Gate Bridge to the western Delta since 1980, indicate that delta smelt thin out in San Pablo Bay and are virtually non-existent in San Francisco Bay (Table 3). And, as mentioned before, delta smelt usually inhabit salinity ranges of less than 2‰ (parts per thousand) although they are rarely found at salinities greater than 10‰.

Delta smelt live principally in the upper portion of the water column. For example, during a 1963-1964 survey of Delta fish populations, a 10 foot by 10 foot surface trawl captured 1960 delta smelt, while a 15 foot by 5 foot otter trawl only captured 461 delta smelt. These results were obtained despite the otter trawl constituting 60 percent of the survey effort of about 1800 tows.

## 5. ABUNDANCE

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 abundance index for 1992 is 2.4 (Figure 3). The summer townet index is one of the two best measures of delta smelt abundance and represents the longest historical record of smelt abundance since 1959. It indicates that the smelt population has varied dramatically from year to year but declined to low values in the early 1980s and has remained at a severely low level 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.

The fall midwater trawl index, which surveys the entire range of delta smelt distribution, is the other best measure of smelt abundance. The annual fall midwater trawl abundance index for 1992 is 156.8 (Figure 4). This is down from 689 for 1991 which was an aberration of low abundance since 1981. The 1992 index represents an 80% decline from the 1967 to 1982 average. In comparing net efficiencies between delta smelt and striped bass, it appears that the standard midwater trawl was about 2.6 times more effective at capturing striped bass than delta smelt in August, 1991 and about 1.8 times more effective in January, 1992. Thus, losses of small fish through the mesh of the standard midwater trawl would have affected actual abundance estimates presented in the 1990 status report for delta smelt based on comparisons of delta smelt catches with striped bass catches and striped bass abundance estimates (Stevens, et.al., 1990). It must be emphasized, however, that these results do not affect the interpretation of temporal trends observed in the fall midwater trawl abundance index. These results only indicate that the proportion of the delta smelt population caught by the midwater trawl is less than the proportion of the striped bass population caught and that the magnitude of both past and present abundance is somewhat greater than suggested by the extrapolations from catches in our standard midwater trawl.

Five other independent measures indicate that the delta smelt population remains at a low level (Figure 5). The Delta Outflow-Bay Study survey is comprehensive in that it samples monthly throughout the year. However, its main deficiency in measuring delta smelt abundance 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. 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 located in one location, and thus the indices are affected by changes in delta smelt distribution. 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 20-30 mm have also been taken. Fish salvage operations at the State Water Project and the Central Valley Project 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. Central Valley Project salvage operations generally reflect the same patterns as shown for State Water Project Salvage numbers in Figure 5. For a discussion of SWP and CVP salvage of delta smelt see Stevens, *et al.* (1990). The Suisun Marsh Survey uses otter trawls to sample fish populations in Suisun Marsh sloughs since 1979. But, because the UC Davis 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. However, all the data sources listed above show a similar pattern of a decline in the early 1980s with no apparent recovery of the population.

For the past eight years, the remaining delta smelt population has been concentrated in the lower Sacramento River. Historically, when the delta smelt population was more abundant, the smelt population was widespread from Suisun Bay and Montezuma Slough through the Delta (Figure 6). The reason for this concentration is that downstream habitat in Suisun Bay has been unsuitable for delta smelt due to increased salinities resulting from reduced outflows caused by increased water diversions and the drought, and delta smelt are scarce in the San Joaquin portion of the Delta, perhaps due to losses in water diversions.

Although the relationship between delta smelt abundance and outflow is weak, there is a strong relationship between delta smelt distribution and outflow. We believe that this concentration of the population in the lower Sacramento River makes the population particularly vulnerable to potential perturbations in the environment such as a toxic event.

Looking at the decline by geographical areas (Figures 7 and 8), it is apparent that the delta smelt decline began earlier in the south and east Delta than in the rest of the Estuary. An earlier decline in these areas is consistent with the decline measured by the fish salvage data from the water project diversions in the south Delta.

Through regression analyses Stevens, *et al.* (1990) evaluated the impacts of delta outflows, water diversions, food abundance, reverse flows, water temperature, and water transparency on population abundance. This approach did not give a good explanation of the population decline. However, this does not mean that these factors are not important. It is possible that one or more factors were not measured with sufficient reliability for us to detect effects, or that some untested factor acts in concert with the measured factors to drive the smelt population. The role of egg production which can be evaluated by use of a spawner-recruit relationship was also examined by Stevens, *et al.* (1990) and considered weak. Recent re-examinations of the relationship between spawning stock abundance and the number of recruits the following year have found that spawning stock size may be more important than previously thought although the strength of the relationship still suggests that environmental factors other than stock size are limiting delta smelt abundance.

## 6. NATURE AND DEGREE OF THREAT

As indicated in the Department of Fish and Game's 1990 status report, the Department has been unable to pinpoint the cause(s) of the Delta smelt population decline. However, inability to pinpoint the cause of decline cannot be considered evidence against listing a species as threatened or endangered.

Subsequent to preparation of that status report, the Department has participated in three major efforts with agency and "outside" experts, which have attempted to define the causes, design appropriate studies and potential solutions to the delta smelt decline.

1) The Delta Smelt Study Program, mandated by the California Fish and Game Commission on August 30, 1990, relied on this type of external input for the study design which included input from representatives of the Department of Fish and Game (CDFG), Department of Water Resources (DWR), U.S. Bureau of Reclamation (USBR), U.S. Fish and Wildlife Service (USFWS), State Water Resources Control Board, outside contractors (including the primary biological consultant to the State Water Contractors), and researchers from the University of California at Davis (UC Davis). The purpose of the study program is to monitor and investigate factors potentially affecting delta smelt population levels in order to insure their long-term survival and to address the management and recovery objectives set forth by the Fish and Game Commission.

2) As part of the consideration for Federal listing, the Delta Smelt Working Group was convened by the US Fish and Wildlife Service in October 1991 to identify possible causes of the decline and to propose possible management measures. The working group consisted of fishery experts from a wide range of agencies and universities. The working group produced a list of 12 recommendations that if implemented would preclude listing of the species.

3) At the request of the Governor of the State of California, the Resources Agency assembled a Delta and Related System Management Program which included a Delta Smelt and Native Fishes Subcommittee. The goal of this program was to identify problems and design specific near-term and longer term management actions which can be taken to improve habitat conditions and hopefully populations of important fish and wildlife in the Delta. The program focused on delta smelt and declining native fish, winter-run salmon, striped bass, and wetland/terrestrial wildlife resources in decline with the expectation that adequately accommodating the needs of these stressed species would strengthen the biological integrity of the entire ecosystem.

Based on the discussions and conclusions of these expert groups, it is believed that the following factors are those most likely inhibiting recovery of the population:

- **Direct entrainment of larval, juvenile, and adult delta smelt.** All life stages of delta smelt are vulnerable to entrainment in water diversions of the Central Valley Project (CVP), State Water Project (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 their 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 of the water project diversions, their impact on Delta flow patterns, and the tendency for young delta smelt to be transported and dispersed by river and estuarine currents. At high export rates, water is drawn up the San Joaquin River reversing its normal flow pattern. 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. There has also been a trend of increasing reverse flows in the San Joaquin River, especially during the spawning months (Moyle, *et al.* 1992).

Entrainment of delta smelt is greatest during spring and summer (Figure 9). This pattern reflects the late winter-spring spawning season and growth and mortality of young fish. During April and May, abundance of young smelt at the SWP and CVP diversions actually is greater than shown because the smelt are so small that they pass through the screens and are not salvaged for the first month or two of life. Also, smaller smelt are not readily identifiable as smelt by the technicians responsible for sampling of salvaged fish.

The intra-year salvage pattern in 1977-1978 was a notable exception to the usual pattern. Through much of 1977, water exports were reduced, due to a major drought, and while a delta smelt peak occurred in July, the greatest entrainment and salvage of the 1977 year class occurred from December 1977 through February 1978 when water exports increased after the drought broke (Table 5). In fact, the salvage of 134,000 delta smelt at the SWP in January 1978 almost equaled the total for all of 1977 (146,000) and exceeds the annual totals for all subsequent years.

Actual losses of delta smelt salvaged at the SWP and CVP cannot be directly calculated with certainty because no information is available on pre-screening losses (predation rates) in Clifton Court Forebay and efficiencies of the diversion louver screens. Survival of delta smelt which have been salvaged may be 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). Based on other fish species of similar size (salmon, striped bass, and American shad) losses could approximate 6 times the salvage rate or higher as the screen efficincy decreases for smaller fish. Therefore, the annual salvage estimate of 15,966 delta smelt at the State facility in 1991 may expand to an annual loss of 189,228 delta smelt. In January 1993, 3087 delta smelt were salvaged at the SWP intakes yielding a calculated loss on the order of 18,000 pre-spawning adults.

- **Delta outflows insufficient 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 mixing zone of the Estuary where outflowing freshwater meets incoming tidal water, 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.

- **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 became 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 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, 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 has been shown to be less vulnerable prey than the native Eurytemora. Increased competition for food may also be occurring due to a population explosion of the Chameleon goby that occurred in 1990 and may be another product of ballast discharge.

- **Genetic dilution 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. Through illegal transport by humans and water transport, the wakasagi has become common in Oroville and Folsom reservoirs, and this past spring was collected from the American River just above the Delta. Hybridization between delta smelt and wakasagi is possible if they should coexist. Thus, there is potential for dilution of the delta smelt gene pool and elimination of its existence as a separate species.

- **Flows out of optimal range.**
  The years of the smelt decline are not only characterized by drought and high exports leading to flows too low to transport young fish to Suisun Bay, but also by unusually wet periods with exceptionally high outflows. These 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.

- **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 delta smelt larvae to look for visual evidence of toxicity is planned. Histological analyses involve microscopic examination of retina attachment, digestive tract tissue development, and liver condition which provide good measures of the extent to which larval fish have been exposed to toxicity. Morphometric analyses consist of measuring various

ratios involving fish length and body depth at various locations along the length of the fish. Body shape is then used to determine health condition. Although the effects of these compounds on fishes are poorly understood, some of these compounds are found in the Estuary at levels that may inhibit their reproduction (Jung, *et al.* 1984) or are sufficient to trigger health warnings regarding human consumption in other fish species. Although there is no direct evidence of delta smelt suffering direct mortality or stress from toxic substances, this factor obviously cannot be eliminated as a potential agent adversely affecting the delta smelt population.

- **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. 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 abundance has been rather erratic. In essence, there has not been a consistent increase in the abundance of any potential predator or competitor that could account for the decline in delta smelt. The recent appearance and explosion of the chameleon goby, a potential larval predator, potentially could inhibit recovery of the delta smelt.

The possibility that the effort to enhance the Sacramento-San Joaquin striped bass population through the stocking of hatchery-reared fish could cause excessive predation on delta smelt has recently been suggested as contributing to the decline in delta smelt. Striped bass are highly pisciverous (eat other fish); however, comprehensive striped bass food habit studies in the 1960's indicated that, while delta smelt were occasionally consumed, they were not a significant prey of striped bass even in the 1960's when delta smelt and striped bass were both much more abundant. That and the small size of the present bass population, including stocked bass, indicate that striped bass have not been a major factor. However, the Director of the Department of Fish and Game discontinued the stocking of mitigation striped bass into the Estuary in 1992. Reinitiation of the stocking program in future years is under evaluation.

## 7. CURRENT MANAGEMENT

There are currently no management measures in place specifically for delta smelt in the Estuary.

## 8. RECOMMENDED MANAGEMENT/RECOVERY MEASURES

The Department of Fish and Game considers the following actions would benefit delta smelt:

- **State Water Resources Control Board Decision 1630 (original draft dated December, 1992).** Several standards proposed in the State Water Resources Control Board's (SWRCB) draft Decision 1630 should somewhat reduce entrainment losses of delta smelt to the Federal and State water projects. These standards include provisions for:

  1. No reverse flows in the lower San Joaquin River from February 1 through June 30.

  2. Reverse flows limited to -1,000 cfs from July 1 through July 31 and to -2,000 cfs from August 1 through January 31. A SWRCB proposed (March 1993) revision to allow -3000 cfs from August through January would reduce this benefit.

  3. Springtime pulse flows to benefit striped bass and salmon in the Sacramento and San Joaquin Rivers. A SWRCB proposed (March 1993) revision to reduce pulse flows in dry and critical years would reduce this benefit.

  4. Limits of CVP/SWP exports in April.

  Because no strong relationship between delta smelt abundance and outflow or exports has been found, there is no guarantee that draft Decision 1630 will enhance the delta smelt population, particularly if causes of the decline are multiple and synergistic.

  One of the long-term goals of draft Decision 1630 (page 70) is to: "Have self-sustaining fishery populations in the Bay/Delta Estuary at the highest levels that can reasonably be achieved". It goes on to state: "Habitat protections will be necessary to achieve this goal". In essence, this Decision will substantially reduce the risk of further decline, but is not likely to cause the delta smelt population to recover.

- **Screen, restrict, or consolidate the agricultural diversions in the Delta**

**when larvae are present.** Losses to local agricultural diversions are a potential drain on the delta smelt population. Studies were implemented by the Department of Water Resources in 1992 to assess the extent to which Delta smelt are lost to these diversions. Results are not yet available.

- **Screen the Contra Costa Water District's water diversion at Rock Slough.** The Central Valley Project Improvement Act (PL 102-575) provides for this diversion to be screened. Meanwhile, the Department of Fish and Game is advocating that it be screened as a condition for proceeding with the Los Vaqueros Project.

- **Reduce diversion to the North Bay Aqueduct during Delta smelt spawning season.** Based on sampling during 1992, the vicinity of the North Bay Aqueduct intake appears to be important for delta smelt spawning.

- **Restrict development of any industry that requires large amounts of water diverted from the Estuary.**

- **Move major water project diversions from the southern Delta to the Sacramento River above the Delta.** Such action would essentially eliminate entrainment losses of young delta smelt by the SWP/CVP. This will be an alternative considered in the comprehensive water planning effort initiated by the Governor.

- **Increase Delta outflows.** In most years, increased spring and summer outflows would transport more young delta smelt to Suisun Bay. This would increase optimum habitat for spawning and rearing and reduce losses to water diversions in the Delta. Increased freshwater in Suisun Bay also would likely reduce the population of the Asian clam which has become so abundant during the recent drought. Although State Water Resources Control Board draft Decision 1630 does not specifically set outflow standards, export rate and reverse flow limitations should provide increased outflow during spring and early summer in all but wet and some above normal water years. However, these increases will be offset by increased exports at other times.

- **Restrict ship ballast water discharges in the Estuary to eliminate or reduce introductions of potentially harmful exotic species.** Assembly Bill 3207 which was enacted into law effective January 1, 1993 requires the Department of Fish and Game to adopt the International Maritime Organization's "Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ship's Ballast Water and Sediment Discharges", and to develop a ballast water control report form to monitor compliance with these guidelines. The guidelines encourage, but do not mandate, ballast exchange at sea to reduce the risk of introducing unwanted freshwater and estuarine

**organisms.** Monitoring compliance is intended to provide information on the proportion of ships which actually exchange ballast at sea, thus, providing a basis for judging whether additional regulatory action is warranted.

- **Research on creating a refuge population and refining hatchery and production techniques.** Such research was implemented in 1992 through contracts between the Department of Water Resources and aquaculture experts at the University of California and a private consulting company. Delta smelt were successfully spawned by these experts, but production was limited by the smelt's low fecundity and excessive larval mortality. Further work is planned for 1993.

## 9. INFORMATION SOURCES


Arthur, J. F. and M.D. Ball. 1979. Factors influencing the entrapment of suspended material in the San Francisco Bay-Delta Estuary. Pages 143-174 in T.J. Conomos, ed. San Francisco Bay, the urbanized Estuary. Pacific Division, American Association for the Advancement of Science, San Francisco.

Committee on Names of Fishes. 1990. Common and scientific names of fishes from the United States and Canada. Fifth ed. American Fisheries Society Special Publication 20. Bethesda, MD.

Doroshov, Serge, University of California at Davis. Primary Investigator which has a contract (1992, 1993) with the Department of Water Resources to culture delta smelt in the laboratory and to study gametogenisis and reproductive development of delta smelt.

Erkkila, L.F., J.W. Moffet, O.B. Cope, B.R. Smith, and R.S. Nelson. 1950. Sacramento-San Joaquin Delta fishery resources: Effects of Tracy Pumping Plant and the Delta Cross channel. U.S. Fish and Wildlife Service Special Scientific Report 56:1-109.

Fry, D.H. 1973. Anadromous fishes of California. California Department of Fish and Game. 112pp.

Jung, M., J.A. Whipple, and M. Moser. 1984. Summary report of the Cooperative Striped Bass Study. Institute for Aquatic Resources. Santa Cruz, California. 117p.

Mager, Randy, University of California at Davis. Researcher under P.I. Serge Doroshov which has a contract (1992, 1993) with the Department of Water Resources to culture delta smelt in the laboratory and to study gametogenisis and reproductive development of delta smelt.

McAllister, D.E. 1963. A revision of the smelt family, Osmeridae. Bulletin National Museum of Canada. 191. 53pp.

McAllister, D.E., R. Boyle, and B. Parker. 1979. Pond Smelt. Page 121 in D.S. Lee, *et al.*,(eds.) Atlas of North American freshwater fishes. North Carolina Museum of Natural History, Raleigh, NC.

Moyle, P.B. 1976. Inland fishes of California. University of California Press, Berkeley. 405pp.

Moyle, P.B., R.A. Daniels, B. Herbold, and D.M. Baltz. 1986. Patterns in distribution and abundance of a noncoevolved assemblage of estuarine fishes in California. Fishery Bulletin. 84(1): 105-118.

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

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

Odenweller, D. 1990. Delta Fish Facilities Study. Chapter 8 in P.L. Herrgesell, (compiler), 1989 Annual Report, Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Sacramento, California.

Orsi, J.J. and A.C. Knutson, Jr. 1979. The role of mysid shrimp in the Sacramento-San Joaquin estuary and factors affecting their abundance and distribution. Pages 401-408 in T.J. Conomos, ed. San Francisco Bay, the urbanized Estuary. Pacific Division, American Association for the Advancement of Science, San Francisco.

Radtke, L.D. 1966. Distribution of smelt, juvenile sturgeon, and starry flounder in the Sacramento-San Joaquin Delta with observations on food of sturgeon. In J.L. Turner and D.W. Kelley (eds), *Ecological Studies of the Sacramento-San Joaquin Delta.* California Department of Fish and Game, Fish Bulletin 136:115-129.

Stevens, D.E. and L.W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin river system. North American Journal of Fisheries Management. 3:425-437.

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

Stevens, D.E., L.W. Miller, and B.C. Bolster. 1990. A status review of the delta smelt, (Hypomesus transpacificus) in California. California Department of Fish and Game. Candidate Status Report 90-2.

Wales, J.H. 1962. Introduction of pond smelt from Japan into California. California Fish and Game. 48(2):141-142.

Wang, J.C.S. 1986. Fishes of the Sacramento-San Joaquin Estuary and adjacent waters, California: A guide to the early life histories. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 9. Sacramento, California.

Wang, J.C.S. 1991. Early life stages and early life history of the Delta smelt, Hypomesus transpacificius, in the Sacramento-San Joaquin Estuary, with comparison of early life stages of the longfin smelt, Spirinchus thaleichthys. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary. Technical Report 28. 52pp.

Table 1. Delta Outflow/San Francisco Bay Study catch of delta smelt by month and area, 1980-1988. Number of sampling sites in parentheses. (Taken from Stevens, et.al., 1990.)

| rea | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| San Francisco Bay (16) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| an Pablo Bay (8) | 4 | 5 | 29 | 1 | 0 | 1 | 0 | 0 | 0 | 54 | 0 | 1 | 95 |
| Carquinez Strait & Western Suisun Bay (6) | 61 | 46 | 86 | 37 | 5 | 55 | 70 | 94 | 71 | 36 | 9 | 38 | 608 |
| Eastern Suisun Bay (3) | 18 | 24 | 15 | 10 | 5 | 8 | 16 | 37 | 54 | 68 | 40 | 12 | 307 |
| /estern Delta (2) | 30 | 13 | 15 | 5 | 2 | 20 | 12 | 23 | 55 | 12 | 33 | 32 | 252 |
| Total | 113 | 88 | 145 | 53 | 12 | 84 | 98 | 154 | 180 | 170 | 82 | 83 | 1262 |

**Table 2.** **Summer townet survey catch frequencies for delta smelt by specific conductance (EC) ranges, 1969-1988.** [1/]

| | Numbers of Smelt Per Catch | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| EC icrosiemens) | 0 | 1-4 | 5-9 | 10-14 | 15-19 | 20-49 | 50-99 | >100 | Total Samples | Number Catches >0 | Percent with smelt |
| No Data | 9 | 4 | 3 | 1 | 0 | 1 | 1 | 0 | 19 | 10 | 52.6 |
| 499 | 541 | 170 | 52 | 17 | 10 | 36 | 16 | 14 | 856 | 315 | 36.8 |
| 500-999 | 105 | 51 | 13 | 16 | 7 | 13 | 14 | 10 | 229 | 124 | 54.1 |
| 00-1999 | 38 | 31 | 15 | 10 | 8 | 17 | 9 | 10 | 138 | 100 | 72.4 |
| 00-3999 | 34 | 41 | 15 | 11 | 8 | 22 | 9 | 8 | 148 | 114 | 77.0 |
| 00-5999 | 31 | 30 | 11 | 6 | 4 | 6 | 8 | 8 | 104 | 73 | 70.0 |
| 00-7999 | 22 | 21 | 9 | 7 | 3 | 11 | 5 | 1 | 79 | 57 | 72.1 |
| >8000 | 338 | 96 | 32 | 14 | 7 | 17 | 14 | 3 | 521 | 183 | 35.1 |
| Total | 1118 | 444 | 150 | 82 | 47 | 123 | 76 | 54 | 2094 | 976 | 46.6 |

/ EC was not measured prior to 1969 even though the survey started in 1959.

**Table 3.** **Fall midwater trawl frequencies for delta smelt by specific conductance (EC) ranges, 1967-1988.**

Numbers of Smelt Per Catch

| microsiemens) | 0 | 1-4 | 5-9 | 10-14 | 15-19 | 20-49 | >50 | Total Samples | Number Catches >0 | Percent with smelt |
|---|---|---|---|---|---|---|---|---|---|---|
| Data | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 |
| 1-499 | 1756 | 604 | 103 | 30 | 16 | 27 | 4 | 2540 | 784 | 30.8 |
| )-999 | 311 | 137 | 35 | 21 | 7 | 12 | 5 | 528 | 217 | 41.1 |
| 000-1999 | 224 | 128 | 43 | 18 | 10 | 18 | 2 | 443 | 219 | 49.4 |
| 0-3999 | 269 | 141 | 44 | 30 | 9 | 14 | 5 | 512 | 243 | 47.4 |
| 0-5999 | 244 | 97 | 45 | 9 | 10 | 12 | 1 | 418 | 174 | 46.1 |
| 000-7999 | 202 | 67 | 23 | 10 | 5 | 9 | 1 | 317 | 115 | 36.3 |
| 000 | 4547 | 173 | 24 | 9 | 9 | 11 | 4 | 4777 | 230 | 4.8 |
| Total | 7562 | 1347 | 317 | 127 | 66 | 103 | 22 | 9544 | 1982 | 20.7 |

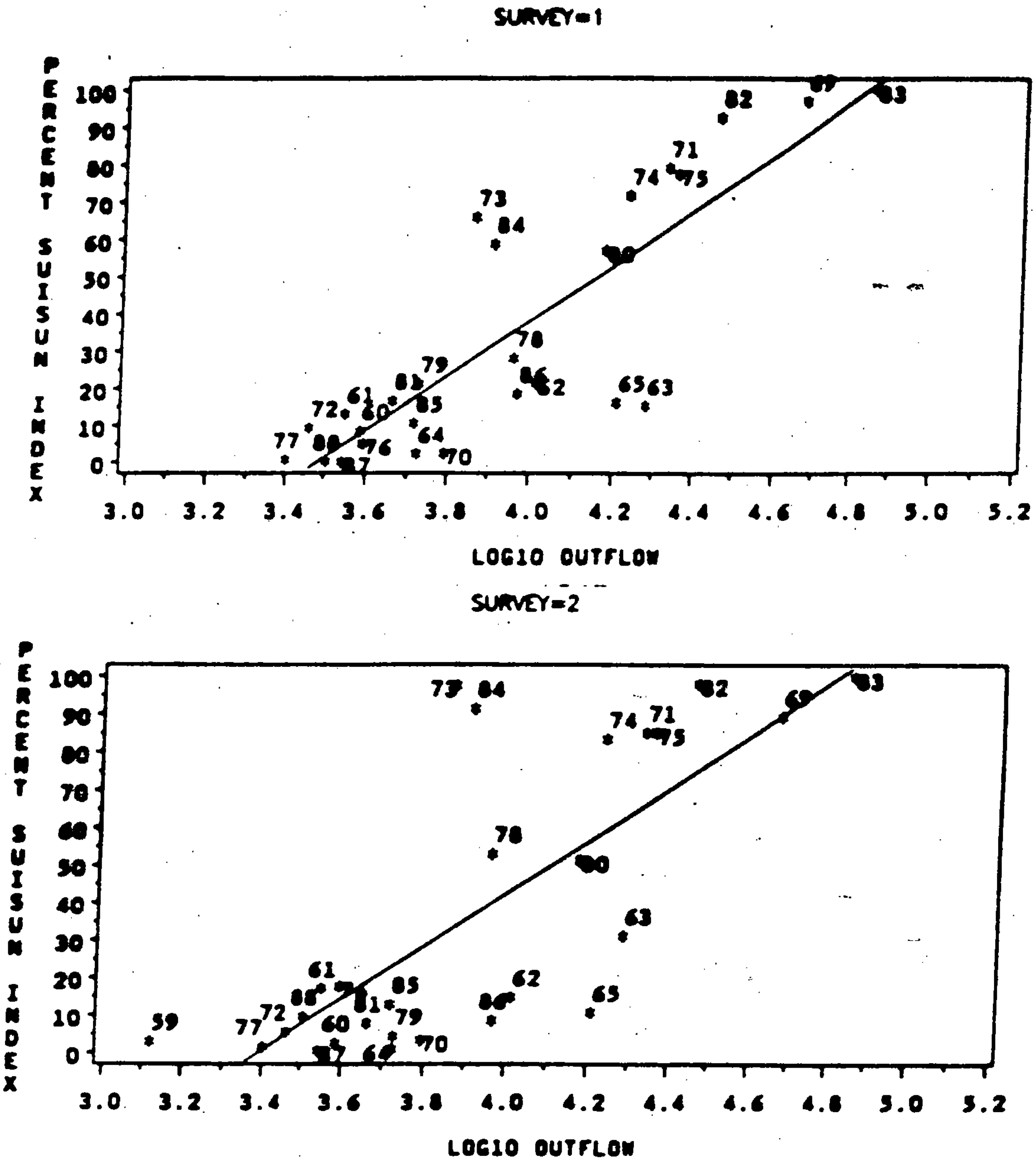



Figure 1. **Relationship between the portion of the delta smelt population occurring west of the Delta and the log delta outflow during the survey period. Data are from the summer townet survey. For arcsine transformed percentages, $R^2 = 0.74$ for survey 1 and $R^2 = 0.55$ for survey 2.**

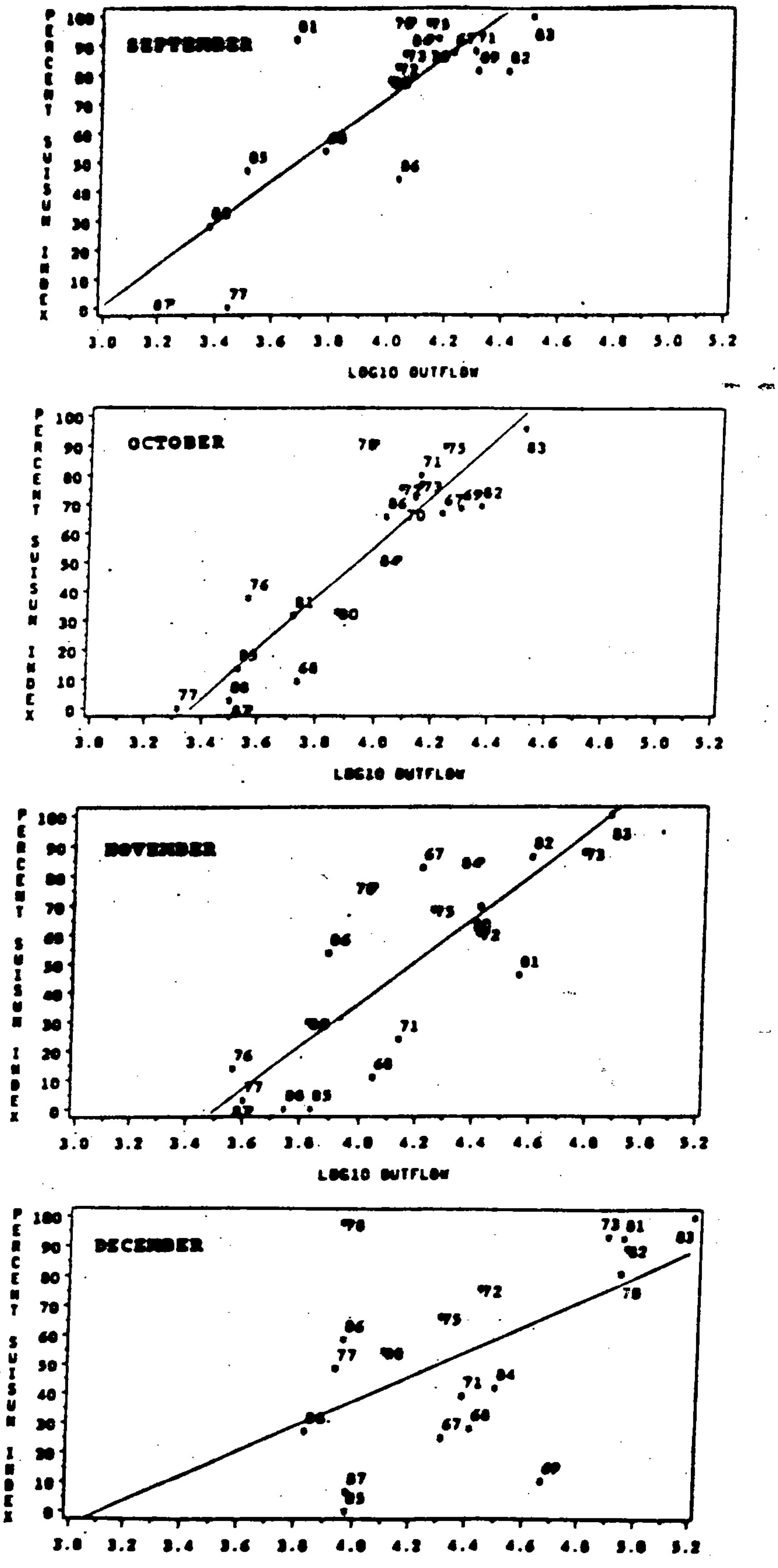



**Figure 2.** **Relationship between the portion of the delta smelt population occurring west of the Delta and log Delta outflow during the survey month. Data are for the fall midwater trawl survey. For arcsine transformed percentages, $R^2 = 0.640$ for September, 0.763 for October, 0.708 for November, and 0.336 for December.**

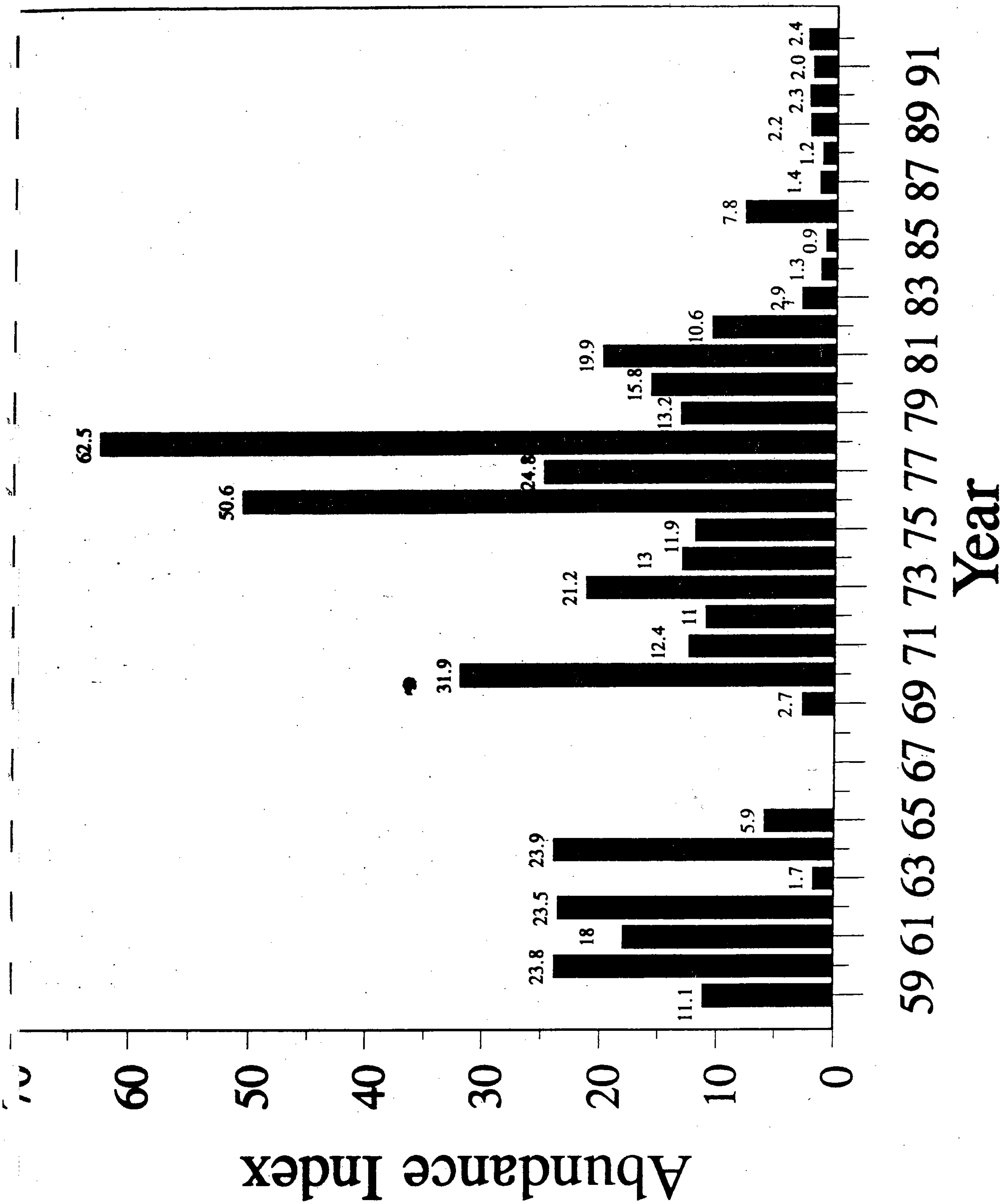



**Figure 3.** **Summer townet abundance index for delta smelt in the Sacramento-San Joaquin Estuary for 1959-1965, 1969-1991. Only surveys 1 and 2 were used.**

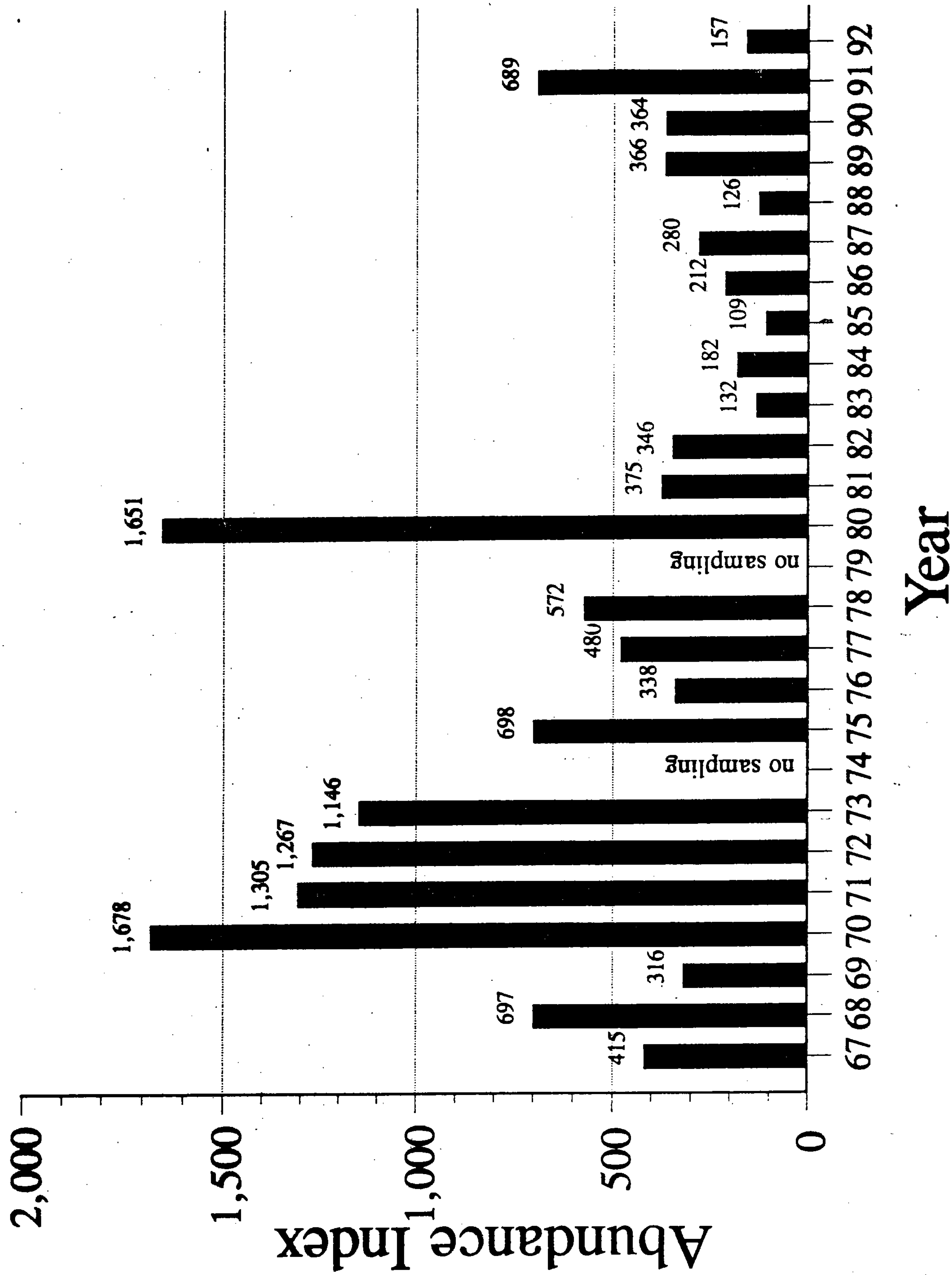



**Figure 4.** **Fall midwater trawl abundance index for delta smelt for the years 1967-1973, 1975-1978, 1980-1991 in the Sacramento-San Joaquin Estuary.**

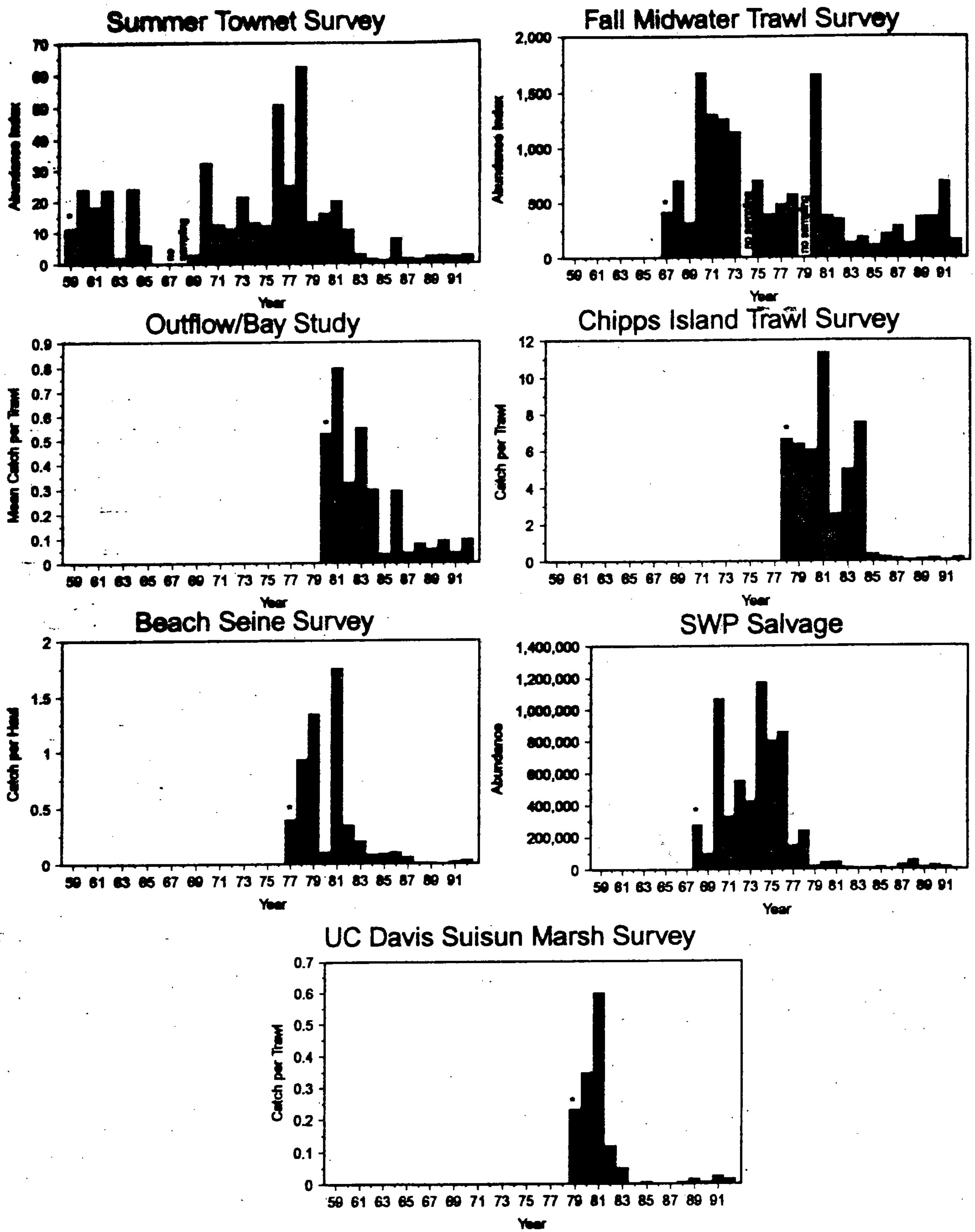



Figure 5. Trends in delta smelt as indexed by seven independent surveys (updated from Stevens, et.al., 1990, Figure 4). Asterisks represent the first year of sampling.

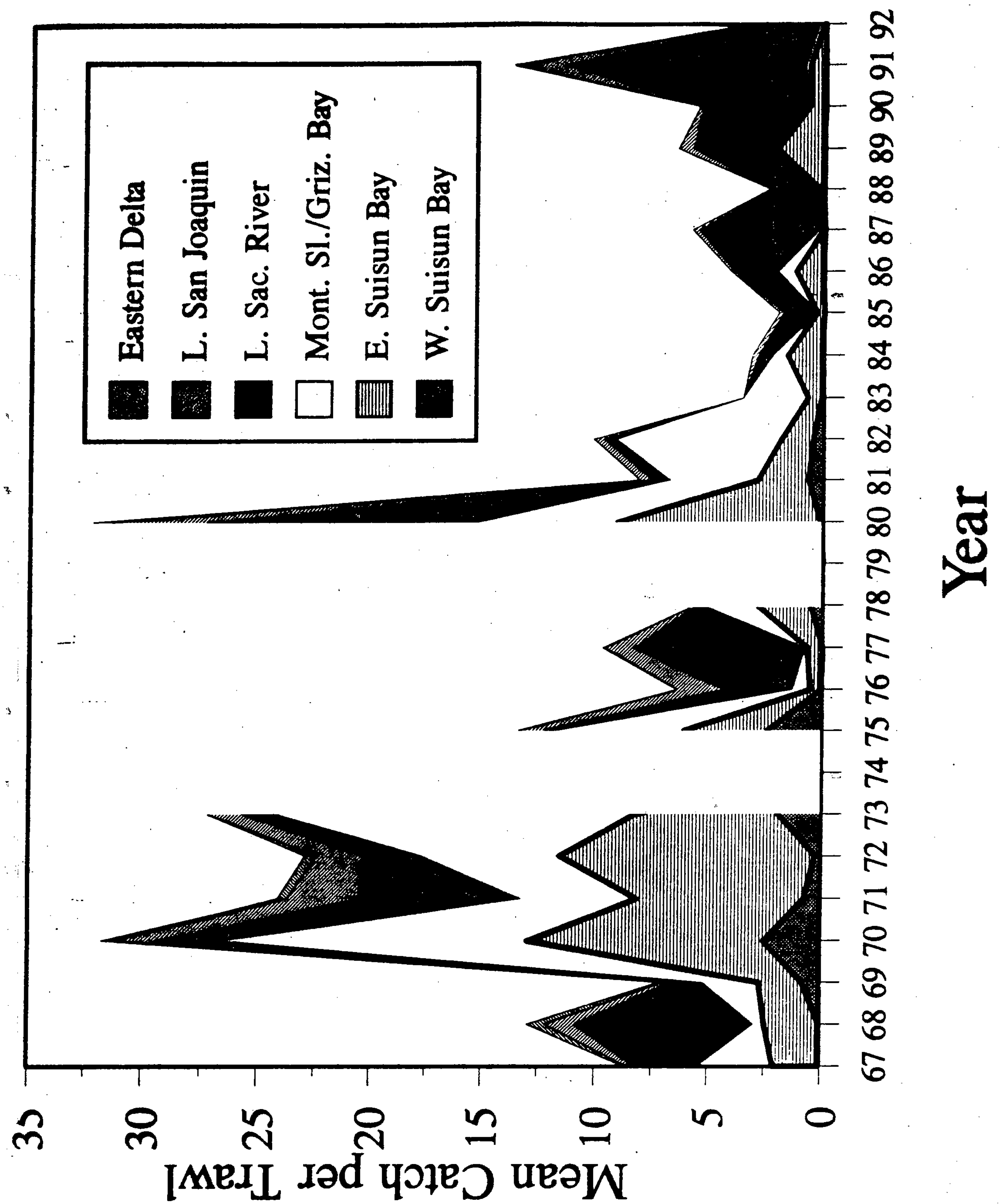



**Figure 6.** Mean catch per trawl from the fall midwater trawl survey for specific areas of the Sacramento-San Joaquin Estuary. Areas represent annual mean catch per trawl for specific areas in the Estuary.

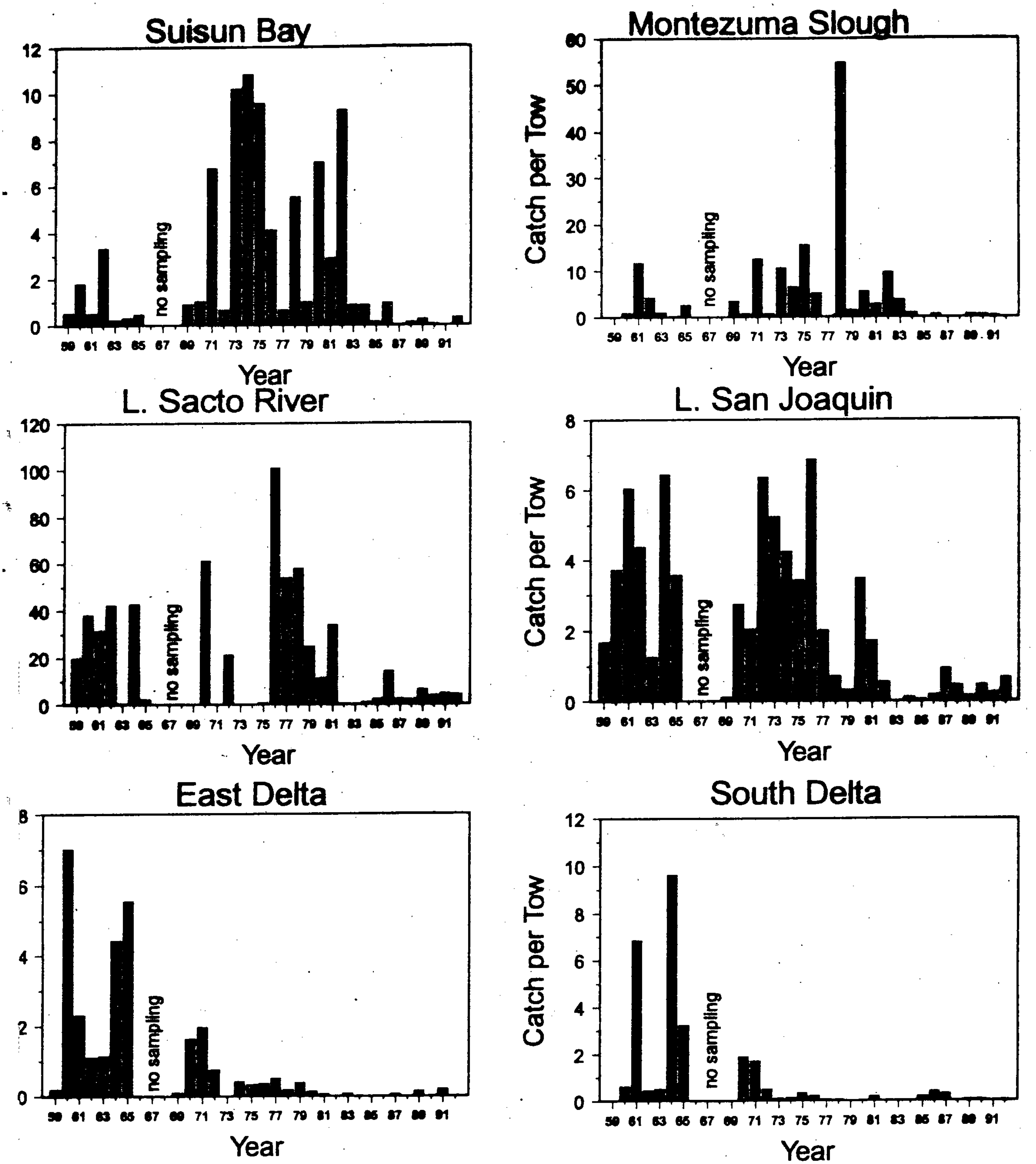



Figure 7. Abundance of delta smelt by area based on the summer townet survey. L. Sacramento is the Sacramento River between Collinsville and Rio Vista. L. San Joaquin is the San Joaquin River between Antioch and San Andreas shoal west of the Mokelumne River. **Note changes in scale.**

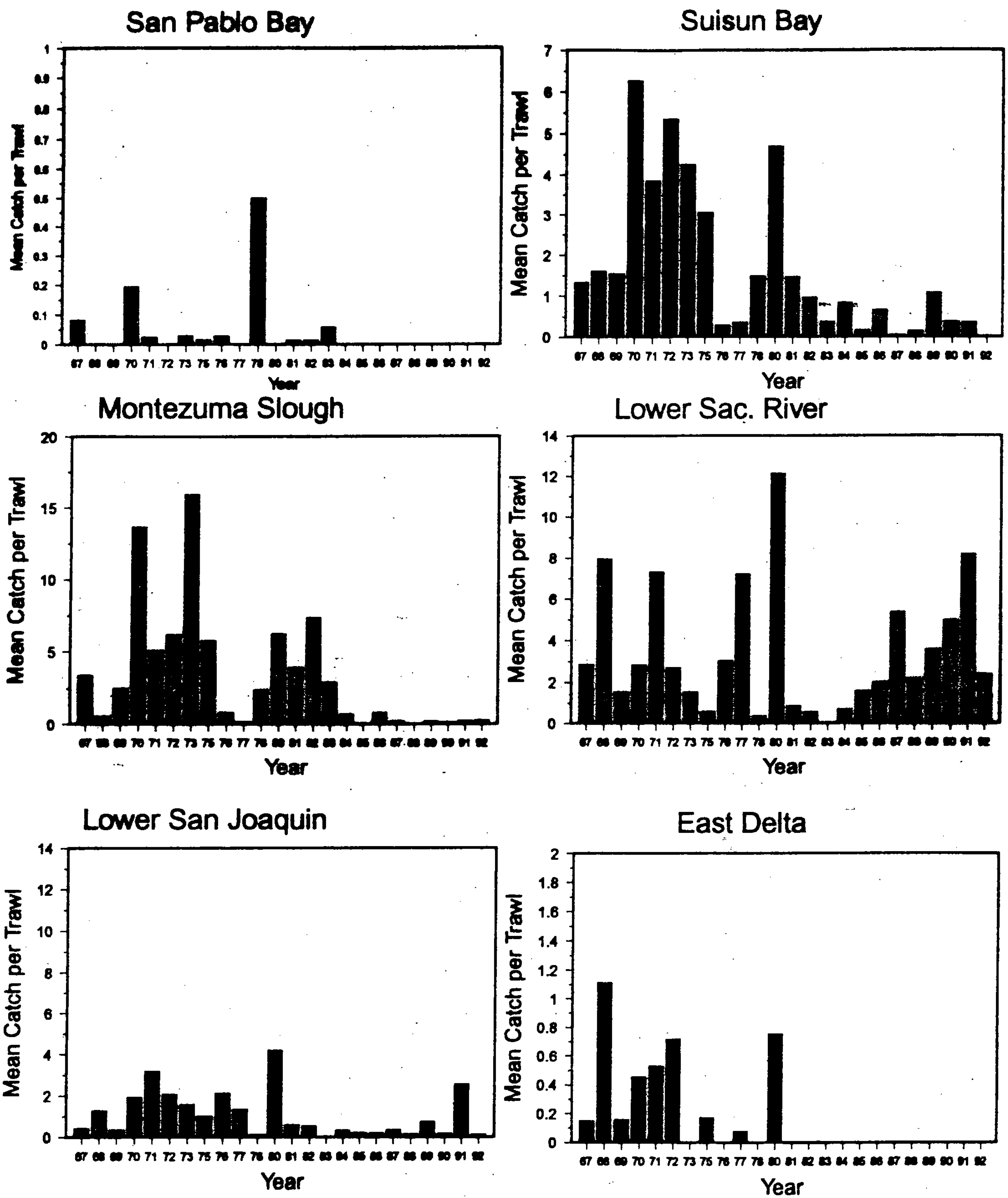



Figure 8. The catch-per-trawl of delta smelt in the midwater trawl survey by areas comparable to those used by the summer townet survey (Figure 7) except for the addition of San Pablo Bay and the South Delta which was not sampled after 1975.

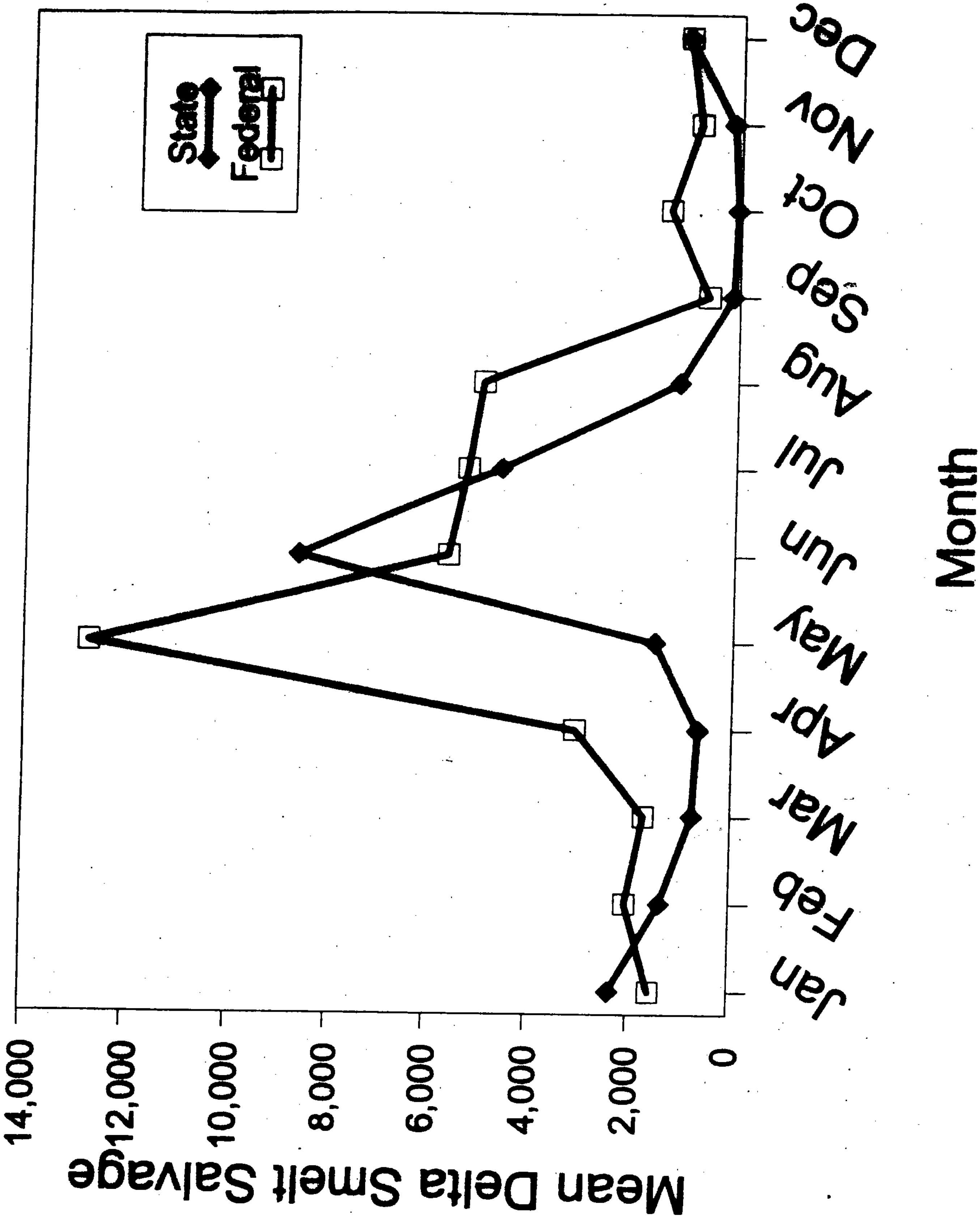



**Figure 9.** Monthly averages of the estimated adult delta smelt salvage at the State and Federal Water Project diversions from 1980-1990.

# APPENDIX A

Section 2074.4 of the Fish and Game Code requires the Department of Fish and Game to notify affected and interested parties and landowners and to solicit data and comments on petitions accepted by the Fish and Game Commission. To fulfill this requirement, the Department sent notices and/or copies of the petition to the following persons and organizations. Legal notices were placed in the newspapers indicated below:

PERSONS/ORGS. RECEIVING DELTA SMELT PETITION AND/OR PUBLIC NOTICE

U.S. Department of the Army
Sacramento District
Corps of Engineers
650 Capitol Mall
Sacramento, California 95814-4794

Raymond E. Barsch, General Manager
State Reclamation Board
1416 Ninth Street, Room 455-6
Sacramento, California 95814

Claire T. Dedrick, Executive Officer
State Lands Commission
1807 13th Street
Sacramento, California 95814

Tim Egan, President
California Waterfowl Association
~~3840 Rosin Court, Suite 200~~ 4630 NORTHGATE BLVD SUITE 150
Sacramento, California 95834 -1125

Alan Rendleton, Executive Director
San Francisco Bay Conservation &
Development Commission
30 Van Ness Avenue, Suite 2011
San Francisco, California 94102-6080

Monica Liquori, Executive Director
Suisun Marsh Natural History Association
1171 Kellogg Street
Suisun, California 94585

Peter Douglas, Executive Director
California Coastal Commission
631 Howard Street
San Francisco, California 94105

William H. Ivers, Director
Department of Boating and Waterways
1629 S Street
Sacramento, California 95814

Peter Grenell, Executive Officer
State Coastal Conservancy
1330 Broadway, Suite 1100
Oakland, California 94610

Eliseo Sanmaniego, Acting Chairman
Water Resources Control Board
Post Office Box 100
Sacramento, California 95801

Richard Spotts, Regional Representative
Defenders of Wildlife
5604 Rosedale Way
Sacramento, California 95822

~~Leland Lehman, President~~
~~Suisun Resource Conservation District~~
~~Post Office Box 426~~
~~Suisun, California 94585~~
4/3/93 no correct address

Rick Coleman
San Francisco National Wildlife Refuge
Post Office Box 524
Newark, California 94560

Huston Carlyle, Jr., Director
Office of Planning & Research
1400 10th Street
Sacramento, California 95814

Orville Abbott, Executive Officer
California Water Commission
1416 Ninth Street, Room 1104-4
Sacramento, California 95814

Henry R. Agonia, Director
Department of Parks and Recreation
Post Office Box 942836
Sacramento, California 94296-001

David N. Kennedy, Director
Department of Water Resources
Post Office Box 942836
Sacramento, California 94236-0001

Sacramento County
Board of Supervisors
700 H Street, Room 2450
Sacramento, California 95814-1280

Bob McKay, Pesident or
Elizabeth Wright, Exec. Secretary
Sacramento Wildlife Federation
1023 J Street, Suite 203
Sacramento, California 95814

Sylvia McLaughlin, President
Save San Francisco Bay Association
Post Office Box 925
Berkeley, California 94701

Laurel Mayer, Vice President
The Nature Conservancy WRO
785 Market Street, 3rd Floor
San Francisco, California 94103

Lawrence Downing, President
Sierra Club
730 Polk Street
San Francisco, California 94109

Richard Hubbard, Executive Director
California Natural Resource Federation
2830 10th Street, Suite 4
Berkeley, California 94710

Robert Nazum, President
California Association Resource
Conservation District
1072 Jaunita Drive
Walnut Creek, California 94595

Edward Hastey, State Director
U.S. Bureau of Land Management
Federal Office Building, Room E-2841
Sacramento, California 95825

Department Chair
Department of Biological Sciences
California State University
6000 J Street
Sacramento, California 95819

Contra Costa County
Board of Supervisors
651 Pine Street, Room 106
Martinez, California 94553

Solano County
Board of Supervisors
Solano County Courthouse
Fairfield, California 94533

Gerald Meral, Executive Director
Planning & Conservation League
909 12th Street, Suite 203
Sacramento, California 95814

Charles Sibley
Tiburon Center for Environmental Studies
San Francisco State University
Box 855
Tiburon, California 94920

Jerry Bogges, President
The Oceanic Society
San Francisco Bay Chapter
Fort Mason Center, Building E
San Francisco, California 94123

Sheila Byrne
Pacific Gas & Electric Company
TES/Moore Building
3400 Crow Canyon Road
San Ramon, California 94583

Dr. John McCosker
California Academy of Sciences
Golden Gate Park
San Francisco, California 94118

Michael Stroud, Head
Natural Resources Branch
U.S. Department of the Navy, Western Division
Naval Facilities Engineer Command,
Code 243, Post Office Box 727
San Bruno, California 94066

Marvin Plenert, Regional Director
U.S. Fish and Wildlife Service
Northwest Regional Office
911 NE 11th Avenue
Portland, Oregon 97232-4181

Dr. Paul Ehrlich
Center for Conservation Biology
Stanford University
Stanford, California 93405

Director
Museum of Vertebrate Zoology
University of California, Berkeley
Berkeley, California 94720

Dr. Peter Moyle
Wildlife and Fisheries Biology
University of California, Davis
Davis, California 95616

Kenneth R. Boyd
American Water Works Association
Post Office Box 2108
Livermore, California 94550

Daniel Phelan
Bay Area League of Industrial Associations
155 Jackson #305
San Francisco, California 94111

David Behar & Scott Hadley
Bay Institute of San Francisco
10 Liberty Ship Way #120
Sausalito, California 94965

Greg Mannesto
U.S. Army Corps of Engineers
650 Capitol Mall
Sacramento, California 95814

Robert Helwick, Senior Attorney
East Bay Municipal Utility District
2130 Adeline Street
Oakland, California 94607

David Stewart
Water Management Division
Environmental Protection Agency
215 Fremont Street
San Francisco, California 94105

Martin Seldon
Federation of Fly Fishermen
Post Office Box 2393
Sunnyvale, California 94807-2393

Ron Davis
California Municipal Utility Association
1225 8th Street, Suite 440
Sacramento, California 95814

Dan Taylor
National Audubon Society
555 Audubon Place
Sacramento, California 95825

Department Chair
Department of Biology/Natural Resources
University of California, Berkeley
Berkeley, California 94720

William H. Geyer
Consulting/Advocacy in California Government
1029 K Street, Suite 33
Sacramento, California 95814

Robert T. Cockburn
Bay Area Dischargers Association
2130 Adeline Street
Oakland, California 94607

Steven McAdam
San Francisco Bay Conservation/
Development Commission
30 Van Ness Avenue
San Francisco, California 94102

Austin Nelson
Contra Costa Water District
Post Office Box H20
Concord, California 94524

Robert Baiocchi, Executive Director
California Sportfishing Protection Association
1859 Salider Way
Paradise, California 95969

Thomas Graff
Environmental Defense Fund
5655 College Avenue, Suite 304
Oakland, California 94618

Don May
Friends of the Earth
2333 Elm Street
Long Beach, California 90806

Ellen Johnck, Executive Director
Bay Planning Coalition
666 Howard Street, Suite 301
San Francisco, California 94105

Association of Water Agencies
910 K Street, Suite 250
Sacramento, California 95814-3577

Lori Smallwood-Wallack
California Water Resources Association
1127 11th Street, Suite 602
Sacramento, California 95814

Jane Darby, Water Chairperson
League of Women Voters of Redlands
309 Marcia Street
Redlands, California 92373

Eric Johnson
Pacific Gas & Electric Company
3400 Crow Canyon Road
San Ramon, California 94503

Mitch Ryan
Senator John Garamendi's Office
State Capitol, Room 4081
Sacramento, California 95814

John Coburn
State Water Contractors
555 Capitol Mall, Suite 575
Sacramento, California 95814

John Beuttler
United Anglers of California
2830 10th Street, Suite 4
Berkeley, California 94710

Jim Arthur
U.S. Bureau of Reclamation
2800 Cottage Way, Room 2137
Sacramento, California 95825

Richard Oltman
U.S. Geological Survey
2800 Cottage Way, Room W-2234
Sacramento, California 95825

Laura King
Natural Resources Defense Council
90 New Montgomery, Suite 620
San Francisco, California 94105

Bill Crooks, Executive Officer
California Regional Water
Quality Control Board
3443 Routier Road
Sacramento, California 95827-3098

Mike Valentine
State Lands Commission
1807 13th Street
Sacramento, California 95814

Dave Beringer
State Water Resources Control Board
Bay Delta Program
901 P Street
Sacramento, California 95814

Dr. Jack Williams
Fisheries Program Manager
U.S. Bureau of Land Management
Division of Wildlife & Fisheries
18th and C Streets, NW
Washington, D.C. 20240

Martin Kjelson
U.S. Fish and Wildlife Service
4001 Wilson Way
Stockton, California 95205

Robert Hagan
Yolo County Flood Control &
Water Conservation District
548 Oak Avenue
Davis, California 95616

James Mayer
Kidder, Peabody, and Company, Incorporated
555 California Street, Suite 2950
San Francisco, California 94104

Henry Loeser
1097 Green Street, # 6
San Francisco, California 94133

Center for Environmental Design Research
390 Wurster Hall
University of California, Berkeley
Berkeley, California 94720

Brenda Jahns
Attorney at Law
770 L Street, Suite 1200
Sacramento, California 95814-3363

Stephan C. Volker
Sierra Club Legal Defense Fund, Incorporated
2044 Fillmore Street
San Francisco, California 94115

Dr. Dennis Murphy
Department of Biological Sciences
Stanford University
Stanford, California 94305-5020

Bob Pine
Office of Endangered Species
U.S. Fish and Wildlife Service
2800 Cottage Way
Sacramento, California 95825

Dr. Don Erman
Department of Forestry and
Resource Management
21 Mulford Hall
University California, Berkeley
Berkeley, California 94720

Ms. Carla Markman, Chair
Conservation Committee
American Fisheries Society
c/o Department of Fish and Game
1701 Nimbus Road
Rancho Cordova, California 95670

Mr. George R. Baumli
State Water Contractors
555 Capitol Mall, Suite 575
Sacramento, California 95814

Harold Meyer
Water Resources Management, Incorporated
1851 Heritage Lane, Suite 172
Sacramento, California 95815

Margaret Johnston, Executive Director
Aquatic Habitat Institute
180 Richmond Field Station
1301 South 46th Street, Building 180
Richmond, California 94804

Susan Joseph
Downy, Brand, Seymour, & Rohwer
555 Capitol Mall, 10th Floor
Sacramento, California 95814

David Anderson
Department of Water Resources
Office of the Counsel
1416 Ninth Street
Sacramento, California 95814

Office of Planning & Research
State Clearing House
1400 Tenth Street
Sacramento, California 95814

Dr. Randy Brown
Department of Water Resources
Central District
3251 S Street
Sacramento, California 95816

Ken Lentz
U.S. Bureau of Reclamation
2800 Cottage Way
Sacramento, California 95825

Chris Bowman
Sacramento Bee
2100 Q Street
Sacramento, California 95816

Diana Jacobs
State Lands Commission
1807 13th Street
Sacramento, California 95814

Phil Hogan
Soil Conservation Services
2020 Milvia
Berkeley, California 94704

Robert Shaffer
William Tully
U.S. Bureau of Reclamation
2800 Cottage Way
Sacramento, California 95825

Cay Goude
U.S. Fish and Wildlife Service
2800 Cottage Way
Sacramento, California 95825

Jim Canaday
State Water Resources Control Board
Division of Water Rights
Post Office Box 2000
Sacramento, California 95810

Barry Nelson
Save San Francisco Bay Association
Post Office Box 925
Berkeley, California 94701

Al Jahns
Merron, Reid, and Sheehy
801 K Street, #2100
Sacramento, California 95814

Dr. C. David Vanicek
Department of Biological Sciences
California State University, Sacramento
6000 J Street
Sacramento, California 95819

Steven A. McAdam
San Francisco Bay Conservation
and Development Commission
Thirty Van Ness Avenue, Suite 2011
San Francisco, California 94102

U.S. Army Corps of Engineers
San Francisco District
211 Main Street
San Francisco, California 94105-1905

Robert Helwick, Senior Attorney
East Bay Municipal Utility District
Post Office Box 24055
Oakland, California 94623

Jim Aurthur
U.S. Bureau of Reclamation
2800 Cottage Way
Sacramento, California 95825

Nadine Kanim
U.S. Fish and Wildlife Service
2800 Cottage Way
Sacramento, California 95825

Wayne White
U.S. Fish and Wildlife Service
2800 Cottage Way
Sacramento, California 95825

Robert King
California Striped Bass Association
1761 Circle Drive
Isleton, California 95641

Jay Sorensen
California Striped Bass Association
Post Office Box 9045
Stockton, California 95208

James Crenshaw
Striped Bass Stamp Advisory Committee
Route 4, Box 1275
Woodland, California 95695

Ron Perry
California Striped Bass Association
West Delta President
Post Office Box 2691
Antioch, California 94531-2691

Susan LeFever
Friends of the River
1228 N Street, Suite 24
Sacramento, California 95814

Pacific Gas and Electric Company
Post Office Box 7442
San Francisco, California 94120

916) 327-5957

April 2, 1993

Los Angeles Times
Times Mirror Square
Los Angeles, California 90053

ATTENTION: LEGAL NOTICES

Please publish the enclosed Public Notice on any two days during the week of Apirl 4, 1993 through April 10, 1993. Send an invoice and proof of publication to:

Celeste Cushman
Assistant Endangered Species Coordinator
California Department of Fish and Game
Natural Heritage Division
1416 Ninth Street
Sacramento, California 95814

Thank you.

Sincerely,

/S/

Celeste Cushman, Assistant Coordinator
Endangered Species/Tax Check-off
Natural Heritage Division

CC:kyb

Enclosure

bc: Mr. Boyd Gibbons
Director

Mr. Banky E. Curtis
Deputy Director

Ms. Susan A. Cochrane, Chief
Natural Heritage Division

Mr. Ron Pelzman
Assistant Executive Director
Fish and Game Commission

SAME LETTER SENT TO NEWSPAPERS ON ATTACHED LIST
CUSHMAN:kyb
FILE: SAC, CC SUBJECT

The Sacramento Bee
P.O. Box 15779
Sacramento, California 95852

The Stockton Record
P.O. Box 900
Stockton, California 95201

Fairfield Daily Republic
P.O. Box 47
Fairfield, California 594533

San Francisco Chronicle
901 Mission Street
San Francisco, California 94103

Contra Costa Times
P.O. Box 5088
Walnut Creek, California 94596-1088

Los Angeles Times
Times Mirror Square
Los Angeles, California 90053

# APPENDIX B

# APPENDIX B

Report to the Fish and Game Commission: A Status Review of the Delta Smelt (Hypomesus transpacificus) in California
Candidate Species Status Report 90-2

State of California
The Resources Agency

DEPARTMENT OF FISH AND GAME

# REPORT TO THE FISH AND GAME COMMISSION:

# A STATUS REVIEW OF THE DELTA SMELT (*HYPOMESUS TRANSPACIFICUS*) IN CALIFORNIA


Prepared by

Donald E. Stevens
Fisheries Management Supervisor

Lee W. Miller
Associate Fishery Biologist

and

Betsy C. Bolster
Associate Fishery Biologist

Approved by

Harold K. Chadwick, Program Manager
Bay-Delta Project
and
Robert R. Rawstron, Chief
Inland Fisheries Division



August 1990

Candidate Species Status Report 90 - 2

TABLE OF CONTENTS

Report to the Fish and Game Commission:

A Status Review of the

Delta Smelt (Hypomesus transpacificus)

in California[1/]

## EXECUTIVE SUMMARY

This report was prepared in response to a petition received by the Fish and Game Commission from Dr. Peter B. Moyle of the University of California at Davis to list the Delta smelt (Hypomesus transpacificus) as an Endangered Species under the authority of the California Endangered Species Act (Fish and Game Code Sections 2050 et seq.).

On August 23, 1989, pursuant to the Section 2074.2 of the California Endangered Species Act (CESA), the Commission determined that the petition contained sufficient information to indicate that the petitioned action may be warranted. Pursuant to Section 2074.6 of CESA, the Department undertook a review of this petition. Based on the best scientific information available on the Delta smelt, the Department has evaluated whether, in fact, the petitioned action should be taken. Information and comments on the petitioned action and the Delta

1/ Prepared August 1990.

smelt were solicited from interested parties, management agencies, and the scientific community.

This report presents the results of our review and analysis.

## Findings

The Delta smelt is a small fish endemic to the Sacramento-San Joaquin Estuary. Delta smelt are euryhaline and much of the year are typically most abundant in the entrapment zone, where incoming saltwater and outflowing freshwater mix. This species feeds exclusively on zooplankton, spawns in freshwater, and usually only lives for one year.

Information from six different data sets all indicate that the population of Delta smelt has declined. The best measures, based on the summer townet and fall midwater trawl surveys, indicate that abundance of this species has been consistently low since 1983. Based on the midwater trawl survey, the average population since 1983 has been only about one-fifth of the average population level from 1967 to 1982, and one-tenth of the peak level in 1980.

## Conclusions

Although the petitioner requested that the species be listed as endangered, the Department finds that the Delta smelt should be listed as a threatened species, based on Section 670.1(b) of Title 14 of the California Code of Regulations and Section 2072.3 of the Fish and Game Code. The Department's findings are based on the following:

1. The recent decline in the copepod, *Eurytemora affinis*, a major diet component of the Delta smelt, must be considered as a potential threat to the smelt's recovery unless other food resources compensate or this copepod recovers to its former abundance.

2. Although spawning stock abundance may not have been an important factor in Delta smelt year class success in the past, present or future low stock levels may inhibit the potential for population recovery. The relatively low fecundity of this species and its planktonic larvae, which undoubtedly incur high rates of mortality, indicate that year class success of the Delta smelt must depend on reproduction by fairly large numbers of fish.

3. The relationship between Delta smelt abundance and water diversions is not clear. Delta smelt are ecologically similar to young striped bass which have been severely impacted by water diversions. Whether or not water diversions are directly responsible for the Delta smelt

population decline, their drain on the population may be a significant factor inhibiting recovery.

4. Although there is no direct evidence of Delta smelt suffering direct mortality or stress from toxic substances, such substances cannot be eliminated as having adverse effects on the population.

5. There is no evidence that Delta outflow has had major effects on Delta smelt abundance.

6. No research has been done to determine if the wagasaki, a closely related species introduced into several reservoirs in the Delta drainage, hybridizes with or competes directly with the Delta smelt.

7. A number of exotic fish and invertebrate species have been introduced into the Sacramento-San Joaquin Estuary. Although none of these species can be directly linked to the decline in Delta smelt, their presence may inhibit the smelt's recovery.

8. Diseases and parasites of Delta smelt have never been studied; thus, there is no evidence concerning their role in the population decline. Should they be important, they

could prevent the recovery of Delta smelt from current low population levels.

9. Although competition and predation cannot be ruled out as threats to Delta smelt, the available evidence suggest that they are not a major threat. In fact, several potential competitors or predators also show signs of population erosion approximately coinciding with or preceding the decline of Delta smelt.

10. The Delta smelt population trend, certain life history attributes, and environmental threats tend to support listing. The scientific information is insufficient, however, to determine whether the population is low enough that it is in imminent danger of extinction. This is a complicated scientific determination, and no study which might be implemented will provide a conclusive answer in the next few years. Meanwhile, the population might become extinct. The most prudent action, therefore, is to list the Delta smelt as a threatened species.

Recommendations

Listing:

1. The Commission should find that the Delta smelt is a threatened species.

2. The Commission should publish notice of its intent to amend Title 14 CCR 670.5 to add the Delta smelt (Hypomesus transpacificus) to its list of Threatened and Endangered Species.

Management and recovery objectives:

1. Improve species identification and fish handling procedures at the existing State and Federal Water Project diversions from the Delta. Such actions could reduce present entrainment losses to these major diversions.

2. Modify pumping strategies at the State and Federal Water project diversions to reduce entrainment losses during periods when delta smelt are most abundant.

3. Increase spring and summer delta outflows to maintain the entrapment zone and major delta smelt nursery in the Suisun

Bay region where food supplies are greater that in the Delta and exposure to diversions is minimal.

4. Support regulations restricting ship ballast water discharges to eliminate or minimize new introductions of potentially harmful exotic species. S 2244 and HR 4214 currently being considered by the U.S. Congress would create such regulations.

5. Evaluate losses to agricultural diversions in the Delta. Screening these diversions probably would reduce entrainment and losses to local crop irrigation.

6. Remove water project diversions from the Delta. Moving the diversion intakes to the Sacramento River upstream from the major nursery area would do this and also provide benefits to other species which formerly made more use of the Delta.

7. Consider developing pond culture techniques for the purpose of creating "refuge" populations.

Public Responses

During the twelve month review period, the Department contacted a number of affected and interested parties, invited comment on the petition and our draft status review, and requested any additional scientific information that may be available. A copy of the Public Notice and a list of parties contacted are contained in Appendix A. A summary of comments on the draft status review is in Appendix B. Scientific comments will be addressed as part of the regulatory proceedings should the Commission find that the petition warrants action.

LIST OF TABLES

LIST OF FIGURES

**Report to the Fish and Game Commission:**

# A Status Review of the Delta Smelt (Hypomesus transpacificus) in California[1/]

## INTRODUCTION

### Petition History

On June 13, 1989, the Fish and Game Commission (Commission) received a petition from Dr. Peter B. Moyle of the University of California at Davis, requesting State listing of the Delta smelt (Hypomesus transpacificus) as an Endangered Species. The Department of Fish and Game (Department) reviewed the petition and recommended to the Commission that they accept it as complete pursuant to Sections 2072.3 and 2073.5 in the California Endangered Species Act (Fish and Game Code Sections 2050 et seq.) and that the petitioned action may be warranted. On August 29, 1989, the Commission accepted the Department's recommendation and designated the Delta smelt as a Candidate Species as provided for in Section 2074.2 of the California Endangered Species Act (CESA). That action initiated a twelve-month review period,

1/ Prepared August 1990

pursuant to Section 2074.6 of CESA, within which the Department must review the best scientific information available on the Delta smelt and provide a written report to the Commission indicating whether the petition is warranted.

## Department Review

This report contains the results of the Department's review, and a recommendation to the Commission, based on the best scientific information available, whether or not the petitioned action is warranted. It also identifies the habitat that may be essential to the continued existence of the species and suggests management activities and other recommendations for the recovery of the Delta smelt.

During the twelve month review period, the Department contacted affected and interested parties, invited comment on the petition and our draft status review, and requested any additional scientific information that may be available, as required under Section 2074.4, Fish and Game Code. A copy of the Public Notice and a list of parties contacted are contained in Appendix A. A summary of comments on the draft status review is in Appendix B. Scientific comments will be addressed as part of the regulatory proceedings should the Commission find that the petition warrants action.

## LIFE HISTORY

### Description

The Delta smelt is a small, slender-bodied fish, with a typical adult size of 55-70 mm (standard length), although some may reach 130 mm. This fish has a small, flexible mouth with a maxilla (upper jaw bone) which does not extend past the middle of the eye. When pressed against the body, the pectoral fins reach less than two-thirds of the way to the pelvic fin bases. The upper and lower jaws contain small, pointed teeth. Live Delta smelt have a steely blue sheen on the sides and appear to be almost translucent (Moyle 1976). Delta smelt, like other members of the family Osmeridae, have an adipose fin. Additional, more detailed descriptive information can be found in Moyle (1976).

### Taxonomy

The confusing taxonomy of this species is described in Moyle (1976). The Delta smelt was once thought to be a population of the widely distributed pond smelt, *Hypomesus olidus*. The two were recognized as distinct species by Hamada (1961), who renamed the Delta smelt _H. sakhalinus_ and retained the name _H. olidus_ for pond smelt. It was later determined, however, that _H. olidus_ does not occur in California waters, and McAllister (1963) redescribed the Delta smelt as _H. transpacificus_, with Japanese and California subspecies, _H. t. nipponensis_ and _H. t. transpacificus_, respectively. Subsequent work has shown that these two subspecies should be recognized as species, with the Delta smelt being _H. transpacificus_ and the Japanese fish (wagasaki) being _H. nipponensis_ (Moyle 1980).

## Range

The delta smelt occurs only in the Sacramento-San Joaquin Estuary.

## Diet

Delta smelt feed exclusively on zooplankton. Department biologists examined gut contents of two 8 mm and 9 mm delta smelt larvae captured in 1988 which had eaten harpacticoid copepods, calanoid copepods and copepod nauplii. The diet of 20-mm to 40-mm-long juveniles collected by the Department in 1974 was comprised mainly of calanoid copepods, especially _Eurytemora affinis_, which was the dominant food (Table 1). There was no evidence of a major shift in diet as the smelt grew larger.

Table 1. Items in the diet of delta smelt collected from the townet survey at station 519 on June 28 and July 13, 1974.

| Length group (mm) | Total fish | Number w/food | Cyclopidae | Eurytemora ---------- | Diaptomus --------- | Harpacticoid copepod | Neomysis -------- | Other copepod |
|---|---|---|---|---|---|---|---|---|
| 20-24 | 2 | 1 | | 2 | | | | -- -- |
| 25-29 | 18 | 17 | | 117 | 1 | 1 | | 8 |
| 30-34 | 18 | 17 | 2 | 585 | | | 1 | 45 |
| 35-39 | 12 | 12 | 0 | 220 | | | 1 | 34 |

Moyle and Herbold (MS) examined the diet of delta smelt from 15 samples collected at various times from 1972 to 1974 and for two fall samples collected in 1988. They found copepods to be the dominant diet item and the opossum shrimp, Neomysis mercedis, was second. E. affinis was the primary copepod in stomachs in the 1972-1974 sample. Pseudodiaptomus forbesi, an accidentally introduced exotic copepod which first became abundant in spring 1988, was an important diet item that year. The amphipod, Corophium sp, and two cladocerans, Bosmina sp. and Daphnia sp., were also eaten.

## Reproduction and Growth

Spawning occurs in freshwater at temperatures of 7-15°C (Wang 1986). It generally takes place from February through June, probably mostly in the dead end sloughs (Radtke 1966) and shallow edge-waters of the channels of the Delta (Wang 1986) and the Sacramento River. Catches of young delta smelt, 20-30 mm in length, during salmon seine surveys in May document the occurrence of spawning in the Sacramento River (Table 2). Some spawning has also been recorded in Montezuma Slough, near Suisun Bay (Radtke 1966, Wang 1986). Each female deposits from 1400 to 2900 demersal, adhesive eggs on substrates such as rock, gravel, tree roots, and submerged vegetation (Moyle 1976; Wang 1986; Moyle and Herbold, MS). Eggs probably hatch in 12-14 days if

Table 2. Catch per haul (C/H) and mean fork length in millimeters (FL) of delta smelt at Sacramento River beach seine sites in 1978. Number of seine hauls in parentheses.

| | Feb | | | Mar | | | Apr | | | May | | | June | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | C/H | | FL | C/H | | FL | C/H | | FL | C/H | | FL | C/H | | FL |
| Isleton | | (0) | | 1.3 | (3) | 69 | 0.0 | (1) | | 2.0 | (1) | 22 | | (0) | |
| Ryde | | (0) | | 1.0 | (2) | 46 | 1.2 | (4) | 75 | 13.3 | (3) | 24 | | (0) | |
| Clarksburg | | (0) | | 0.0 | (5) | | 5.8 | (4) | 68 | 70.7 | (3) | 26 | | (0) | |
| Garcia Bend | 0.0 | (2) | | 1.5 | (4) | 66 | 0.2 | (4) | 71 | 5.7 | (3) | 24 | | (0) | |
| Mouth American River | 0.0 | (2) | | 0.0 | (5) | | 0.0 | (3) | | 0.2 | (4) | 68 | 0.0 | (1) | |

developmental rates are similar to those of the closely related wagasaki (Wales 1962).

After hatching, larvae float to the surface (Moyle 1976) and many are carried by currents downstream to the mixing (entrapment) zone (see "Distribution and Essential Habitat"). Growth is rapid; juvenile smelt are 40-50 mm long by early August (Erkkila et al. 1950, Ganssle 1966, Radtke 1966). Adult lengths are reached by the time they are 6 to 9 months old (Moyle 1976). Thereafter, they only grow another 3-9 mm, presumably because most energy is being channeled into the development of gonads (Erkkila et al. 1950, Radtke 1966).

Most Delta smelt die after spawning, although a few may survive to be 2 years old. There is evidence that almost total reproductive failure can occur in some years. Erkkila et al. (1950), for example, collected no young-of-the-year smelt in their second year of sampling, although their previous year's data suggested that large numbers should have been present.

## DISTRIBUTION AND ESSENTIAL HABITAT

Delta smelt are euryhaline, and much of the year are typically most abundant in the entrapment zone (Arthur and Ball 1979) where incoming saltwater and outflowing freshwater mix (Tables 3, 4, and 5). This mixing effect allows organisms which swim poorly, such as zooplankton and larval fish, to remain in the entrapment zone rather than being flushed out to sea. Hence, delta smelt spend their life from the larval period to pre-spawning adulthood in the Delta and brackish areas downstream, particularly the Suisun Bay region (Ganssle 1966, Radtke 1966, Moyle and Herbold 1989). Surveys by the San Francisco Bay - Outflow Study, which has sampled fish in the Estuary from San Francisco Bay to the western Delta since 1980, indicate that delta smelt thin out in San Pablo Bay and are virtually non-existent in San Francisco Bay (Table 3).

Summer townet and fall midwater trawl surveys (pages 17 to 23), conducted by the Department for young striped bass (Morone saxatilis), indicate delta smelt are most frequently caught where specific conductance ranges from 500 to 8000 microsiemens (Tables 3, 4 and 5). These surveys also demonstrate that the geographical distribution of delta smelt during summer and fall is strongly influenced by delta outflow. As flows increase and saltwater is repelled, more of the population occurs in Suisun and San Pablo bays and less occurs in the Delta (Figures 1 and 2).

Table 3. San Francisco Bay - Outflow study catch of delta smelt by month and area, 1980-1988. Number of sampling sites in parentheses.

| Area | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
| San Francisco Bay (16) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| San Pablo Bay (8) | 4 | 5 | 29 | 1 | 0 | 1 | 0 | 0 | 0 | 54 | 0 | 1 | 95 |
| Carquinez Strait and Western Suisun Bay (6) | 61 | 46 | 86 | 37 | 5 | 55 | 70 | 94 | 71 | 36 | 9 | 38 | 608 |
| Eastern Suisun Bay (3) | 18 | 24 | 15 | 10 | 5 | 8 | 16 | 37 | 54 | 68 | 40 | 12 | 307 |
| Western Delta (2) | 30 | 13 | 15 | 5 | 2 | 20 | 12 | 23 | 55 | 12 | 33 | 32 | 252 |
| Total | 113 | 88 | 145 | 53 | 12 | 84 | 98 | 154 | 180 | 170 | 82 | 83 | 1262 |

Table 4. Summer townet survey catch frequencies for delta smelt by specific conductance (EC) ranges, 1969-1988. 1/

Numbers of smelt per catch

| EC (microsiemens) | 0 | 1-4 | 5-9 | 10-14 | 15-19 | 20-49 | 50-99 | >100 | Total Samples | Number Catches >0 | Percent with smelt |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No Data | 9 | 4 | 3 | 1 | 0 | 1 | 1 | 0 | 19 | 10 | 52.6 |
| 1-499 | 541 | 170 | 52 | 17 | 10 | 36 | 16 | 14 | 856 | 315 | 36.8 |
| 500-999 | 105 | 51 | 13 | 16 | 7 | 13 | 14 | 10 | 229 | 124 | 54.1 |
| 1000-1999 | 38 | 31 | 15 | 10 | 8 | 17 | 9 | 10 | 138 | 100 | 72.4 |
| 2000-3999 | 34 | 41 | 15 | 11 | 8 | 22 | 9 | 8 | 148 | 114 | 77.0 |
| 4000-5999 | 31 | 30 | 11 | 6 | 4 | 6 | 8 | 8 | 104 | 73 | 70.0 |
| 6000-7999 | 22 | 21 | 9 | 7 | 3 | 11 | 5 | 1 | 79 | 57 | 72.1 |
| >8000 | 338 | 96 | 32 | 14 | 7 | 17 | 14 | 3 | 521 | 183 | 35.1 |
| Total | 1118 | 444 | 150 | 82 | 47 | 123 | 76 | 54 | 2094 | 976 | 46.6 |

1/ EC was not measured prior to 1969 even though the survey started in 1959.

Table 5. Fall midwater trawl catch frequencies for delta smelt by specific conductance (EC) ranges, 1967-1988.

| | Numbers of smelt per catch | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| EC (microsiemens) | 0 | 1-4 | 5-9 | 10-14 | 15-19 | 20-49 | >50 | Total Samples | Number Catches >0 | Percent catch with smelt |
| No Data | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 |
| 1-499 | 1756 | 604 | 103 | 30 | 16 | 27 | 4 | 2540 | 784 | 30.8 |
| 500-999 | 311 | 137 | 35 | 21 | 7 | 12 | 5 | 528 | 217 | 41.1 |
| 1000-1999 | 224 | 128 | 43 | 18 | 10 | 18 | 2 | 443 | 219 | 49.4 |
| 2000-3999 | 269 | 141 | 44 | 30 | 9 | 14 | 5 | 512 | 243 | 47.4 |
| 4000-5999 | 244 | 97 | 45 | 9 | 10 | 12 | 1 | 418 | 174 | 46.1 |
| 6000-7999 | 202 | 67 | 23 | 10 | 5 | 9 | 1 | 317 | 115 | 36.3 |
| >8000 | 4547 | 173 | 24 | 9 | 9 | 11 | 4 | 4777 | 230 | 4.8 |
| Total | 7562 | 1347 | 317 | 127 | 66 | 103 | 22 | 9544 | 1982 | 20.7 |

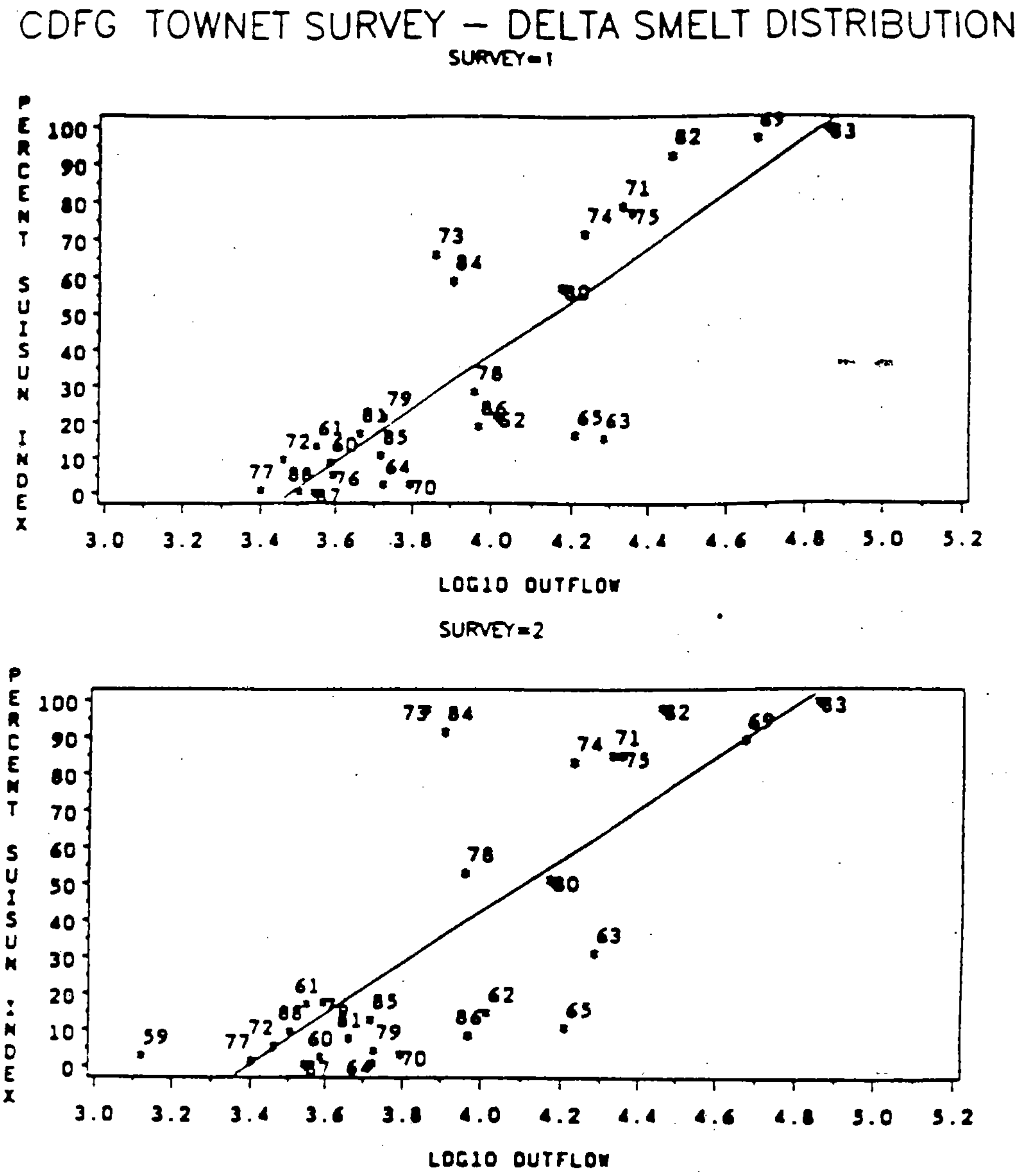



Figure 1. Relationship between the portion of the delta smelt population occurring west of the delta and log delta outflow during the survey period. Data are from the summer townet survey. For arcsine transformed percentages, $R^2$= 0.74 for survey 1 and $R^2$= 0.55 for survey 2.

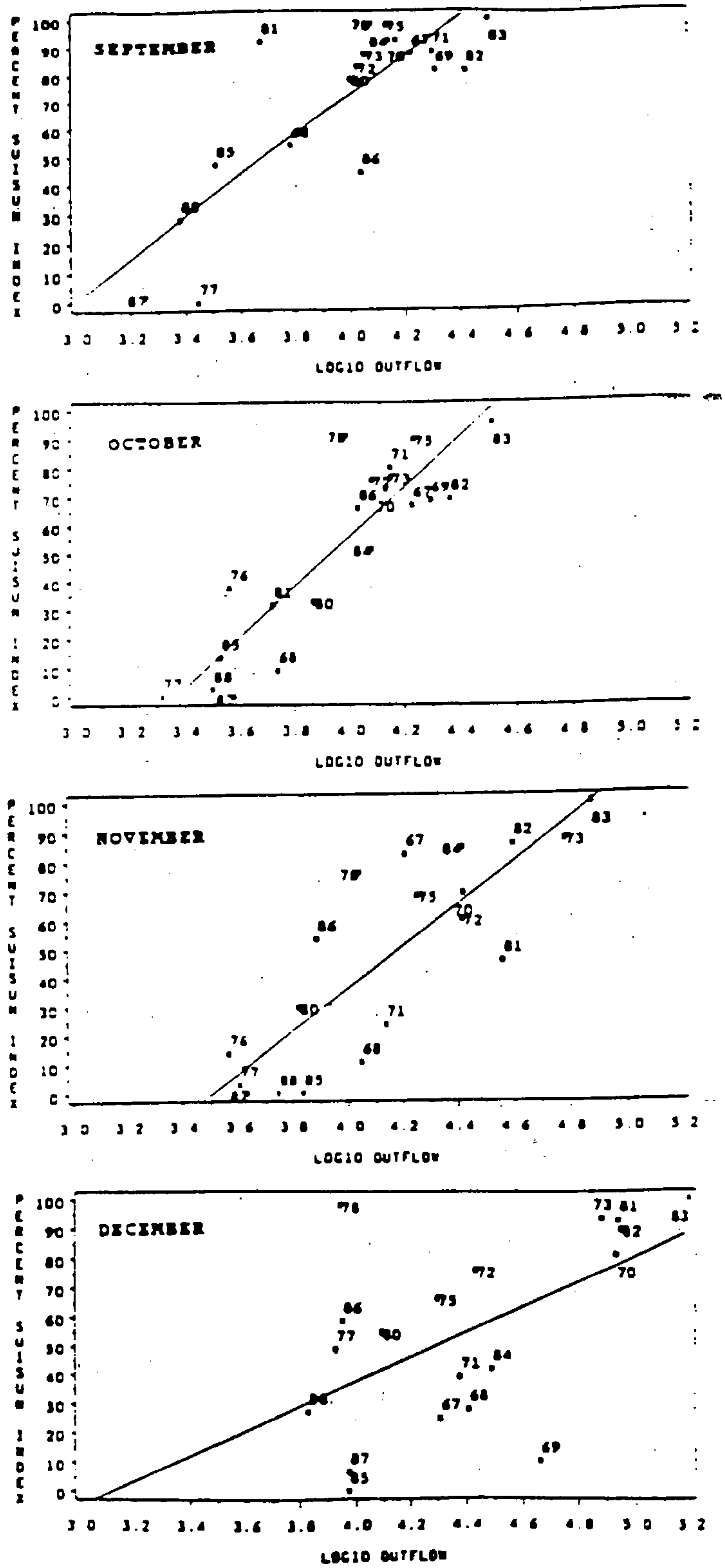



Figure 2. Relationship between the portion of the delta smelt population occurring west of the delta and log delta outflow during the survey month. Data are for the fall midwater trawl survey. For arcsine transformed percentages, $R^2$= .640 for September, .763 for October, .708 for November and .336 for December.

In late winter and spring, as the spawning period approaches, adult delta smelt disperse widely into freshwater, as far upstream in the Delta as Mossdale on the San Joaquin River (Radtke 1966) and (as indicated by trawling and seining during recent chinook salmon, Oncorhynchus tshawytscha, surveys) the mouth of the American River on the Sacramento River (Tables 2 and 6).

Delta smelt live principally in the upper portion of the water column. During a 1963-1964 survey of delta fish populations a 10 foot by 10 foot surface trawl captured 1960 delta smelt while a 15 foot by 5 foot otter trawl only captured 461 delta smelt. These results were obtained despite the otter trawl constituting 60 percent of this surveys effort of about 1800 tows (Radtke 1966, Turner 1966).

## ABUNDANCE

Information from five Interagency Ecological Study Program monitoring programs and one University of California program was summarized to evaluate recent trends in delta smelt abundance:

1. the summer townet survey for young striped bass,
2. the fall midwater trawl survey for young striped bass,
3. the San Francisco Bay-Outflow Study's monthly midwater trawl survey,

Table 6. Catch of Delta Smelt by midwater trawl in the Sacramento River at Clarksburg, 1976-1981. This site has not been sampled in more recent years. N/M means not measured. Lengths in mm.

| | May | | | June | | | July | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Catch | Mean Length | No. Tows | Catch | Mean Length | No. Tows | Catch | Mean Length | No. Tows |
| 1976 | 218 | 79 | 147 | 69 | 80 | 342 | 7 | 84 | 94 |
| 1977 | 242 | N/M | 443 | 117 | N/M | 550 | 0 | | 95 |
| 1978 | | | 0 | 8 | 82 | 127 | | | 0 |
| 1979 | | | 0 | 15 | 78 | 100 | | | 0 |
| 1980 | | | 0 | 6 | 84 | 240 | | | 0 |
| 1981 | | | 0 | 29 | 80 | 139 | | | 0 |

4. the seine and midwater trawl monitoring of young chinook salmon,
5. "salvage" of fish at the State and Federal water project fish screens in the south Delta, and
6. the University of California, Davis, Suisun Marsh fish survey.

While these data sets all provide information on delta smelt abundance at the time and location of sampling, each has inherent strengths and weaknesses in depicting the true population trend. These strengths and weaknesses are discussed as appropriate in the subsequent sections of this report.

<u>Summer Townet Survey</u>

The Department has conducted semi-monthly tow net surveys in the Delta and Suisun Bay, from late June to early August, each year since 1959 (except 1966) to index the abundance of young striped bass. On each survey run, three tows are made at each of about 30 sites from San Pablo Bay upstream through most of the Delta (Figure 3). Each survey run takes 5 days, and runs are made at 2-week intervals until the young bass average 38 mm (1.5 inches) in length. The number of runs has varied from two to five annually . The sampling gear and methods are described in detail by Calhoun (1953), Chadwick (1964), Turner and Chadwick (1972) and Stevens (1977). Catches of delta smelt are a by-product of

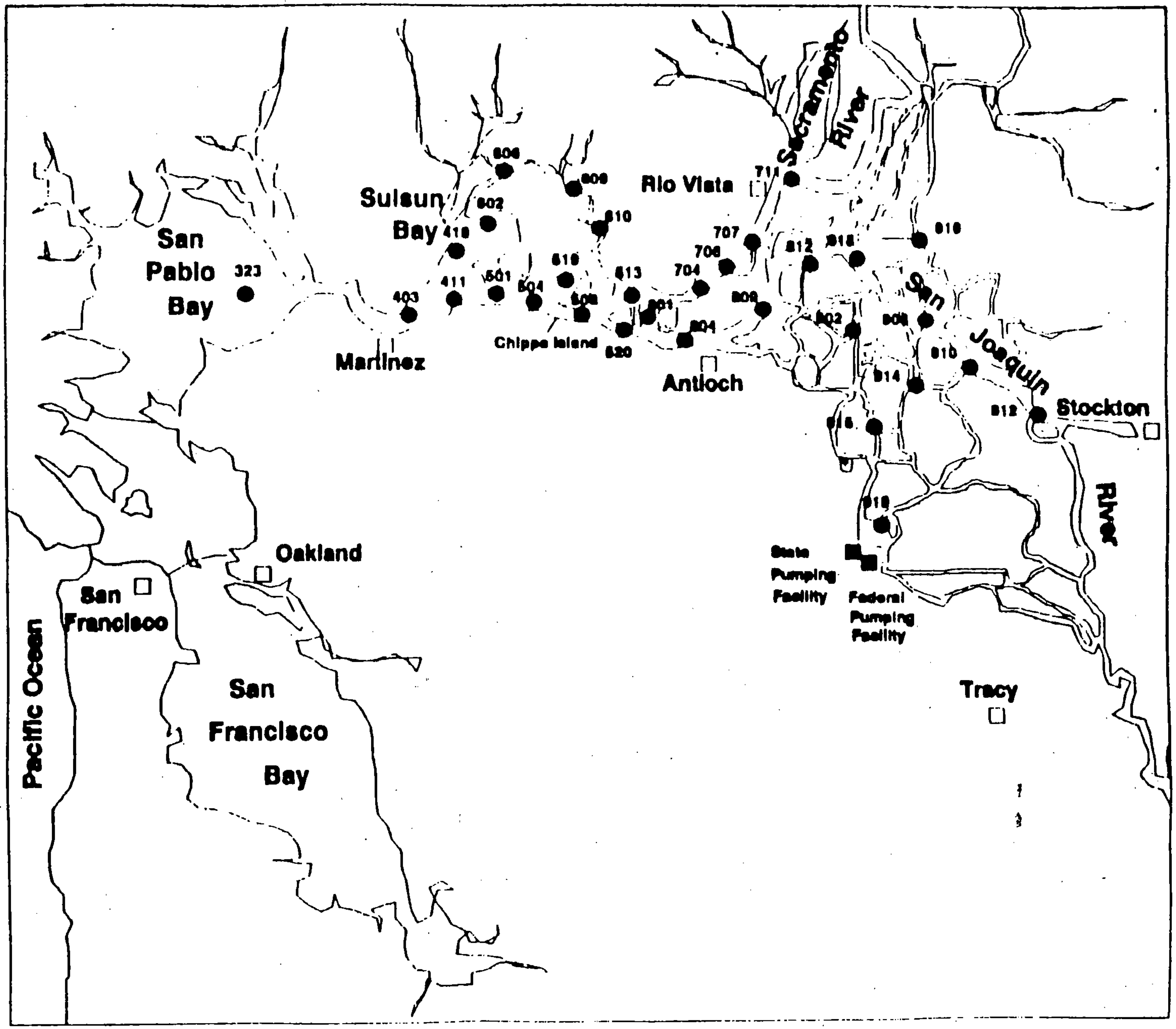



Figure 2. Summer townet survey sampling sites

this survey and records of these catches were kept in all years except 1967 and 1968. Annual abundance indices for delta smelt were calculated by summing, over all sample sites, the products of: total catch in all tows at a site x water volume in acre feet (Chadwick 1964) represented by that site. Delta smelt abundance indices were calculated only for the first two survey runs since runs 3,4, and 5 were not made in all years. The delta smelt abundance index is the mean of the abundance indices for the two runs after dividing by 1000 to scale the index for convenience. (Appendix C)

This survey provides good coverage of the delta smelt nursery and, in general, should yield an excellent index of young delta smelt abundance during early summer. In high flow years, however, the townet survey may undersample the population because many young smelt are washed downstream to San Pablo Bay or beyond.

The townet survey abundance index shows that annual production of young delta smelt has been quite variable since the survey began in 1959. The peak index of 62.5 in 1978 was 78 times greater than the lowest index of 0.8 in 1985. Abundance has been very low every year since 1983 including, the present year, 1990 (Figure 4). Similar low abundance indices occurred in several

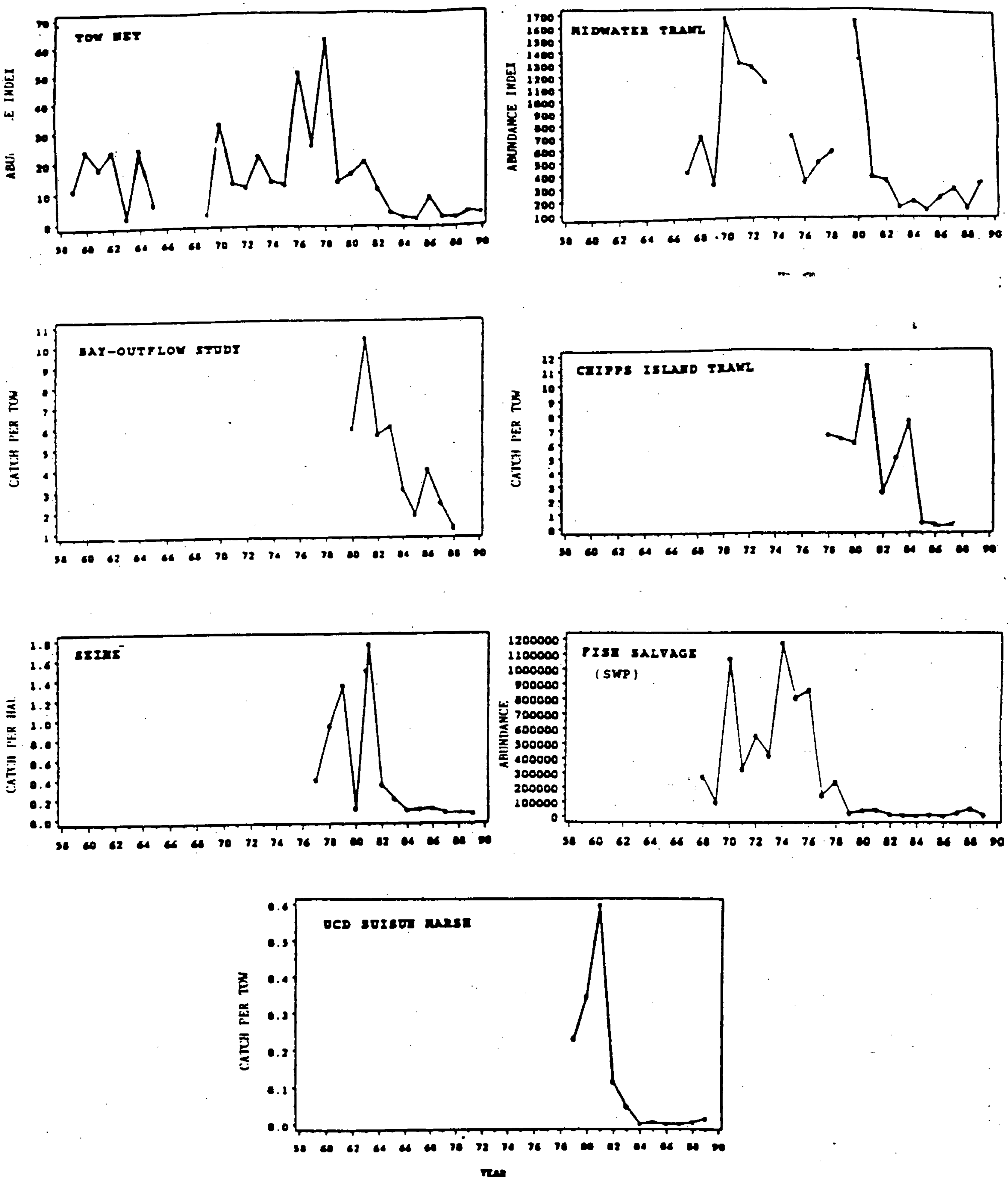



Figure 4. Trends in delta smelt as indexed by seven independent surveys.

earlier years (1963,1965,1969), but never for consecutive years. Thus, the townet results indicate that there has been a collapse in the production of young delta smelt.

Fall Midwater Trawl Survey

Starting in 1967, a 12 ft X 12 ft midwater trawl has been used to measure abundance of young-of-the-year striped bass and other species, including delta smelt, during the fall. About 87 sites are sampled from San Pablo Bay upstream to Rio Vista on the Sacramento River and Stockton on the San Joaquin River (Figure 5; Stevens 1977). Originally, the midwater trawl survey was done monthly from August or September through the following March. However, due to extraneous variability in striped bass abundance indices caused by pulses of high winter runoff, sampling has been restricted since 1980 to September through December. Surveys were not conducted in 1974 or 1979 or in November 1969 and September and December 1976.

Delta smelt, which on average are smaller than young striped bass during the fall, probably are at least equally vulnerable to capture by this survey. This survey provides reasonable coverage of the delta smelt population and should yield reasonable measures of the ultimate success of each year class.

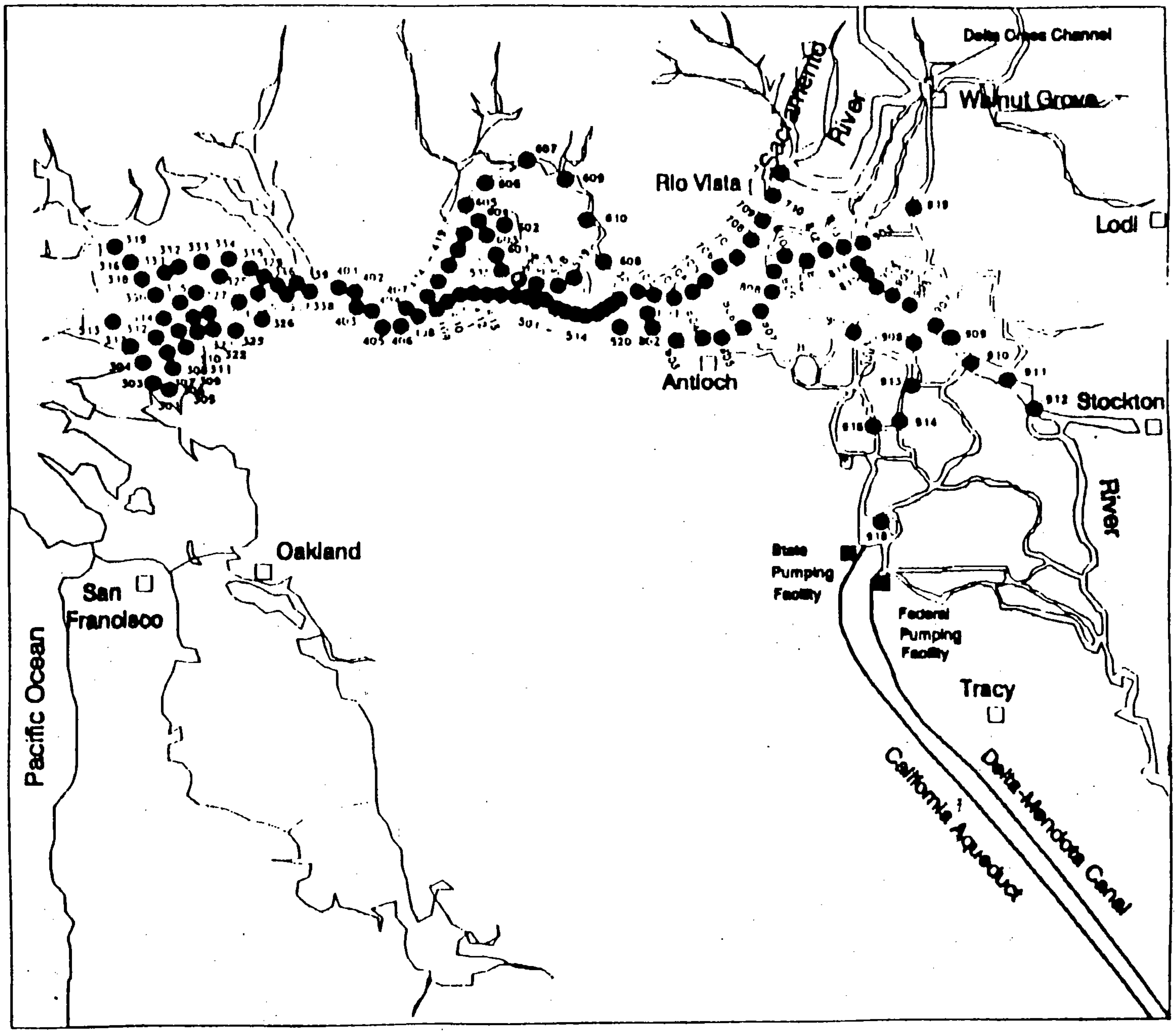



Figure 5 Fall midwater trawl survey sampling sites

Monthly abundance indices for delta smelt were calculated by summing, over all sampling sites, the product of: the mean catch per 12 minute tow in 17 subareas of the Estuary x the water volume in each subarea (Appendix D). The annual total abundance index is the sum of the monthly indices for September through December. Abundance indices for the surveys missing in 1969 and 1976 were estimated by interpolation or extrapolation of the months actually sampled.

Like the summer townet survey, the fall midwater trawl survey indicates that abundance of delta smelt has been highly variable, and has suffered a major decline (Figure 4). The peak fall index of 1678 occurred in 1970 and was 15 times greater than the minimum fall index of 109 which occurred in 1985. A general downward trend in fall abundance appears to extend back to the peak population of 1970 interrupted by a high index in 1980. The fall index has been consistently low since 1983 and from 1983 to 1988 was lower than in any previous year.

## San Francisco Bay - Outflow Study

Midwater trawl catches of delta smelt by the Interagency Ecological Study Program's San Francisco Bay - Outflow Study provide yet another set of delta smelt abundance measures. These measures are based on catches of smelt as small as 25 mm up to adult size and are available from 1980 through 1988. They are based on monthly sampling (12-minute tows) at 42 locations extending from South San Francisco Bay to the western Delta (Figure 6).

The Bay-Outflow Study survey is comprehensive in that it samples monthly throughout the year. Its main deficiency in measuring delta smelt abundance 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. This is particularly important in dry years when the population is concentrated in the Delta.

Typically, the Bay-Outflow survey's delta smelt catches peak from August to October as the new year class grows to a size at which they become vulnerable to capture by the sampling gear (Table 7). Average catches remain moderate through March and then decline into May when the bulk of the adults are spawning upstream from the sampling area and begin to die out. A few remaining adults and the next year class appear in the catches in June and July.

Bay survey catches show a striking decline in delta smelt abundance after 1981 (Figure 4). The 1981 catch rate was about twice that for 1980 but since 1981 there has been an irregular but persistent decline leading to a catch rate in 1988 that was

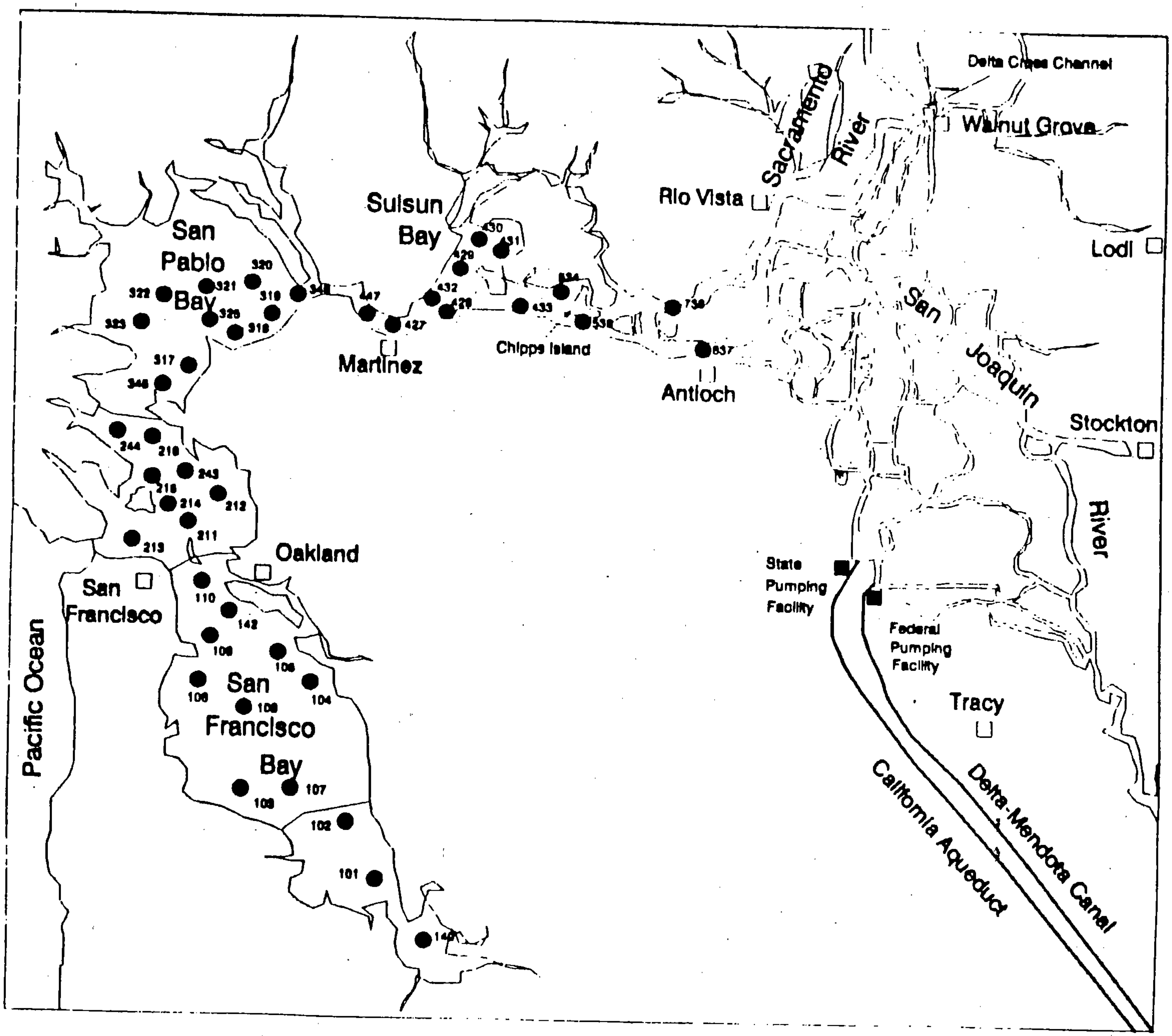



Figure 6. San Francisco Bay - outflow survey sampling sites.

Table 7. San Francisco Bay - Outflow study catches of delta smelt by month and year.

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1980 | 1 | 4 | 37 | 2 | 0 | 53 | 31 | 51 | 20 | 36 | 4 | | 239 |
| 1981 | 27 | 46 | 26 | 19 | 3 | 23 | 15 | 39 | 53 | 19 | 11 | 26 | 307 |
| 1982 | 41 | 15 | 9 | 5 | 4 | 4 | 35 | 13 | 7 | 9 | 7 | 22 | 171 |
| 1983 | 30 | 12 | 41 | 5 | 1 | 2 | 1 | 15 | 29 | 66 | 14 | 3 | 219 |
| 1984 | 2 | 5 | 14 | 21 | 4 | 0 | 5 | 11 | 29 | 5 | 6 | 5 | 107 |
| 1985 | 5 | 1 | 1 | 0 | 0 | 1 | 4 | 2 | 1 | 1 | 0 | 21 | 37 |
| 1986 | 1 | 3 | 14 | 0 | 0 | 1 | 1 | 23 | 21 | 29 | 9 | 6 | 108 |
| 1987 | 6 | 0 | 2 | 1 | 0 | 0 | 6 | 0 | 4 | 0 | 25 | 0 | 44 |
| 1988 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 16 | 5 | 6 | 0 | 30 |
| Total | 113 | 88 | 145 | 53 | 12 | 84 | 98 | 154 | 180 | 170 | 82 | 83 | 1262 |

only about one-tenth that for 1981. All of the catch rates since 1984 have been lower than in any previous year. The trend in catch frequency is consistent with the trend in annual catch rates. From 1981 through 1984, delta smelt were caught during all monthly surveys (Table 7). During 1985 and 1986 they were caught during 9 and 10 surveys, respectively. Delta smelt were caught only during 6 of the 12 monthly surveys in 1987 and only during 5 surveys in 1988.

Based on the Bay-Outflow Study data, the current population of delta smelt is distinctly depressed. Part, but by no means all, of this depression likely is due to incomplete coverage of the delta smelt's geographical range: four of the five years since 1983 have been low flow years and the population has been concentrated in the Delta.

Salmon Survey Trawl and Seine Catches

The Interagency Program has used midwater trawl and seine surveys to measure annual abundance of young chinook salmon. These surveys are currently administered by the U.S. Fish and Wildlife Service. Delta smelt are an incidental catch in these salmon surveys.

The primary trawl survey has been conducted from April through June, since 1976, at Chipps Island in upper Suisun Bay. Data from this survey currently are available through 1987. A major deficiency of delta smelt abundance measures from this trawl survey is that the survey only samples at one location, thus the indices are affected by annual differences in delta smelt distribution. Nevertheless, the catches may still reflect major changes in population status.

The seine survey generally has sampled about 23 sites at beaches in the Delta and Sacramento River upstream to the mouth of the American River (Figure 7). This survey is run several times each month from January to April, May, or June. Data currently are available from 1977 to 1989. Since the sampling is entirely in the Delta and the Sacramento River and in late winter and spring, catches primarily reflect numbers of delta smelt undertaking their spawning migration, although, occasionally, young smelt around 20-30 mm long also have been taken.

As for the other data sources, catches of delta smelt in the salmon surveys were low during the most recent years. In the Chipps Island trawl survey, the catch of delta smelt fell dramatically in 1985 (1984 year class) and remained low in 1986 and 1987 (Figure 4 and Table 8). Catches during these years were considerably lower than in any previous year except 1977 when a drought caused salinity encroachment and most of the delta smelt

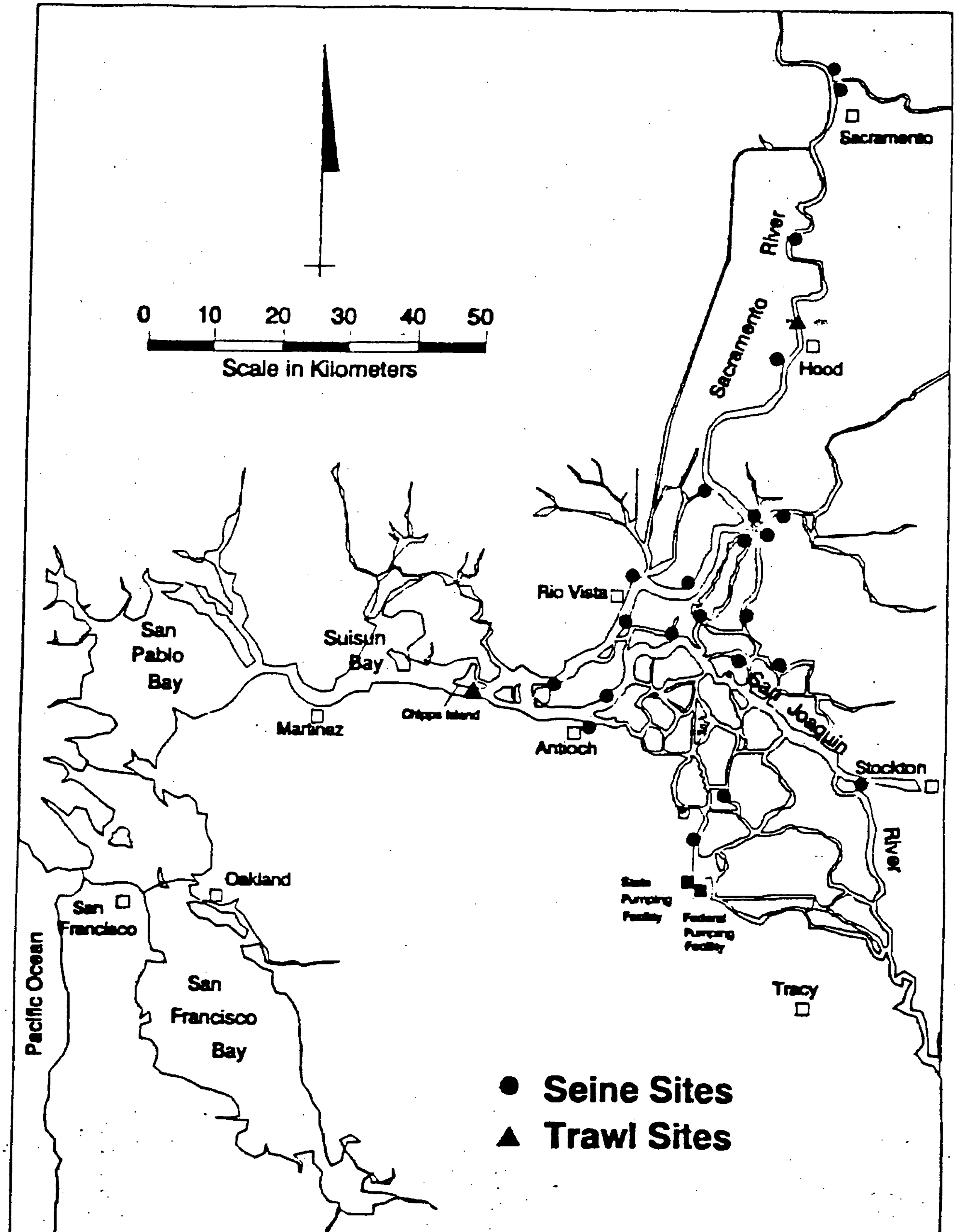



Figure 7. Sampling sites of the salmon trawl and seine surveys.

Table 8. Catch of delta smelt per tow during the chinook salmon trawl survey in the western Delta at Chipp's Island, April-June, 1976-1986. Number of tows in parentheses.

| Year | April | May | June | Mean Apr-Jun |
|---|---|---|---|---|
| 1976 | | 3.38( 76) | 15.54(188) | |
| 1977 | | 0.00(174) | 0.01(227) | |
| 1978 | 2.48(101) | 2.28( 90) | 15.06(174) | 6.61 |
| 1979 | 3.83( 77) | 1.18( 78) | 14.02(190) | 6.34 |
| 1980 | 0.69( 65) | 0.49( 81) | 16.88(252) | 6.02 |
| 1981 | 14.15( 52) | 3.69( 61) | 16.11(124) | 11.32 |
| 1982 | 1.46( 43) | 4.07(121) | 2.08(125) | 2.54 |
| 1983 | 7.73( 67) | 4.27(128) | 2.85(146) | 4.95 |
| 1984 | 15.94( 73) | 1.85( 99) | 4.78(164) | 7.52 |
| 1985 | 0.91( 86) | 0.05(298) | 0.11( 45) | 0.36 |
| 1986 | 0.23( 95) | 0.19(288) | 0.28(149) | 0.23 |
| 1987 | 0.25(159) | 0.21(290) | 0.00( 43) | 0.15 |

population probably moved upstream from the sampling site. The relatively high average catch of more than seven delta smelt per tow in 1984 (1983 year class) also is inconsistent with the population trend depicted by the broader based surveys and again may reflect an anomalous smelt distribution relative to the single sampling location.

In the seine survey, the lowest average catches of adult delta smelt occurred in 1980 and 1984-1989 (Figure 4 and Table 9). The reason for the low catch in 1980 (1979 year class) is unknown. However, the persistent low catches from 1984-1989 (1983-1988 year classes) are consistent with the population decline exhibited by the fall midwater trawl and summer townet surveys.

Salvage at SWP and CVP Fish Screens

Fish salvage operations at the State Water project (SWP) and the U.S. Bureau of Reclamation's Central Valley Project (CVP) fish screens provide huge samples of fish populations in the Delta; however, a major deficiency relative to measuring fish population trends is that all of the sampling occurs at only one location so the samples are affected by annual variations in the geographical distribution of each species. The salvage is also affected by seasonal and annual variations in water export rates, which affect numbers of fish that are diverted and screening

Table 9. Mean monthly catch of adult delta smelt per haul during the chinook salmon seine survey in the Sacramento-San Joaquin Delta, January-April 1977-1987.

| Year | Mean monthly catch per haul | No. hauls |
|---|---|---|
| 1977 | 0.39 | 152 |
| 1978 | 0.93 | 105 |
| 1979 | 1.34 | 250 |
| 1980 | 0.10 | 359 |
| 1981 | 1.75 | 397 |
| 1982 | 0.34 | 352 |
| 1983 | 0.20 | 321 |
| 1984 | 0.08 | 291 |
| 1985 | 0.09 | 321 |
| 1986 | 0.10 | 222 |
| 1987 | 0.06 | 238 |
| 1988 | 0.01 | 233 |
| 1989 | 0.01 | 281 |

efficiency. Also, at times, particularly before 1979 at the CVP, there have been species identification and other data quality problems. Nevertheless, considering the lengthy period of fish salvage information, the records provide another independent, albeit imperfect, source of information on the delta smelt population trend.

Salvage of delta smelt has been monitored since 1968 at the SWP fish screens and since 1979 at the CVP screens. Estimates of total smelt (delta smelt and longfin smelt) salvage provide additional information on smelt trends at the CVP back to 1973. Salvage estimates represent numbers of fish screened from the water that is exported from the Delta, but over-represent numbers of fish that are actually saved because many of these salvaged fish die due to the handling and trucking that is necessary to return fish to the Delta, and to predation by larger fish at the release sites.

Total salvage is estimated from estimates for consecutive periods (typically 2 hours long) based on the salvage rate (fish per minute entering the holding tanks) during each period. These salvage rates are estimated from fish counts ranging from one minute to the total length of the period. Sample counts are expanded to account for the amount of water exported when counts were not made. Because numbers of fish salvaged are affected by the amount of water diverted, salvage per-acre-foot diverted was also examined.

At the SWP, delta smelt salvage estimates were less than 300,000 fish in the initial two years of sampling, 1968 and 1969, but exceeded 300,000 fish, ranging up to more than 1 million fish in 1970 and 1974 (Figure 8). In 1977, there was a precipitous decline to 146,000 fish from 856,000 fish the previous year. Salvage increased to about 238,000 delta smelt in 1978; however, since 1979, the salvage of delta smelt has been consistently low, less than 60,000 fish, and as low as 3,600 fish in 1986.

At the CVP, the estimated salvage of delta smelt was on the order of 45,000 fish in 1979 and 1980, when smelt species identification began (Figure 9). In 1981, the estimate increased to about 275,000 fish, but since 1982, salvage has been very low, ranging from 2,800 to 34,000 fish.

Despite the lack of smelt species identifications, total smelt salvage estimates suggest that, as at the SWP, CVP salvage of delta smelt tended to be greater from 1973 to 1978 than it has been since 1979. Except in very recent years when the delta smelt population has been very low, the vast majority of identified smelt have been delta smelt at both the CVP and SWP (Table 10). All of the pre-1979 CVP estimates of total smelt

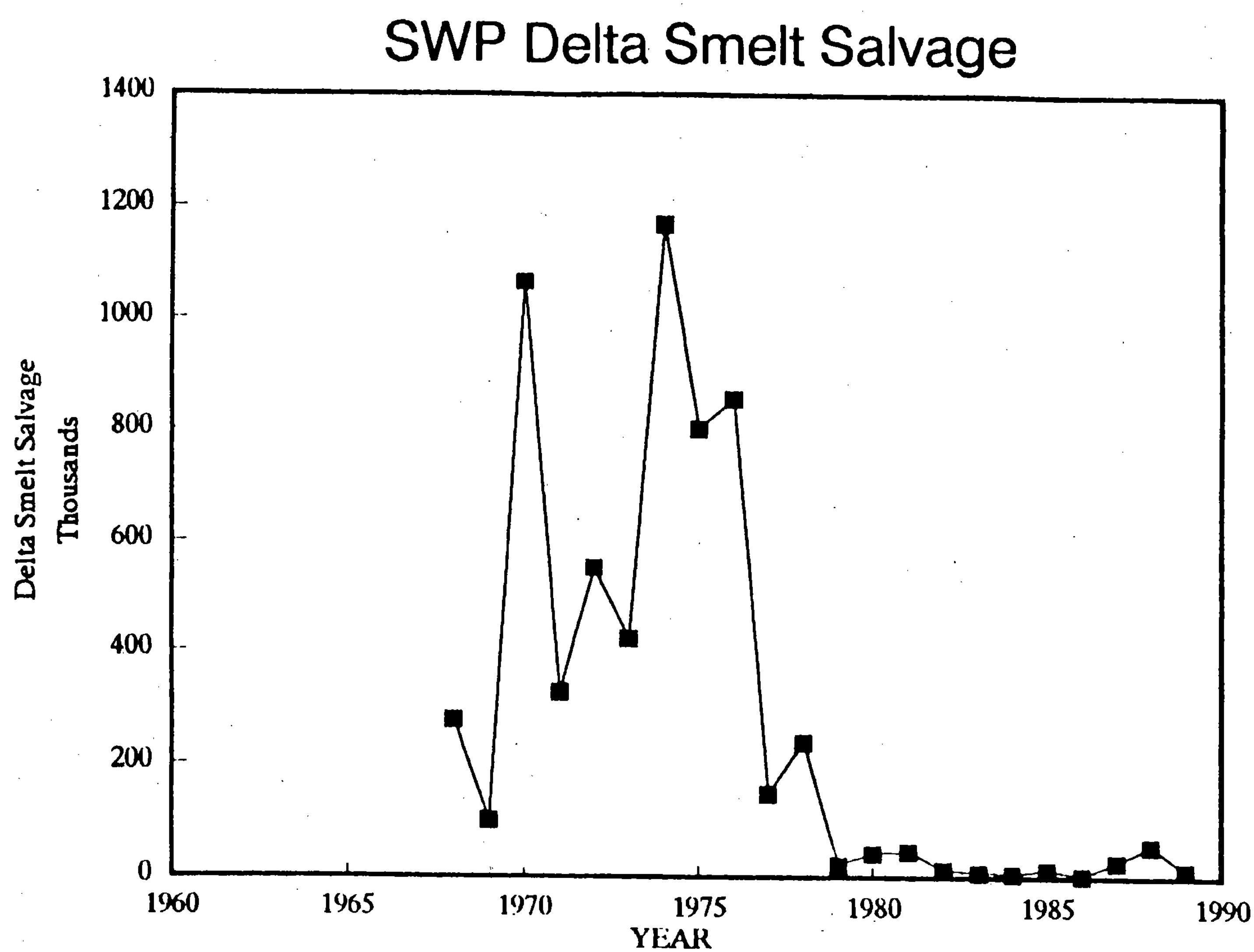



Figure 8. Annual salvage estimates for delta smelt at the State Water Project fish screens.

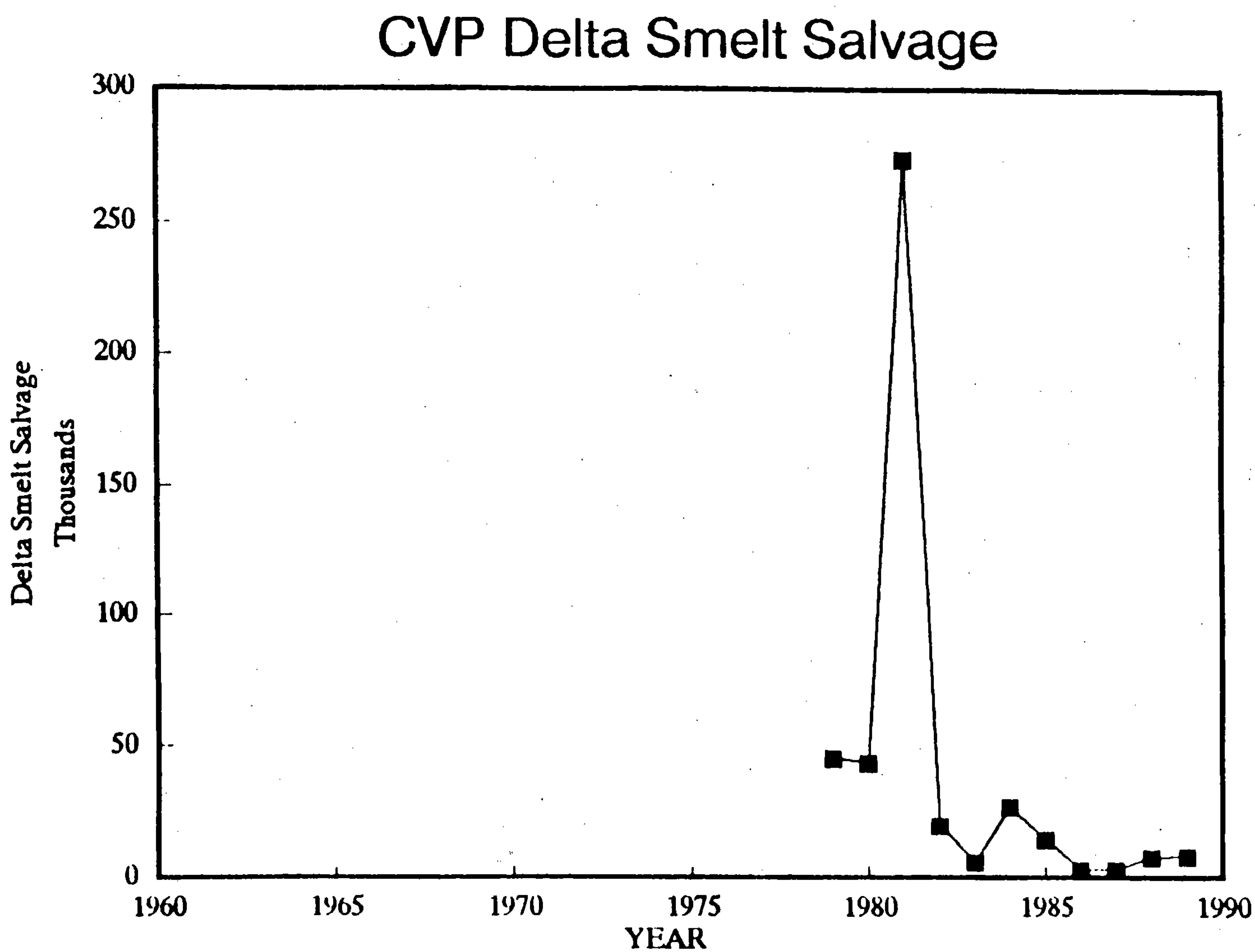



Figure 9. Annual salvage estimates for delta smelt at the Central Valley Project fish screens.

Table 10. Percentage of smelt salvage at State and Federal Water Project fish screens formed by delta smelt, 1968-1989.

| Year | State Water Project Percent delta smelt | Central Valley Project Percent delta smelt |
|---|---|---|
| 1968 | 100.0 | |
| 1969 | 99.8 | |
| 1970 | 97.3 | |
| 1971 | 30.0 | |
| 1972 | 98.9 | |
| 1973 | 100.0 | |
| 1974 | 100.0 | |
| 1975 | 100.0 | |
| 1976 | 100.0 | |
| 1977 | 78.6 | |
| 1978 | 98.5 | |
| 1979 | 78.3 | 54.9 |
| 1980 | 81.6 | 100.0 |
| 1981 | 94.8 | 99.9 |
| 1982 | 99.6 | 100.0 |
| 1983 | 96.5 | 99.0 |
| 1984 | 88.5 | 55.4 |
| 1985 | 41.8 | 80.6 |
| 1986 | 63.0 | 94.3 |
| 1987 | 34.7 | 7.4 |
| 1988 | 28.6 | 54.7 |
| 1989 | 16.4 | 25.4 |

salvage varied from about 130,000 to 311,000 fish, a level equaled subsequently only in 1981 (Figure 10).

Overall, salvage at the SWP and CVP fish screens has trended substantially downward since 1976 (Figures 4, 8, and 9), despite a trend of increasing water exports (Figure 11) which would lead to increased salvage of fish if the smelt population was stable or increasing. The one anomaly in this trend is the estimated salvage of 275,000 delta smelt at the CVP screens in 1981.

When sampling effort is considered, by calculating numbers of smelt salvaged per acre-foot of water diverted, pre-1979 abundance patterns appear to change somewhat, but, as for total salvage, subsequent salvage per-unit-effort measures are extremely low (except for 1981 at the CVP) (Figure 12).

Hence, the CVP/SWP salvage records are consistent with the other data sets indicating that a major decline has occurred in the delta smelt population; however, considering the sampling deficiencies (all sampling in one location, seasonal and annual variability in water export rate, and data quality control problems) in these data bases, the midwater trawl and townet surveys undoubtedly provide a better depiction of the timing and magnitude of decline.

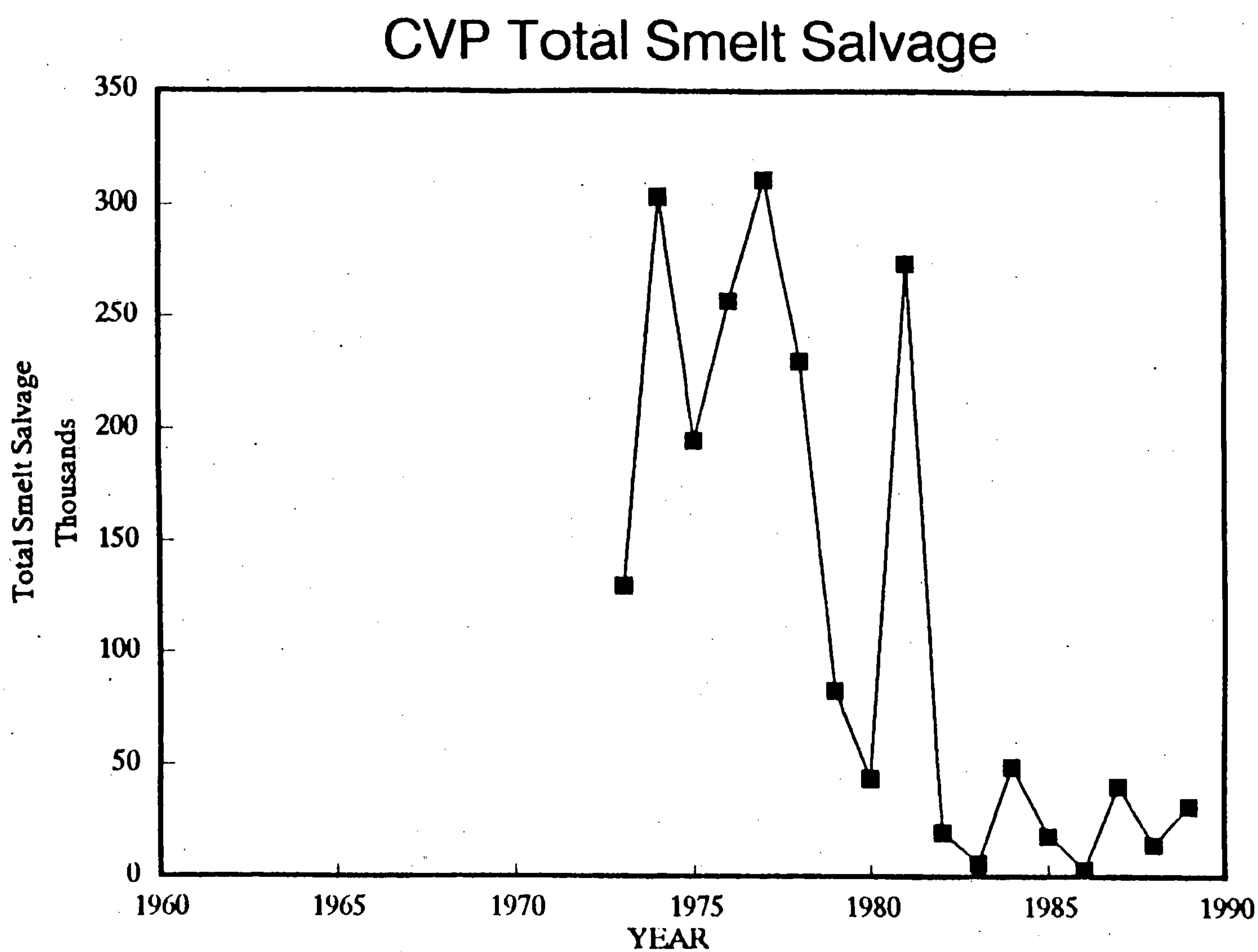



Figure 10. Annual salvage estimates for total smelt (delta smelt and longfin smelt) at the Central Valley Project fish screens.

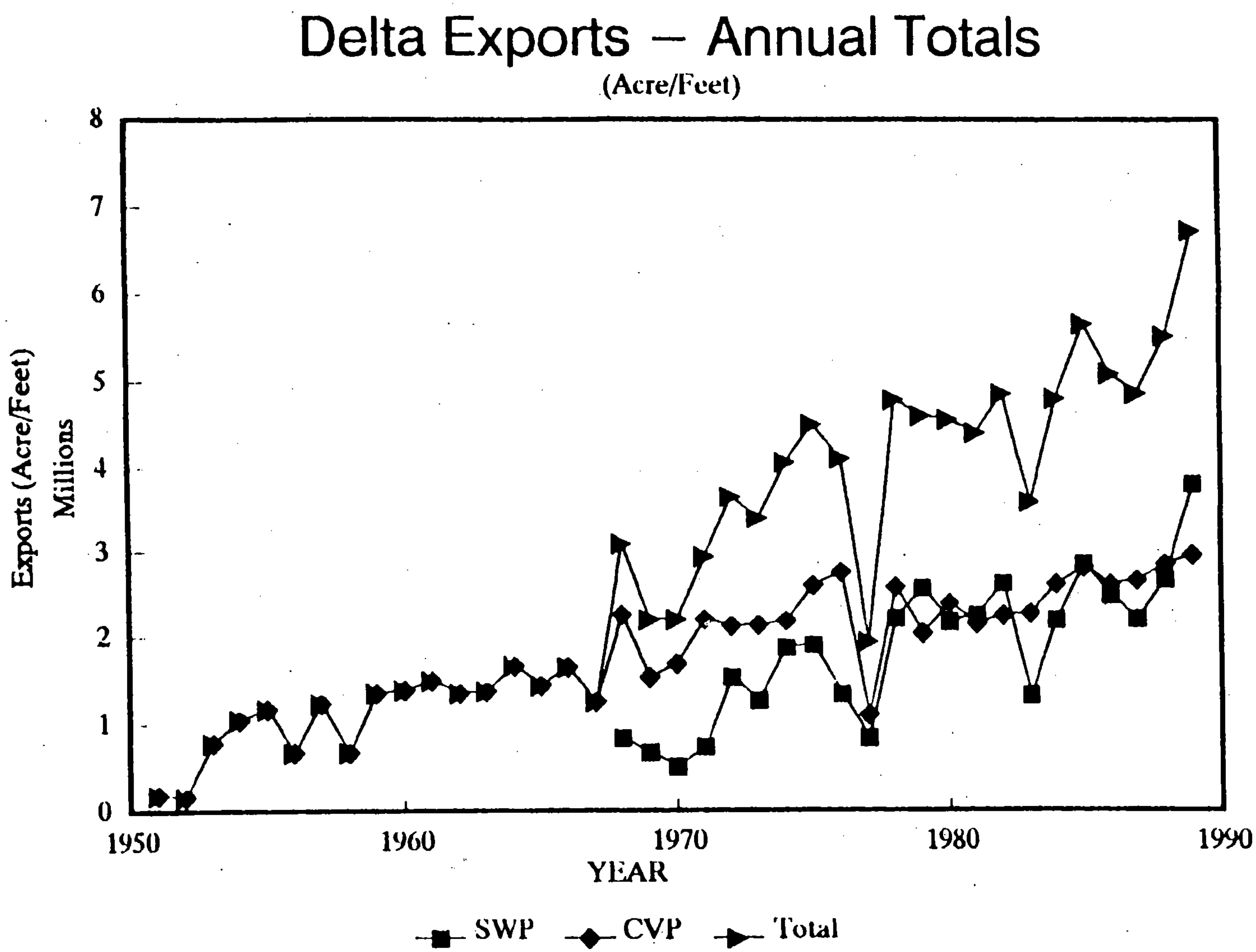



Figure 11. Trend in annual water exports by the State Water Project and Central Valley Project.

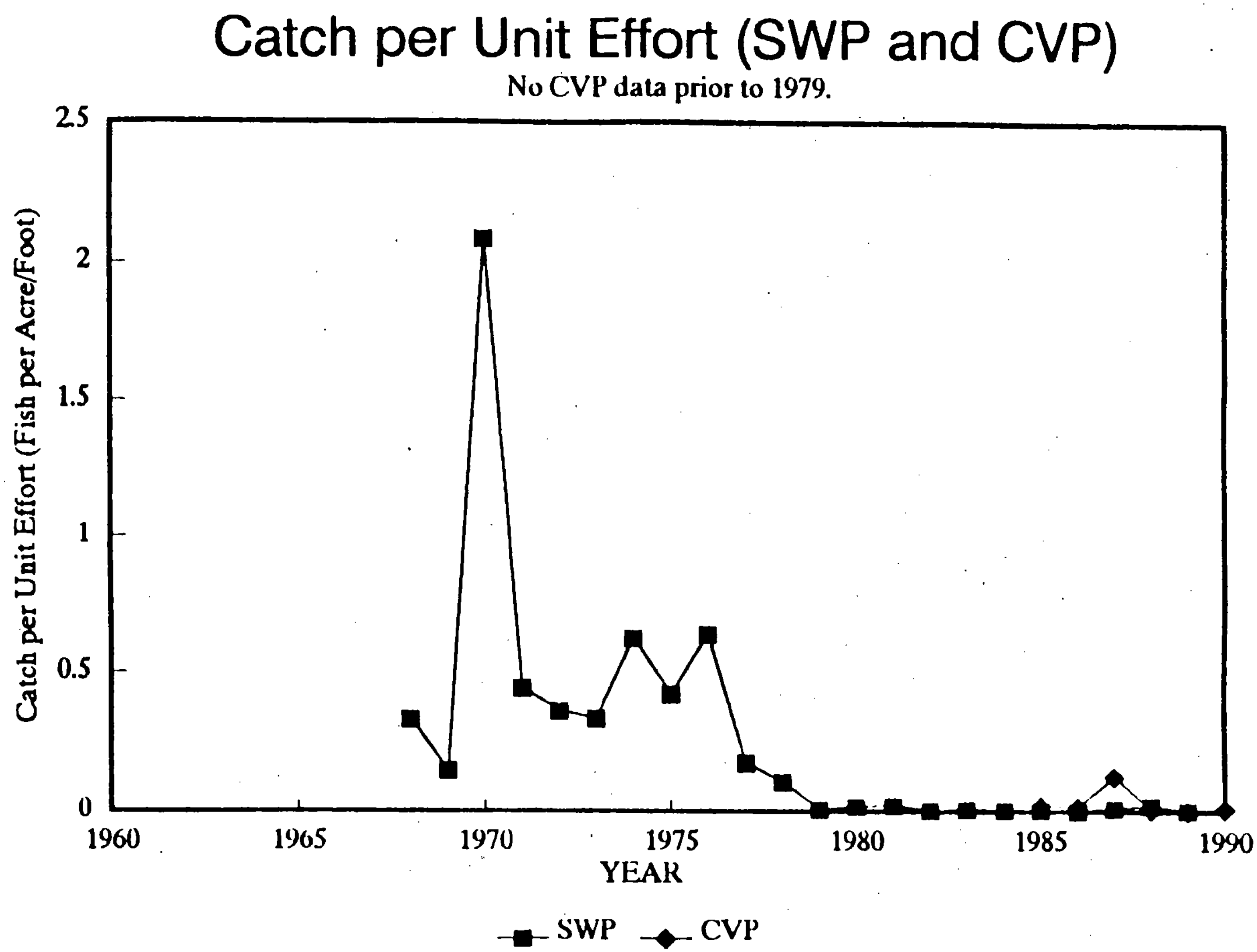



Figure 12. Salvage of delta smelt per acre foot of water diverted by the State Water Project and Central Valley Project.

UC Davis Suisun Marsh Survey

Drs. Peter Moyle and Bruce Herbold and classes at the University of California, Davis have used otter trawls to sample fish populations in Suisun Marsh sloughs since 1979. They have provided us with their delta smelt abundance index for the Marsh based on the number of smelt caught per tow each year. Over the 11-year survey, the UC Davis classes collected 465 delta smelt, all but one of which was collected before 1984 (Figure 4). Delta smelt were rather scarce when the survey began in 1979. Catches improved considerably in 1980 and 1981 with the peak catch of 229 fish occurring in 1981. Subsequently, in 1982 and 1983, delta smelt abundance declined below the 1979 level, and since 1984 they have been virtually non-existent.

Because the UC Davis sampling locations are limited geographically and because the geographical distribution of delta smelt varies annually, we believe that other data sources provide a better depiction of the overall population trend. However, the UC Davis survey is consistent with the other data sources in exhibiting a much lower current population of delta smelt.

Conclusions Regarding Delta Smelt Abundance Trend

All delta smelt abundance indices have declined in recent years, but the timing of their decline varies somewhat depending on which measure is used. The summer townet survey and fall midwater trawl survey provide the best geographical coverage of the delta smelt population; thus, they provide the best basis for evaluating population trends. Information from the other data sources confirms the general downward trend in delta smelt abundance and allowed additional insight into distribution patterns not covered by the summer and fall surveys.

Based on the summer and fall surveys, the delta smelt population has been consistently low every year since 1983. While the population had been as low or nearly as low in some previous years, no multiple year period of low abundance had occurred previously during the period of record beginning in 1959.

Looking at the decline by geographical areas (Figures 13 and 14), it is apparent that the delta smelt decline may have begun earlier in the south and east delta than in the rest of the Estuary. An earlier decline in these areas is consistent with the decline suggested by the fish salvage data from the water project diversions in the south Delta.

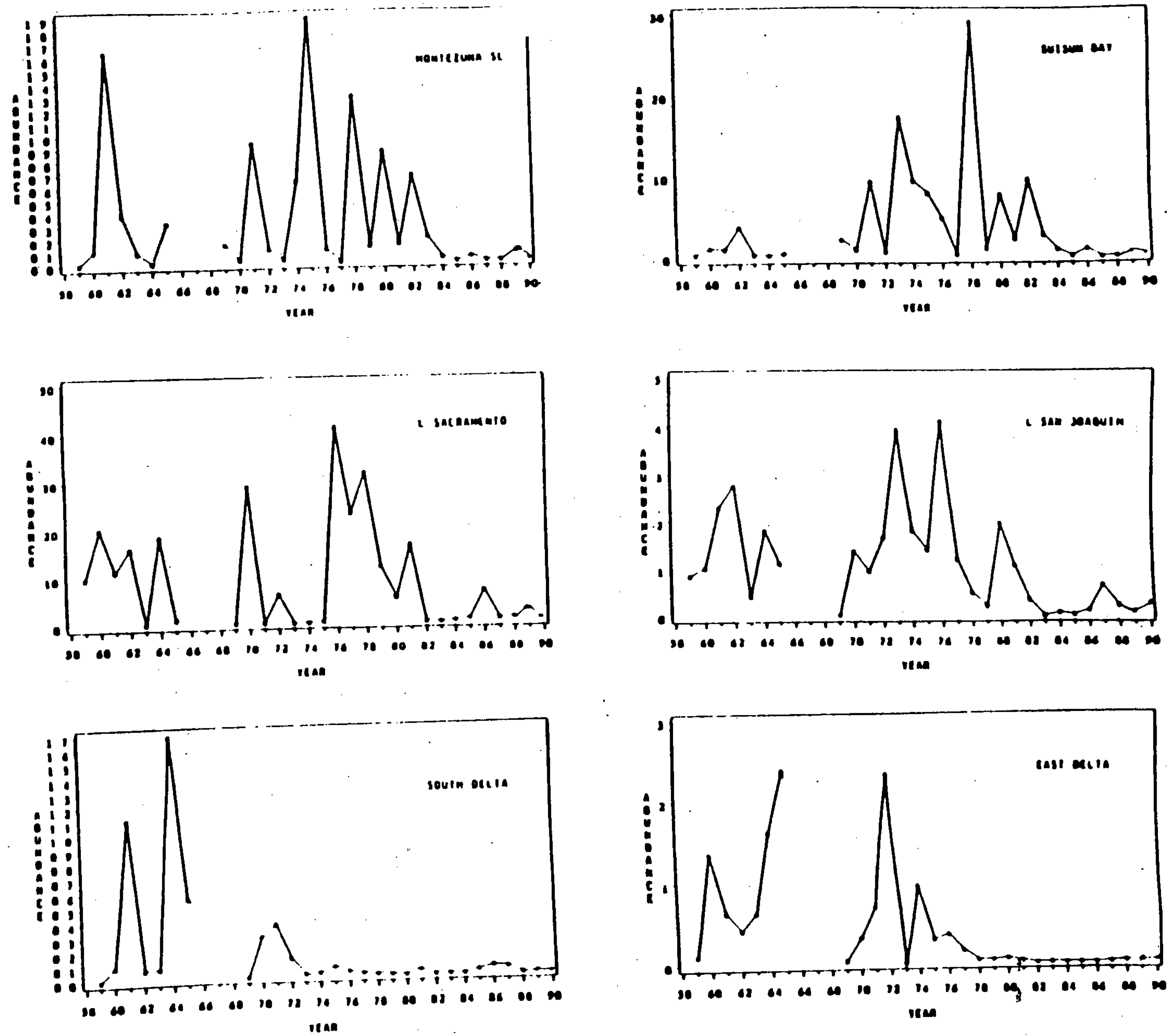



Figure 13. Abundance of delta smelt by area based on the summer townet survey. L. Sacramento is the Sacramento River between Collinsville and Rio Vista. L. San Joaquin is the San Joaquin River between Antioch and San Andreas shoal west of the Mokelumne River.

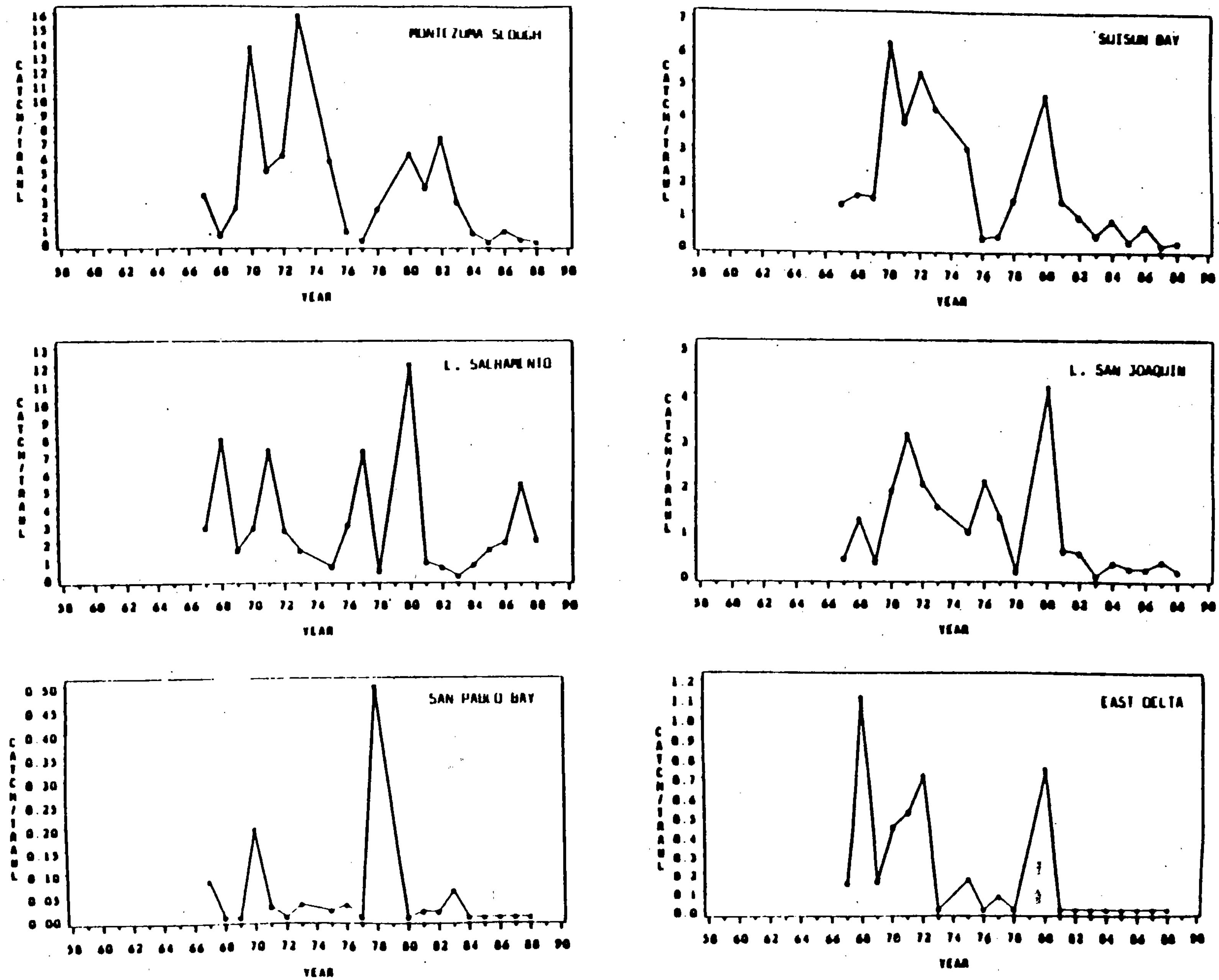



Figure 14. The catch-per-tow of delta smelt in the midwater trawl survey by areas comparable to those used for the townet survey (Figure ) except for the addition of San Pablo Bay and the deletion of the South Delta which was not sampled after 1975.

Except for the years since 1981, the fall indices do not show good agreement with the summer indices, possibly reflecting imprecision in one or both data sets, or that before 1981 environmental factors modified year class strength substantially between summer and fall. In either case, the delta smelt population decline since 1983 appears to have been a direct result of lower recruitment to the summer population.

For further insight into the nature of the decline, we examined the percent of the townet and midwater trawl survey tows that caught one or more delta smelt and the mean catch in those tows (Figure 15). In the townet survey the frequency of tows capturing smelt has declined as has the mean catch in those tows.

These trends indicate that the summer population has fewer and less dense aggregations than it did previously. The frequency of fall tows capturing delta smelt has also declined, but the mean catch in those tows has not changed appreciably. Hence, in the fall there now are fewer aggregations, but those present are similar in density and/or size to those of the past. This difference in summer and fall data may reflect an increased tendency toward schooling behavior as the smelt grow older. Since delta smelt abundance has declined in all areas (Figures 13 and 14), it is apparent that the decline in the number of tows

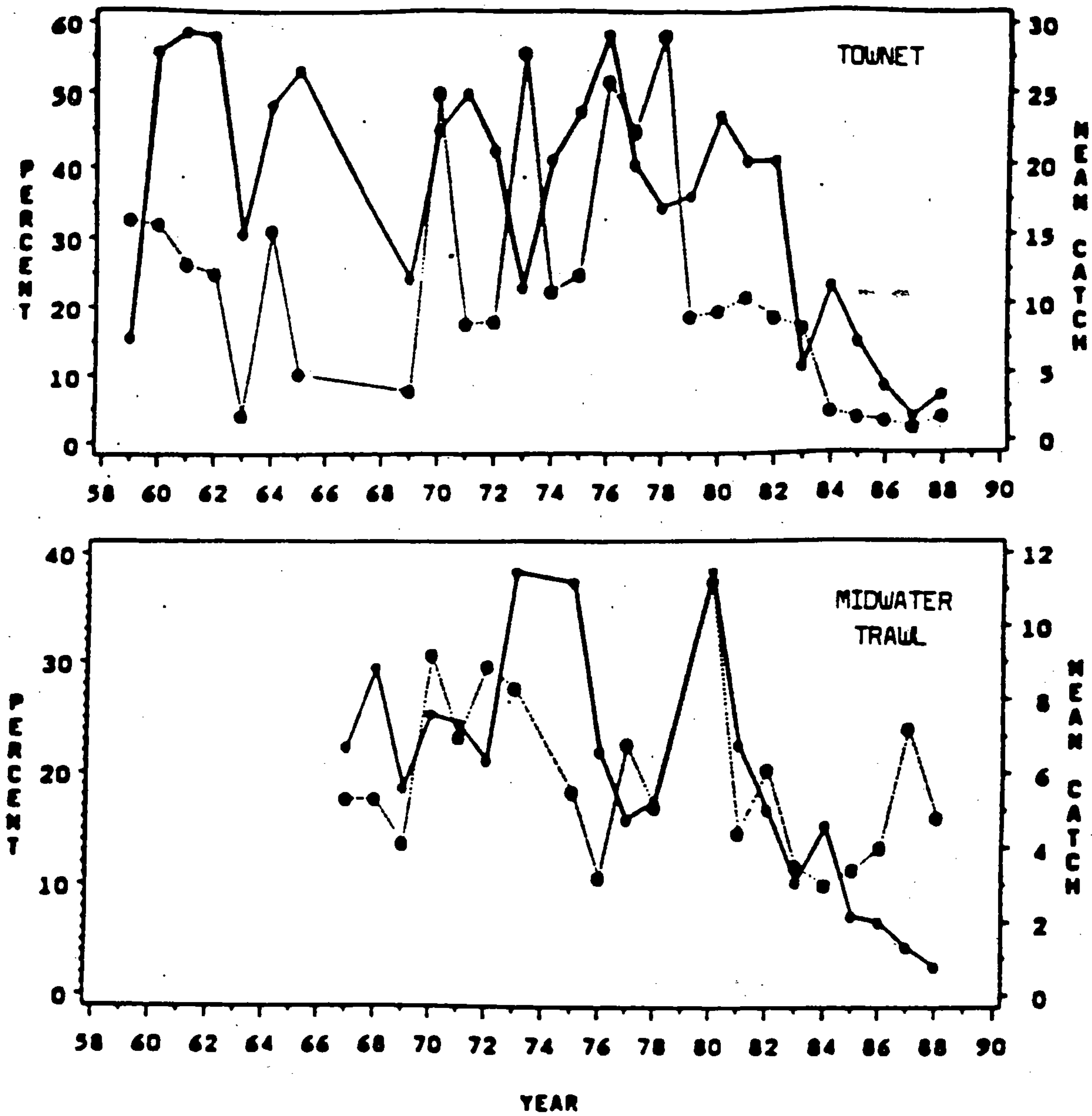



Figure 15. The percent of tows capturing delta smelt (solid line) and the mean catch of delta smelt in those tows (dotted line).

capturing them is not due to a diminishing of the delta smelt's range within the Estuary. Instead, the decline is simply due to reduced probability of capture associated with a general decline in abundance.

To determine if the apparent decline in delta smelt abundance was statistically significant, we used an Analysis of Variance (ANOVA) with Tukey's test for grouping years for which there are no significant differences. This analysis was based on logarithmic transformations of catch per tow in the townet and trawl surveys. The ANOVA demonstrated significant differences between years and the Tukey's ranking generally separated the recent years into a common group separate from earlier years although there were a few exceptions such as 1959, 1963 and 1969 in the townet survey groupings (Tables 11 and 12).

Population Size

To address the question of delta smelt abundance, we multiplied, for the fall midwater trawl survey, the ratio of delta smelt juveniles to young striped bass by rough estimates of striped bass population size which are available for 8 years. Using this approach, albeit imperfect due to unknown catch vulnerabilities, we estimate that the fall delta smelt population is now several hundred thousand fish (Table 13). In the early 1970s, estimates were on the order of 2 million fish.

Table 11. Tukey's studentized range test for detecting differences in $\log_{10}$ mean catch per tow of delta smelt by the townet survey. Means with the same Tukey grouping letter are not significantly different ($p. < 0.10$).

| Tukey Grouping | Mean | N | Year |
|---|---|---|---|
| A | 0.56 | 174 | 1961 |
| A B | 0.53 | 167 | 1976 |
| A B C | 0.48 | 186 | 1962 |
| A B C D | 0.43 | 176 | 1971 |
| A B C D | 0.43 | 186 | 1964 |
| A B C D | 0.42 | 135 | 1960 |
| A B C D | 0.41 | 175 | 1975 |
| A B C D | 0.40 | 184 | 1978 |
| B C D E | 0.38 | 183 | 1980 |
| B C D E | 0.38 | 172 | 1974 |
| B C D E | 0.38 | 186 | 1970 |
| B C D E | 0.36 | 176 | 1982 |
| C D E | 0.35 | 152 | 1977 |
| C D E | 0.35 | 176 | 1981 |
| C D E F | 0.38 | 186 | 1965 |
| D E F G | 0.29 | 172 | 1972 |
| D E F G H | 0.27 | 178 | 1973 |
| E F G H I | 0.22 | 189 | 1979 |
| F G H I | 0.17 | 134 | 1959 |
| F G H I | 0.16 | 181 | 1986 |
| G H I | 0.14 | 186 | 1963 |
| H I | 0.12 | 151 | 1983 |
| H I | 0.11 | 182 | 1969 |
| H I | 0.10 | 161 | 1984 |
| I | 0.07 | 159 | 1988 |
| I | 0.07 | 175 | 1987 |
| I | 0.05 | 164 | 1985 |

Table 12. Tukey's studentized range test for detecting differences in $log_{10}$ mean catch per tow of delta smelt for the midwater trawl survey. Means with the same Tukey grouping letter are not significantly different ($p < 0.10$).

| Tukey Grouping | | | | | | | Mean | N | Year |
|---|---|---|---|---|---|---|---|---|---|
| A | | | | | | | 0.31 | 326 | 1980 |
| A | | | | | | | 0.30 | 324 | 1973 |
| A | B | | | | | | 0.25 | 295 | 1975 |
| | B | C | | | | | 0.20 | 385 | 1970 |
| | B | C | | | | | 0.19 | 404 | 1968 |
| | | C | D | | | | 0.17 | 390 | 1971 |
| | | C | D | E | | | 0.17 | 364 | 1972 |
| | | C | D | E | F | | 0.14 | 335 | 1967 |
| | | C | D | E | F | | 0.14 | 332 | 1981 |
| | | | D | E | F | G | 0.11 | 332 | 1969 |
| | | | D | E | F | G | 0.11 | 478 | 1977 |
| | | | | E | F | G | 0.10 | 456 | 1978 |
| | | | | E | F | G | 0.10 | 358 | 1982 |
| | | | | | F | G | 0.08 | 364 | 1986 |
| | | | | | F | G | 0.08 | 353 | 1984 |
| | | | | | F | G | 0.07 | 386 | 1987 |
| | | | | | | G | 0.05 | 370 | 1983 |
| | | | | | | G | 0.04 | 358 | 1985 |
| | | | | | | G | 0.04 | 369 | 1988 |

Table 13. Estimates of Delta Smelt abundance based on the ratio of Delta smelt abundance to young striped bass abundance in the fall midwater trawl survey multiplied by population estimates of young striped bass derived from a life table analysis.

| Year | Striped Bass Index | Delta Smelt Index | Ratio Smelt: Bass | Striped Bass Population (in millions) | Delta Smelt Population (in thousands) |
|---|---|---|---|---|---|
| 1968 | 4109 | 696 | .17 | 1.8 | 300 |
| 1970 | 8144 | 1677 | .21 | 8.1 | 1670 |
| 1971 | 9069 | 1306 | .14 | 11.9 | 2670 |
| 1972 | 6101 | 1267 | .21 | 12.7 | 2630 |
| 1975 | 4538 | 698 | .15 | 1.6 | 240 |
| 1977 | 844 | 483 | .57 | 0.4 | 230 |
| 1984 | 6584 | 181 | .03 | 11.8 | 350 |
| 1985 | 1757 | 109 | .06 | 4.7 | 280 |

## Population Age Structure

We examined length-frequency data for the townet and midwater trawl surveys for 1977, 1978 and 1980 to learn more about the size and age structure of the population (Figures 16 and 17). In both data sets, two year classes of delta smelt were evident. The juveniles from the current year's production form one group in the size range of 15 mm to about 65 mm in summer and up to about 90 mm in the fall. Second groupings of larger smelt up to 130 mm indicate that a few adults survive the rigors of spawning and live into the following winter. However, since these larger adults are so scarce, one-year old fish form almost the entire spawning population each year.

# FACTORS AFFECTING DELTA SMELT ABUNDANCE

What factors regulate abundance of each year class of delta smelt? Considering that most delta smelt spawn only once, the abundance of the previous year class and its egg production is potentially important. We evaluated the potential role of egg production by examining spawner-recruit relationships using the summer townet survey data alone, a combination of the summer townet data and the midwater trawl data, and the midwater trawl data alone (Figure 18). In the best case, that for the midwater trawl data alone, the spawning stock abundance accounted for

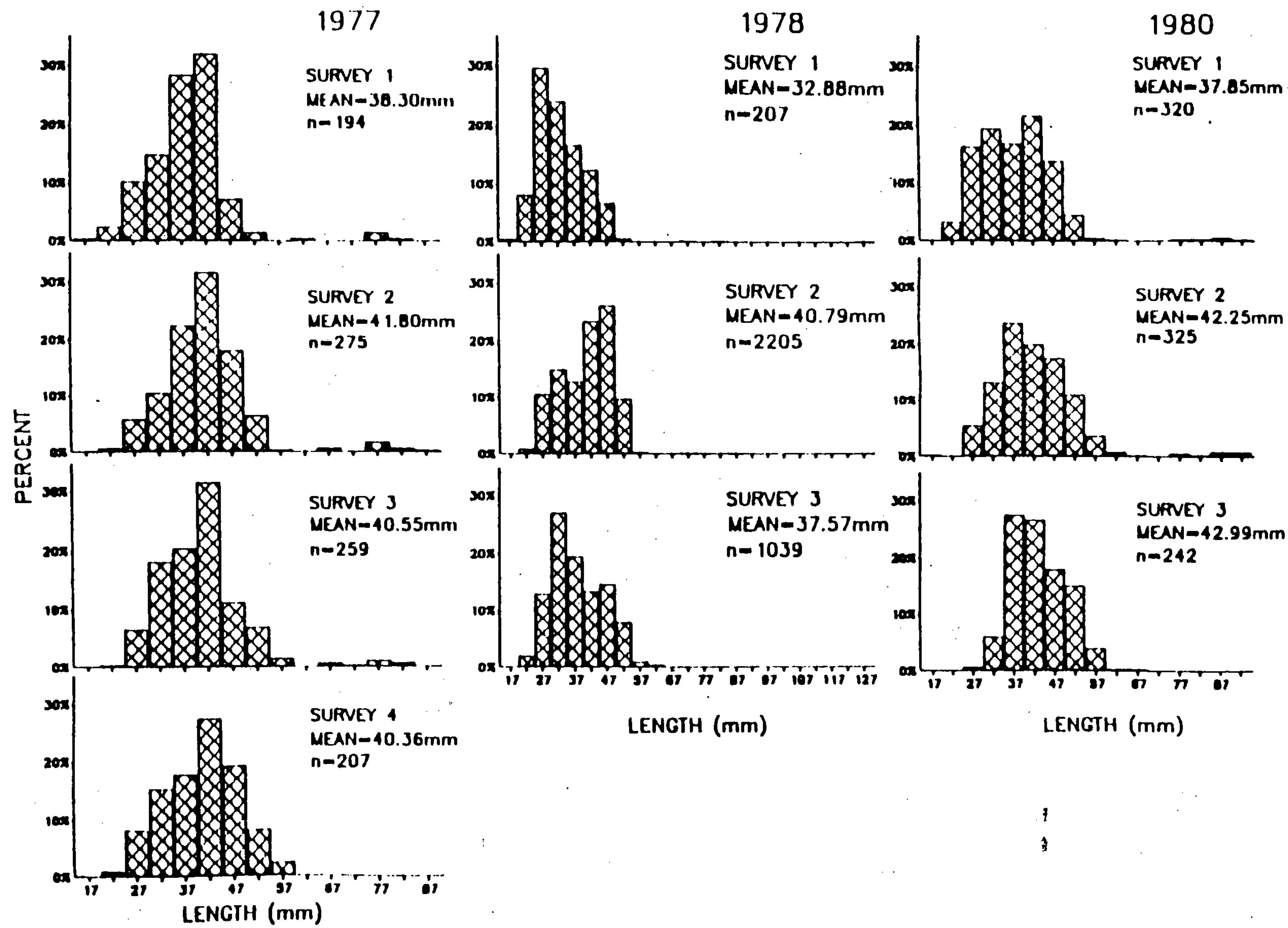



Figure 16. Length frequency distribution of delta smelt catches in the 1977, 1978 and 1980 townet surveys.

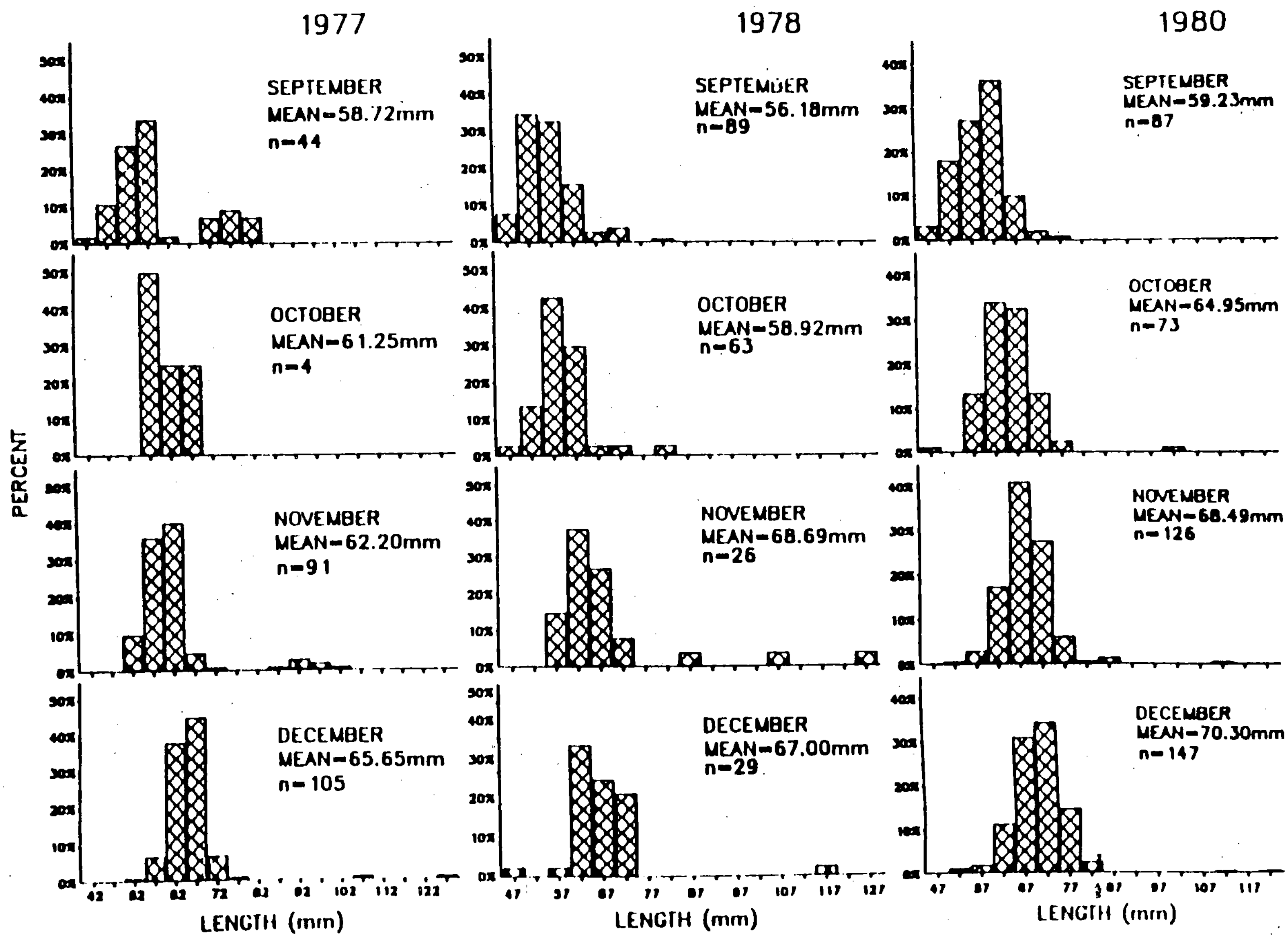



Figure 17. Length frequency distribution of delta smelt catches in the 1977, 1978 and 1980 midwater trawl surveys.

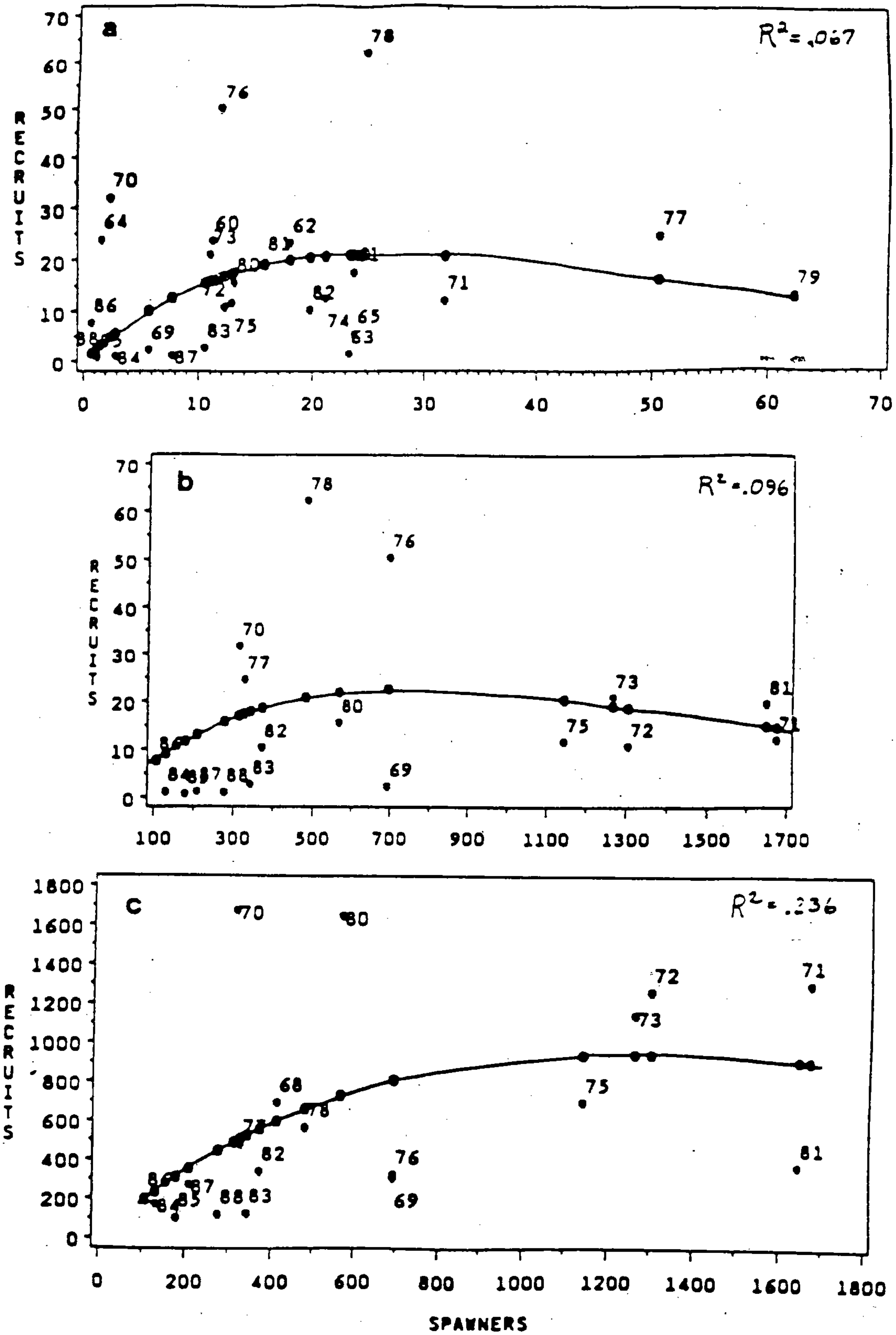


Figure 18. Spawner-recruit relationships for delta smelt: (a) the townet index (spawners) and the townet index for the following years (Recruits), (b) the midwater trawl index (spawners) and the townet index the following year (Recruits) and (c) the midwater trawl index (spawners) and the midwater trawl index the following year (recruits).

about one-quarter of the variability in recruitment (abundance ofthe next year class).

If egg production was the sole factor influencing year class success, the delta smelt population would be stable. In reality, abundance indices (based on fall trawl survey) have varied from 105 (1985) to 1840 (1980), a 17.5 fold difference. Also, as described previously, until 1981, the fall and summer indices did not show good agreement. These facts and the relatively weak spawner-recruit relationships strongly suggest that abundance of a delta smelt year class largely depends on the environmental conditions experienced by the eggs and young fish. We used multiple regression analyses to search for environmental factors which may affect delta smelt abundance. Specifically, we examined potential effects of:

1) Delta outflows - Moyle and Herbold (1989) suggest that delta smelt year class production is favored by moderately high flows which place the primary nursery area in the Suisun Bay region. Outflows are known to influence abundance of several other species in the Estuary including striped bass (Turner and Chadwick 1972, CDFG 1987), longfin smelt (*Spirinchus thaleichthys*), American shad (*Alosa sapidissima*) (Stevens and Miller 1983) and bay shrimp (*Crangon* sp) (Bay-Delta Project, unpublished). We included outflow and $outflow^2$ terms. The $outflow^2$ term allows the regression

predictions to decline if smelt abundance peaks at moderate flows and declines at higher flows.

2) Diversions from the spawning and nursery area - Major State and Federal water projects, Pacific Gas and Electric Company power plants, and other industry and local agriculture operations divert huge amounts of water from the Delta during the spawning and nursery period (pages 62 to 73). Many young and adult delta smelt entrained by these diversions are removed from the population. Recent analyses (Stevens et al. MS) indicate that such entrainment losses have caused a severe decline in the Sacramento-San Joaquin Estuary's striped bass population. We used total water exports as measures of diversions.

3) Food supply - Delta smelt feed on zooplankton, especially copepods (pages 4 to 6). Thus, availability of these zooplankton for young smelt potentially could affect their growth, survival and abundance. We used copepod densities (exclusive of nauplii and Sinocalanus doerii) to measure food supply.

4) Reverse flow - Due to water project pumping in the south delta the lower San Joaquin River frequently flows backwards and transports small fish toward the diversions (pages 64 to 67). Moyle and Herbold (1989) suggest that this process is detrimental to delta smelt. We used the number of days of net reverse flow at Jersey Point on the San Joaquin River as our measure of reverse flow.

5) <u>Water temperature</u> - Temperatures may affect delta smelt abundance through effects on growth and mortality. We used average maximum temperatures from the U.S. Geological Survey monitoring station on the Sacramento River at Freeport to provide a general, albeit imperfect, indication of annual temperature conditions.

6) <u>Water transparency</u> - Water transparency may reflect general productivity of the Estuary and/or vulnerability of delta smelt to predation by other fishes. Delta waters have tended to become clearer in recent years (California Fish and Game 1988). We used average Delta-Suisun Bay secchi disc readings from the Bay-Delta project's zooplankton survey as a general indicator of water transparency.

We tested one, two and three variable models for the summer townet survey and fall midwater trawl survey indices using all combinations of these environmental factors (RSQUARE procedure in SAS version 5, 1985). Both abundance indices were evaluated against averages of the environmental factors during the March-June spawning and early nursery period, and the fall midwater trawl index was also evaluated against averages for the July-October late nursery period.

Care must be taken in interpreting results of such regression searches, as even the moderate number of input variables that we used, may lead to some chance relationships which are spurious.

At best, any of the regression models should only be considered as "suggestive" mechanisms which require further testing.

$R^2$ values indicate that none of the models based on March-June environment explain a satisfactory amount of variability in smelt abundance (Appendices E and F). Of the July-October variables, copepod abundance and water transparency dominated the best models and themselves accounted for almost 70% of the variability in the midwater trawl index (Appendix G). However, despite this apparent association between delta smelt abundance and July-October copepods and water transparency, the importance of these factors should, at best, be considered tentative. Comparisons between the summer townet survey and fall midwater trawl indices suggest that since 1983, at least, delta smelt year class strength has been set before July.

## THREATS

Numerous factors potentially threaten the existence of the delta smelt which has probably been at all-time low abundance levels since 1983. Discussion of several of the most obvious factors follows.

## Food Supply

Zooplankton abundance in the Estuary has been monitored by the Department's zooplankton monitoring survey since 1972. Zooplankton also have been monitored in the spring since 1984 by the striped bass egg and larva survey. These surveys demonstrate that densities of *E. affinis*, the most common copepod in the delta smelt's diet, were relatively stable prior to 1988. However in 1988, a major decline in *E. affinis* occurred over much of the delta smelt's range (Table 14). This decline coincided with the accidental introduction and population explosion of the clam, *Potamocorbula amurensis*, (pages 78 and 79). The most recent years, 1988 and 1989, provide somewhat ambivalent results regarding the impact of the decline of *E. affinis* on delta smelt. In 1988, the midwater trawl index for delta smelt was at its next to lowest level; however, in 1989, while still very low from a historic perspective, this index rebounded to its highest level since 1983. Nevertheless, the recent decline in this major diet component, still must be considered as a potential threat to the delta smelt's recovery unless other food resources compensate or *E. affinis* recovers to its former abundance.

Table 14. Mean Density of *Eurytemora affinis* per m³ in the Estuary during May and June.

| Year | EC < 1000 uS Zooplankton Survey | EC < 1000 uS Egg and Larva Survey | EC > 1000 uS Zooplankton Survey | EC > 1000 uS Egg and Larva Survey |
|---|---|---|---|---|
| 1972 | 588 | | 4301 | |
| 1973 | 589 | | 1884 | |
| 1974 | 1017 | | 4980 | |
| 1975 | 378 | | 1378 | |
| 1976 | 369 | | 1794 | |
| 1977 | 370 | | 2232 | |
| 1978 | 639 | | 4172 | |
| 1979 | 262 | | 2390 | |
| 1980 | 176 | | 1466 | |
| 1981 | 258 | | 1410 | |
| 1982 | 533 | | 3246 | |
| 1983 | 806 | | 2673 | |
| 1984 | 128 | 64 | 1556 | 737 |
| 1985 | 51 | 50 | 1006 | 465 |
| 1986 | 485 | 82 | 2504 | 1128 |
| 1987 | 389 | -- | 1437 | -- |
| 1988 | 106 | 48 | 88 | 58 |
| 1989 | --- | 22 | -- | 29 |

Low Spawning Stock

Our evaluation of factors regulating delta smelt abundance failed to show that spawning stock abundance had a major influence on delta smelt year class success (pages 52 to 56). Nevertheless, the relatively low fecundity of this species and their planktonic larvae, which undoubtedly incur high rates of mortality, means that annual reproduction must be accomplished by fairly large numbers of fish if the population is to perpetuate itself (Moyle and Herbold 1989). Thus, while the stock abundance may not have been an important factor in the past, present or future low stock levels may inhibit potential for population recovery. Pimm et al. (1988) show that small species with variable populations, like delta smelt, become increasingly vulnerable to extinction as their populations decrease.

**Entrainment in Water Diversions**

Delta smelt larvae are lost to entrainment in water diversions of the CVP, SWP, and Delta agriculture, the Pacific Gas and Electric Company (PGE) and other industry using water from the Estuary.

The 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 (delta smelt & longfin smelt --

larval smelt are difficult to identify to species and there has not been an attempt to identify them during any of the entrainment monitoring programs) 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 on the power plant intake screens were 11,000 fish at Pittsburg and 6,400 fish at Contra Costa.

There is no information available on delta smelt losses in the myriad of delta agriculture diversions which are not screened at all. However, during sampling on 20 days from November 1980-May 1981 and September 1981-March 1982, the delta smelt was the most numerous species entrained in the unscreened Roaring River Slough diversion from Montezuma Slough for water distribution in the Suisun Marsh (Pickard et al. 1982). This sampling, which generally consisted of placing a net over 1 of 8 intake culverts for several hours, captured 5,841 delta smelt.

Substantial entrainment losses also occur at the CVP and SWP despite their intakes being miles from the primary spawning and nursery areas. These losses occur due to the magnitude of the water project diversions, their impact on Delta flow patterns, and the tendency for young delta smelt to be transported and dispersed by river and estuarine currents.

The CVP and SWP pumps are located at the southern edge of the Delta, but pumping rates usually exceed the flow of the San Joaquin River entering the Delta from the south; therefore, most of the water that they export must come from the Sacramento River. Approximately the first 3,500 cfs of flow exported from the Sacramento River crosses the Delta through the CVP's Delta Cross Channel and Georgiana Slough near Walnut Grove and flows to the pumps through natural channels upstream from the mouth of the San Joaquin River. Young smelt that were spawned in the water transport channels or in the Sacramento River upstream from Walnut Grove would be particularly vulnerable to this water management scheme. At higher export rates, water is drawn up the San Joaquin River from its junction with the Sacramento River (Figure 19). Such net upstream flows in the San Joaquin River are typical in all but wet springs, and in the summer and fall of all years. The upstream flows entrain young smelt from the western Delta and carry them to the water project intakes.

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 (Figure 20) while low frequencies of reverse flows sometimes were associated with high abundances of delta smelt. They (MS) also point to a trend of increasing reverse flows in the San Joaquin River, especially during the spawning months.

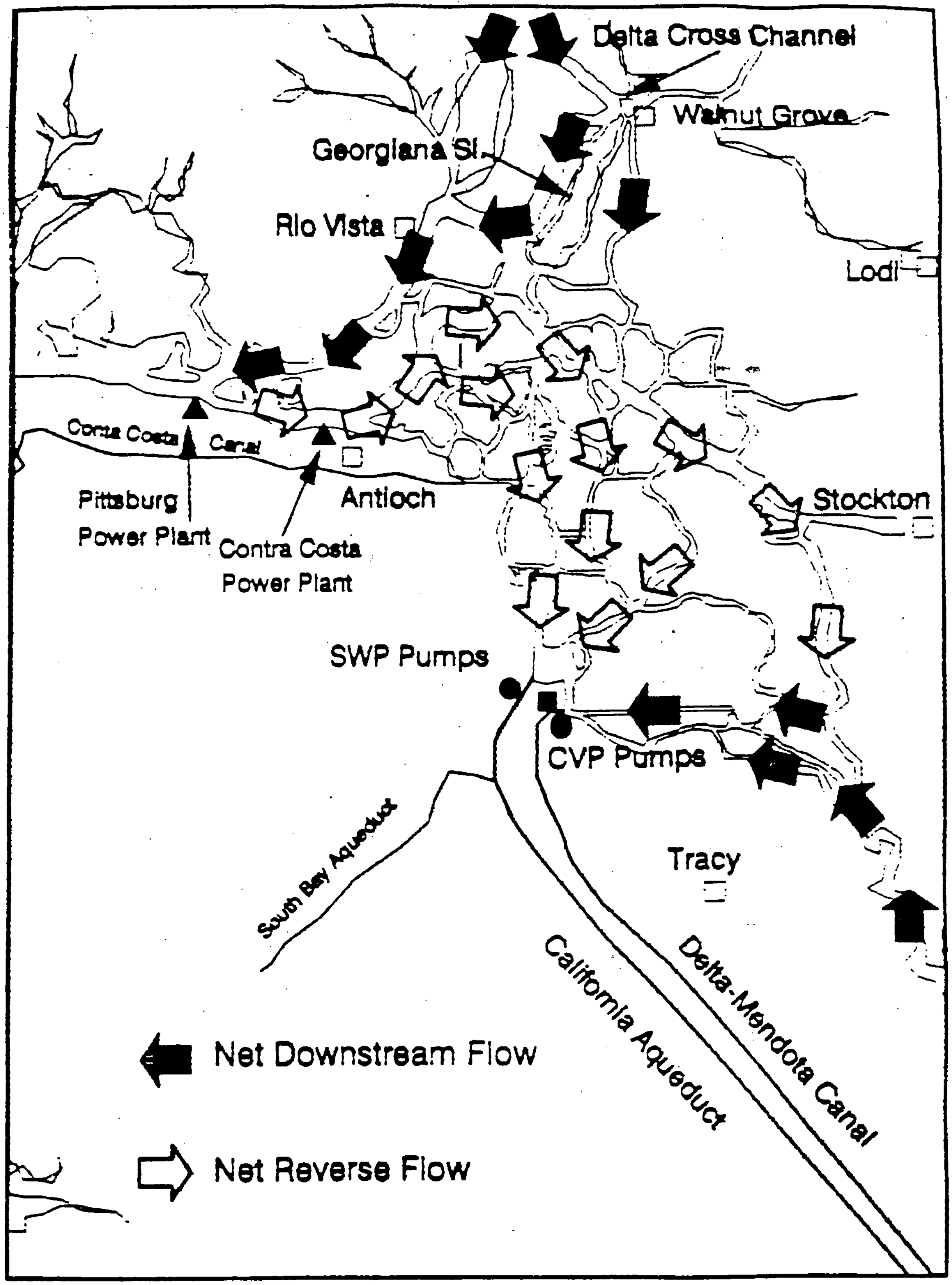



Figure 19. Typical summer flow patterns in the Sacramento-San Joaquin Delta. CVP-SWP export pumping has changed the natural flow patterns. Reverse flows transport many delta smelt from their nursery to the CVP-SWP diversions in the south Delta.

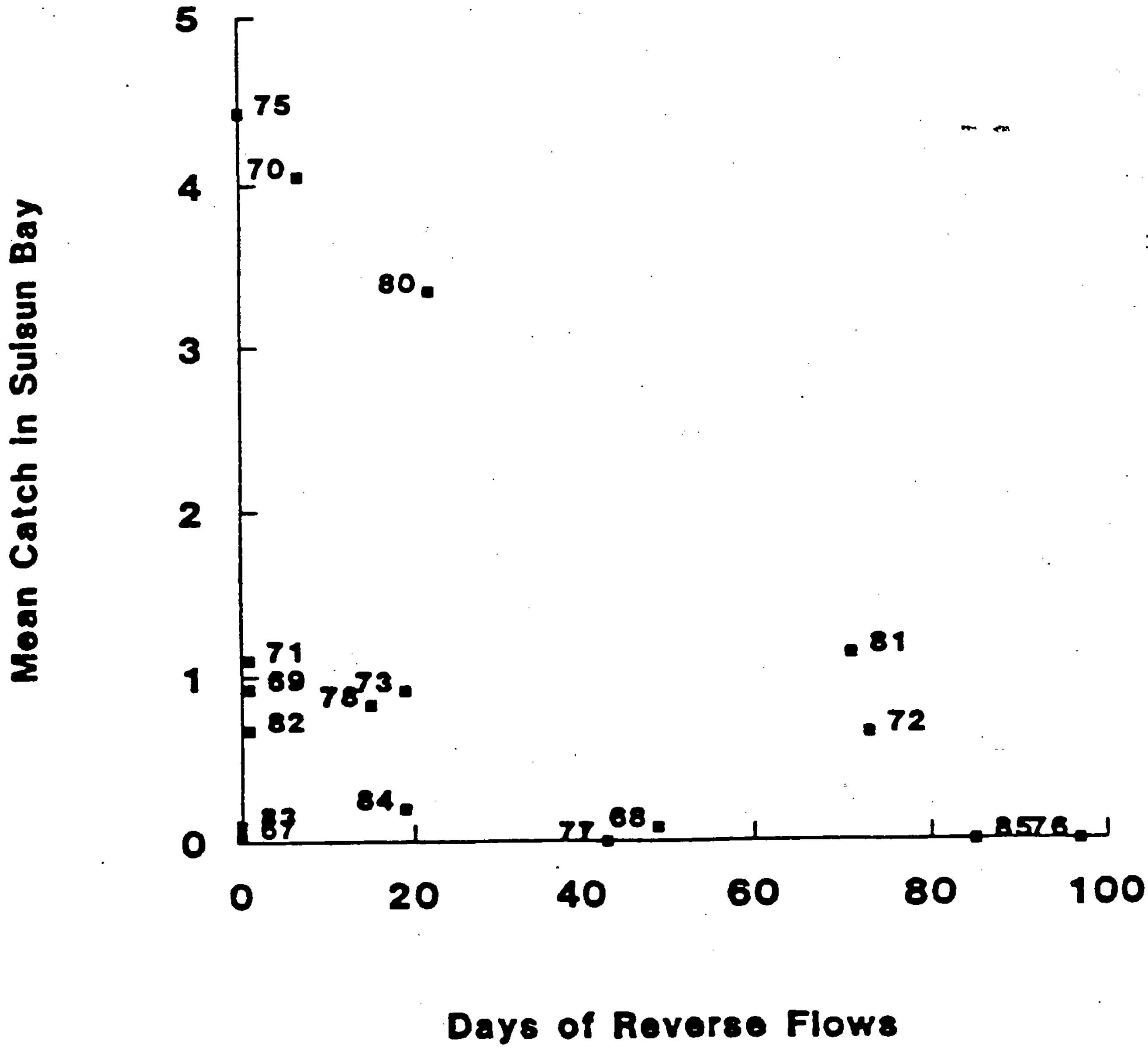



Figure 20. Mean Densities of fall populations of Delta smelt in Suisun Bay vs. numbers of days of reverse flows in the San Joaquin River during March to June. From Moyle and Herbold (1989).

Such, an association between reverse flows and smelt abundance is conceptually reasonable although it may, at least partly, reflect other correlated impacts of low river inflows or outflows. The sometimes low abundance indices at low reverse flows and the lack of association between reverse flows and smelt since 1983 indicate that reverse flows are not the sole mechanism driving the delta smelt population. A plot using the total population index is similar to that for the Suisun Bay portion, except for 1972 when delta smelt abundance was high despite 72 days of reverse flows during March-June (Figure 21).

Even when the net flow of the lower San Joaquin River is not reversed, net flow usually is still reversed in the southern Delta; thus, deltawide, there is dispersal of fish associated with the ever changing tides which maintains their exposure to entrainment by the CVP and SWP. The reverse flow of the southern Delta draws young fish and their food organisms out of the spawning and nursery areas to the north and transports them to the diversion sites.

The louver screens in front of the SWP and CVP pumps guide many of the young fish to holding tanks and tank trucks in which they are transported back to the western Delta and released. However, numerous fish, particularly larvae and others too small to swim well, pass through the screens and are lost into the aqueduct

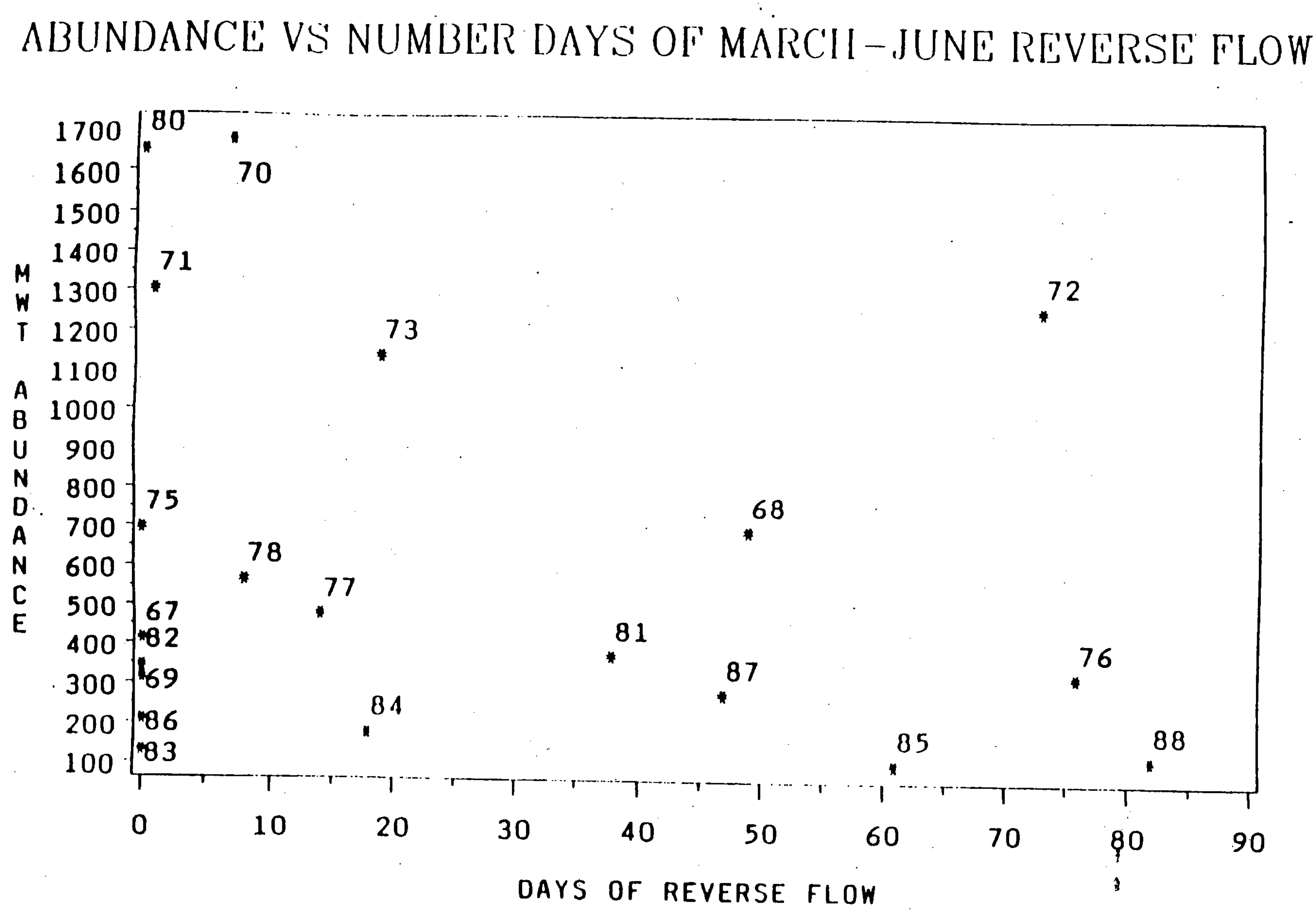



Figure 21. Relationship between fall midwater trawl index of delta smelt abundance and the number of days of reverse flows in the Lower San Joaquin River from March to June.

system. Substantial numbers of the many young delta smelt that are salvaged (pages 31 to 41) also die due to stresses received during the handling and trucking. Others are eaten by larger fish in the SWP's Clifton Court Forebay and near the trash racks at both the CVP and SWP screens. These factors have not been evaluated for delta smelt but are known to be significant detriments to striped bass (DFG 1987).

Delta smelt are most vulnerable to entrainment during spring and summer as shown by the number salvaged per-acre-foot of exports by the SWP (Figure 22). This pattern reflects the late winter-spring spawning season and growth and mortality of young fish. During April and May, abundance of young smelt at the SWP and CVP diversions probably is greater than shown in Figure 22. However, this tendency is not displayed by the salvage estimates because the smelt are so small that they pass through the screens and are not salvaged during the first month or two of life. Also, smaller smelt are not readily identifiable by the technicians responsible for sampling salvaged fish.

The intra-year salvage pattern in 1977-1978 was a notable exception to the typical pattern. Through much of 1977, water exports were reduced, due to a major drought, and while a delta smelt salvage peak occurred in July, the greatest entrainment and salvage of the 1977 year class occurred from December 1977

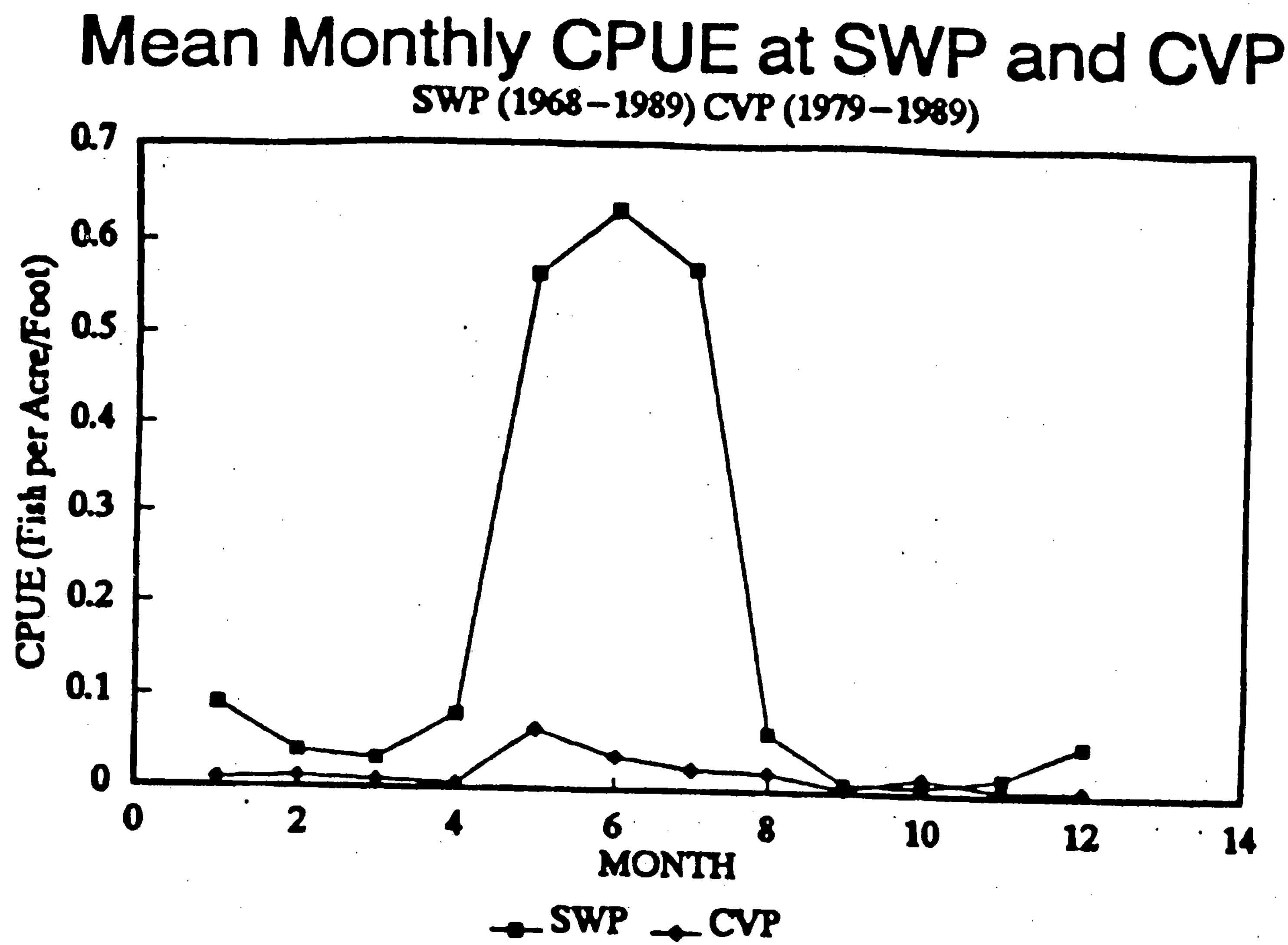



Figure 22. Mean monthly salvage of delta smelt per acre foot of water diverted by the State Water Project and Central Valley Project.

through February 1978 when water exports increased after the drought broke (Table 15). In fact, the salvage of 134,000 delta smelt at the SWP in January 1978 almost equaled the total for allof 1977 (146,000 fish) and exceeds the annual totals for all subsequent years.

What is the importance of entrainment losses with respect to the population decline of delta smelt? This is unclear. Comparisons of estimated population levels (Table 13) and salvage estimates (Figures 4, 8 and 9) suggest entrainment losses potentially could cause major reductions in delta smelt abundance. The greatest annual salvage, and probably losses, to water project diversions occurred from 1970 to 1976 (Figure 8). Considering that few delta smelt live beyond 1 year, if such entrainment depleted the population, the impact should be noticeable the following year. Yet the population apparently did not crash until 1983, 13 years after 1970, the initial year of record with a major salvage. Also, looking at the salvage data alone, one might hypothesize that the unusual entrainment of maturing adults in 1977-1978 had critically depleted the stock, but again this hypothesis is inconsistent with the population trend depicted by the more comprehensive trawl and townet survey indices.

Nevertheless, delta smelt are ecologically similar to young striped bass which have been severely impacted by water

Table 15. Estimated Salvage of Delta Smelt and Water Exports at the State Water Project diversion in the southern delta, during 1977-1978.

| | Month | Delta Smelt Salvage | Exports (thou. acre ft) |
|---|---|---|---|
| 1977 | Jan | 6980 | 205 |
| | Feb | 2430 | 106 |
| | Mar | 1707 | 97 |
| | Apr | 2975 | 14 |
| | May | 3017 | 68 |
| | Jun | 3033 | 17 |
| | Jul | 43489 | 20 |
| | Aug | 6435 | 15 |
| | Sep | 17890 | 9 |
| | Oct | 2528 | 8 |
| | Nov | 350 | 51 |
| | Dec | 55101 | 224 |
| 1978 | Jan | 134089 | 365 |
| | Feb | 53960 | 343 |
| | Mar | 4217 | 108 |
| | Apr | 130 | 35 |
| | May | 3523 | 59 |
| | Jun | 36289 | 201 |
| | Jul | 1034 | 211 |
| | Aug | 2658 | 246 |
| | Sep | 244 | 211 |
| | Oct | 60 | 127 |
| | Nov | 473 | 131 |
| | Dec | 900 | 169 |

diversions (CDFG 1987, Stevens et al. MS.). Delta smelt are vulnerable to diversions throughout their life cycle, particularly in dry years, when they are concentrated in the Delta from which the water is diverted. Thus, even if water diversions were not directly responsible for the delta smelt population decline, their drain on the population may be a significant factor inhibiting recovery.

Toxic Substances

Dr. Moyle's petition points out that the Estuary receives a variety of toxic substances, including agricultural pesticides, heavy metals, and other products of our urbanized society. The effects of these compounds on delta smelt have never been tested, and their effects on fishes in general are poorly understood. Some of these substances are known to occur in the Estuary's fishes at levels that may inhibit their reproduction (Jung et. al 1984) or are sufficient to trigger health warnings (e.g. Mercury in striped bass) regarding human consumption. Also, recent bioassays by the Central Valley Regional Water Quality Control Board (Foe 1989) suggest that water in the Sacramento River is, at times, toxic to larvae of the fathead minnow, a standard EPA test organism . However, the timing of the delta smelt decline is not consistent with the increased, mid-to late-1970s, use of the chemicals thought to cause mortality in these bioassays.

Although there is no direct evidence of delta smelt suffering direct mortality or stress from toxic substances, this factor obviously cannot be eliminated as a potential agent adversely affecting the delta smelt population.

Flows Out of Optimal Range

Moyle and Herbold (1989) point out that the years of the major smelt decline have been characterized by not only unusually dry years with exceptionally low outflows (1987, 1988), but also by unusually wet years with exceptionally high outflows (1983, 1986). They suggest that moderately high flows are most beneficial in that they cause the primary delta smelt nursery area, which is the mixing zone of the Estuary, where outflowing freshwater meets incoming tidal water, to be located in Suisun Bay. Moyle and Herbold developed a complex analysis which suggests high productivity (as reflected in phytoplankton and zooplankton abundance) in the mixing zone is one of the strongest determinants of delta smelt abundance. This high productivity is associated with the establishment of the mixing zone in the shallow water of Suisun Bay. Thus, they suggest moderately high outflows are important in that food becomes more available for larval smelt than when outflows are extremely high or too low. Higher and lower outflows place the mixing zone and nursery too far downstream or upstream. Low outflows also are detriments in that the delta smelt population concentrates in the Delta portion of the Estuary where they are most vulnerable to becoming entrained in water diversions.

Moyle and Herbold's thesis is logical; however, it is not entirely supported by the abundance indices that we have described. For example in 1972, the fall midwater trawl index was quite high despite low outflows and a levee break on Andrus Island drawing the mixing zone well into the Delta during June. Also, relatively high summer townet survey indices suggest early survival of delta smelt larvae was high during the drought of 1976 and 1977. Subsequent survival of these year classes appeared to be low, however. Furthermore, our multiple regression analysis (pages 56 to 59) did not indicate that delta smelt abundance is controlled by delta outflows.

Figure 23 illustrates the best relationship (selected from $R^2$ values after running all possible 2 consecutive monthly subsets from February to June) between the fall midwater trawl abundance index, delta outflow, and delta outflow$^2$. As explained previously, the outflow$^2$ term allows the regression predictions to decline if smelt abundance peaks at moderate flows and declines at high flows. Again, there is no evidence that outflow has had major effects on delta smelt abundance.

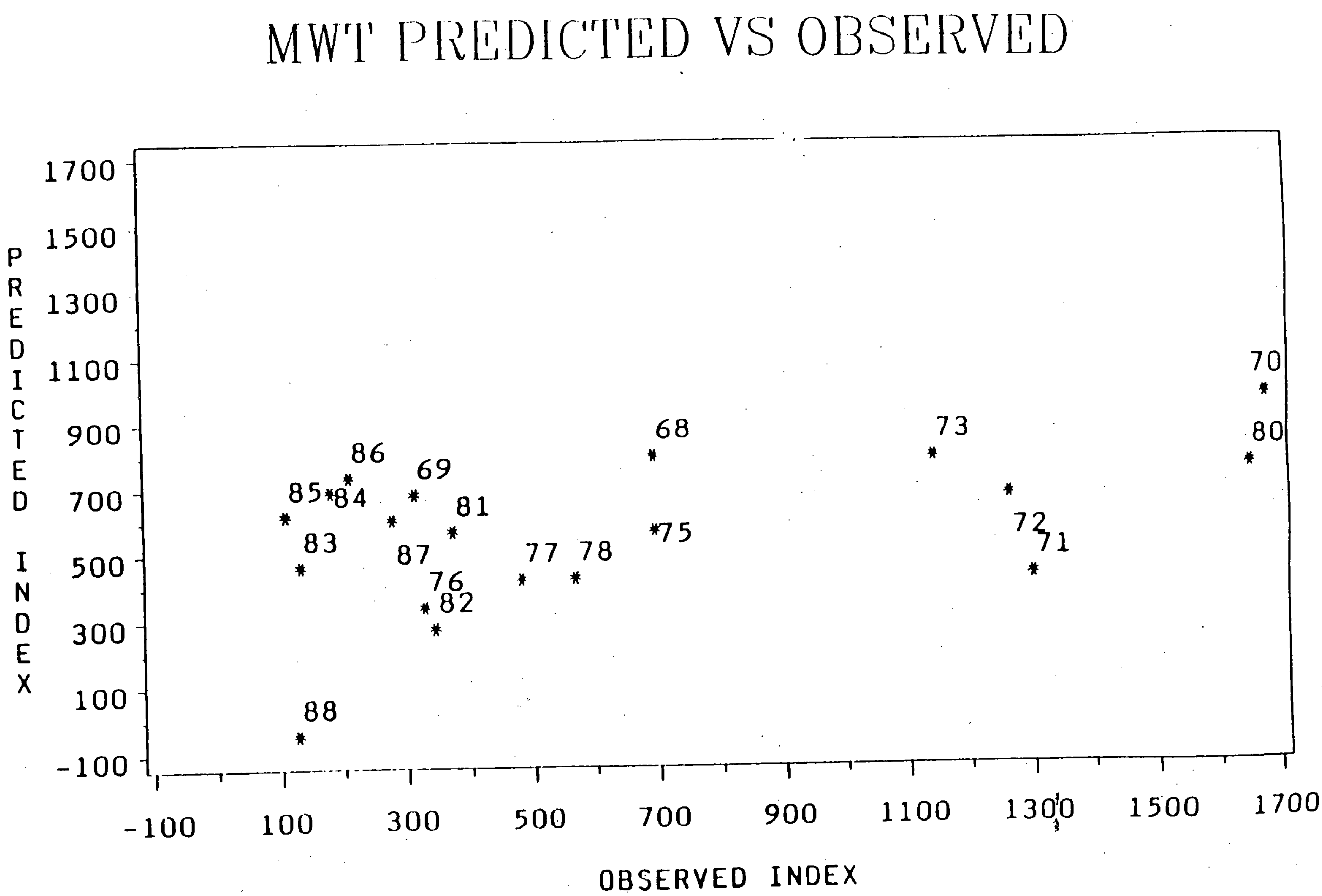



Figure 23. Relationship of midwater trawl observed abundance indices and those predicted by the equation: -2635.7 + 1347.26 ($Log_{10}$ mean February-March Delta outflow) -146.9 ($Log_{10}$ mean March-April Delta outflow)$^2$. $R^2$ = 0.22.

Notably, the recent series of very weak year classes began in 1983 which had a record sustained period of high spring outflows. That year, a substantial portion of the year class likely was washed far beyond Suisun Bay and perhaps entirely out of the Estuary.

Genetic Dilution

The closely related wagasaki, or Japanese smelt, was introduced in 1959 by the Department of Fish and Game into six California lakes and reservoirs: Dodge Reservoir (Lassen County), Dwinnell Reservoir (Siskiyou County), Freshwater Lagoon (Humboldt County), Spaulding Reservoir (Nevada County), Sly Park Reservoir (El Dorado County) and Big Bear Lake (San Bernardino County) (Wales 1962). They have subsequently been introduced into other reservoirs, including Shastina Reservoir (Siskiyou County) and Almanor Reservoir (Plumas County) (Moyle 1974, Moyle and Herbold 1989). Although the status of the introduced populations is uncertain, the potential exists for this fish to appear anywhere in the lower Klamath River system, the Sacramento River system, and possibly other systems as well (Moyle 1974). Wagasaki were collected from Folsom Reservoir (El Dorado County) by Department biologists in 1989 (D.P. Lee, Associate Fishery Biologist, CDFG, pers. comm.).

The wagasaki may hybridize with Delta smelt, but whether they have is not known, nor is it known if such hybridization could have a negative effect on the fitness of the Delta smelt. Thus, the threat of loss of genetic integrity or the possibility that the wagasaki could displace the Delta smelt completely through introgression or direct competition (Moyle and Herbold 1989) should be considered as speculative.

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. A fish, the inland silverside (*Menidia berylina*), similar in size and food requirements to delta smelt, entered the Estuary in 1975 (Meinz and Mecum 1977) after flood flows transported it to the Delta from Clear Lake where it was intentionally, but illegally, introduced in 1967 (Fisher 1973). The invertebrate introductions have occurred through the discharge of organisms carried in ballast water of ships. The exotic invertebrates have included, since 1978, four species of zooplankton, all copepods (*Sinocalanus doerii*, *Limnoithona sinensis*, *Oithona davisae*, and *Pseudodiaptomus forbesi*); an amphipod (*Lagunogammarus sp.*); and a clam (*P. amurensis*). All of these invertebrates are of Asian origin. Some of these exotic species invasions and their population explosions occurred before, others occurred after, but none coincide with the delta smelt decline.

Of the exotic copepods, *S. doerii* (established 1978) and *P. forbesi* (established 1986) have become particularly abundant. *S. doerii* apparently is rarely eaten by delta smelt; however, *P. forbesi* is now a major part of their diet. Laboratory experiments (Meng and Orsi, University of California, Davis and CDFG, respectively) have shown that larval striped bass readily take *P. forbesi*, but have difficulty capturing *S. doerii.* Apparently, the same is true for delta smelt. Potentially, the establishment of *P. forbesi* should compensate for the substantial decline in *E. affinis* which occurred during 1988 and 1989. However, since *P. forbesi*'s annual cycle is such that it does not become abundant until summer, it is not readily available for the initial feeding of young smelt during the spring. Circumstantial evidence, from field monitoring and some sketchy laboratory experiments, suggests that filtering by the clam, *P. amurensis*, may have caused the decline in *E. affinis* which, historically, was available to delta smelt during their early nursery period. While this decline in *E. affinis* occurred after the decline in delta smelt, its near absence, possibly caused by the exotic, *P. amurensis*, may inhibit the smelt's recovery.

**Disease and Parasites**

Diseases and parasites of delta smelt have never been studied; thus, there is no evidence concerning their role in the population decline. General studies on parasites of Delta fishes, however, have found numerous protozoans, worms (trematodes, cestodes, nematodes, etc.) and crustaceans which have affected at least 28 species of fish (Edwards and Nahhas 1968, Hensley and Nahhas 1975). Striped bass in the Delta are more heavily infested with parasites than Atlantic coast striped bass, perhaps indicating that the Delta environment may be degraded by toxicants or pollutants to the point that resistance to parasites in resident fishes is weakened (CDFG 1989). Also, widespread sightings of dead fish suggest that, in some years, disease outbreaks have caused mass mortalities of carp (Cyprinus carpio) and white catfish (Ictalurus catus) in California's Central Valley including the Delta. If disease or parasites are important or should they become important, they certainly could prevent the recovery of delta smelt from current population levels.

**Competition and Predation**

Delta smelt evolved with native predators such as squawfish (Ptychocheilus grandis), Sacramento perch (Archoplites interruptus), and steelhead (Oncorhynchus mykiss); however, predation by these species, none of which is currently abundant in the Estuary, is unlikely to be responsible for the relatively recent decline observed in Delta smelt. Striped bass, which were introduced 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 also have suffered a serious decline which began in the 1970s and preceded the decline in delta smelt. Also, abundance indices for several other potential predators or competitors did not exhibit increases that could account for reduced delta smelt abundance (Figure 24). In fact, several of those potential competitors or predators--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.

In essence, there just has not been a consistent increase in the abundance of any potential predator or competitor that could account for the decline of delta smelt.

Drs. Moyle and Herbold (1989) suggest that the Department's effort to enhance the Sacramento-San Joaquin striped bass population through the stocking of hatchery-reared fish could cause excessive predation on delta smelt. Striped bass are highly pisciverous (eat other fish); however, comprehensive striped bass food habit studies (Stevens 1966, Thomas 1967)

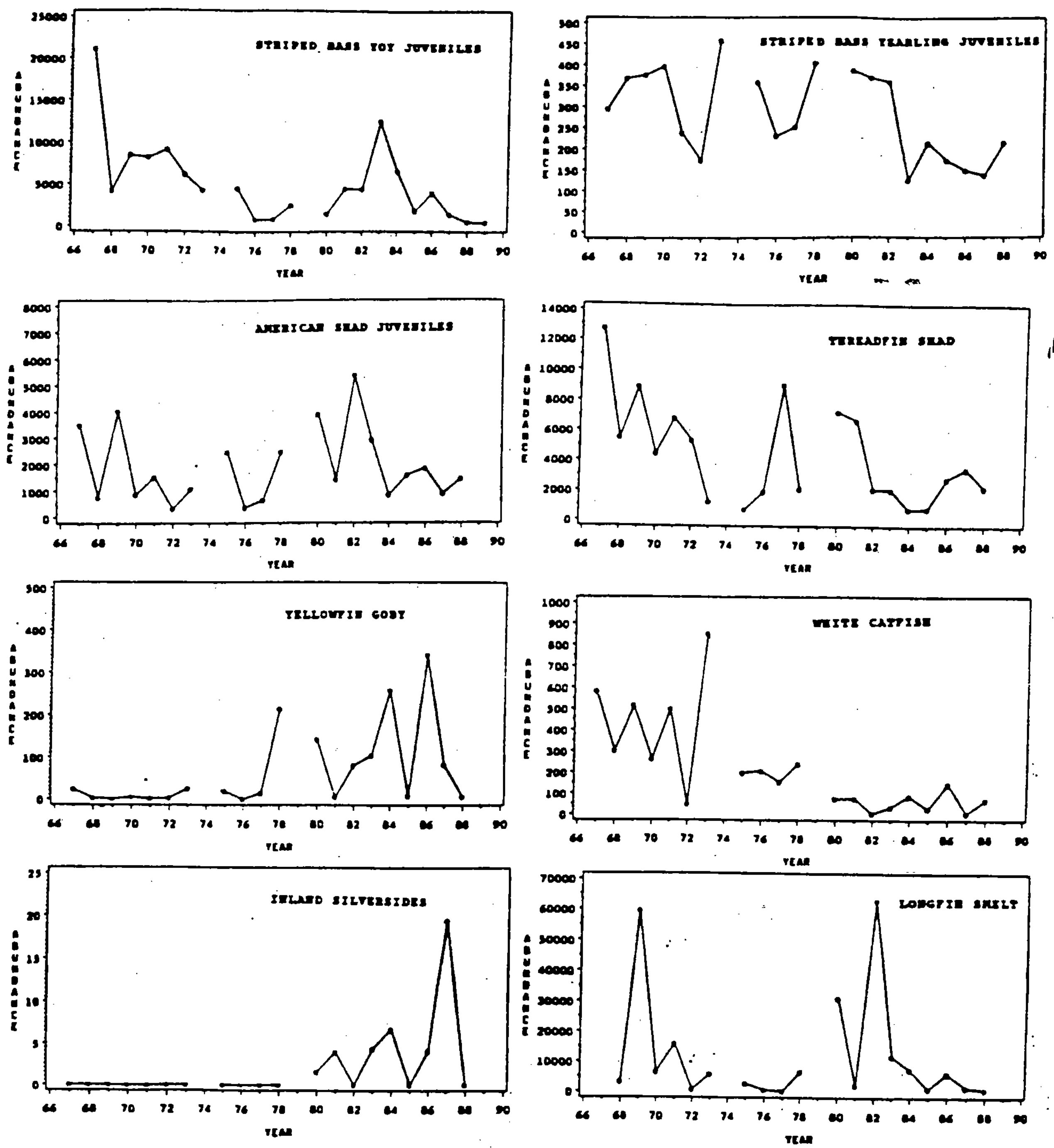



Figure 24. Trends in midwater trawl abundance indices of potential competitors or predators of delta smelt. These abundances have either decreased or been stable coincident with the period of decline in Delta smelt except for the yellowfin goby which generally has been more abundant. There were no trawl surveys in 1974 and 1979.

indicated that, while delta smelt were occasionally consumed, they were not a significant prey of striped bass even in the early 1960s when delta smelt and striped bass were both much more abundant. Thomas (1967) notes that several potential prey species, including delta smelt, were less abundant in the striped bass diet than expected based on their abundance in the environment. Factors which reduce the availability of delta smelt and certain other species to striped bass are not understood.

Thus, while competition and predation cannot be ruled out as threats to delta smelt, the available evidence suggests that they are not a major threat.

## CONCLUSIONS

We have examined several measures of delta smelt abundance; all indicate that the population has declined, although these measures are not consistent in their depiction of the timing and magnitude of the decline. The best measures, based on the summer townet and fall midwater trawl surveys, indicate that delta smelt abundance consistently has been lower since 1983 than in previous years. Based on the midwater trawl survey, the average population since 1983 (index of 175) has only been about one-fifth of the average population level (index of 861) from 1967 to 1982, and one-tenth of the peak level (index of 1840) in 1980. Delta smelt abundance has been highly variable over the period of record. Our evaluation of factors potentially affecting delta smelt abundance did not point strongly to any particular cause of this variability or the sustained population decline since 1983. However, failure to identify factors regulating the population does not mean the tested factors are not important. Such failure may simply reflect sampling associated variability in our measures of delta smelt abundance and/or the environment.

The Fish and Game Commission is guided by the State Endangered Species Act and the guidelines promulgated under this Act in determining whether a species may be properly listed as endangered or threatened. Section 670.1(b) of Title 14 of the California Code of Regulations sets forth the listing criteria. Under this section, the Commission may list a species if it finds that its continued existence is in serious danger, or is threatened by any of the following factors.

- Present or threatened modification or destruction of its habitat;
- overexploitation;
- predation;
- competition;

- disease; or
- other natural occurrences or human-related activities.

To meet the State Endangered Species Act's definition of "endangered", a species must be:

(1) a native species or subspecies;
(2) a bird, mammal, fish, amphibian, reptile or plant;
(3) in serious danger of becoming extinct throughout all, or a significant portion, of its range;
(4) affected by loss of habitat, change in habitat, overexploitation, predation, competition, or disease (Cal. Fish and Game Code Sec. 2062).

A "threatened" species is a species which is "likely to become an endangered species in the foreseeable future" in the absence of the special protection provided by the Act. (Sec. 2067). The Fish and Game Code (Sec. 2072.3) lists additional factors relevant to a determination that a species is threatened or endangered:

- population trend;
- range;
- distribution;
- abundance;
- life history;

- ability to survive and reproduce;
- degree and immediacy of threat;
- existing management efforts;
- type of habitat.

Dr. Moyle's petition declares: "The Delta smelt fits the definition of an endangered species as it is in danger of extinction throughout its entire limited range. It is vulnerable to extinction because (1) it is short-lived, (2) it has relatively low fecundity, (3) it is a planktivore throughout its life cycle, and (4) it is confined to the upper Sacramento-San Joaquin estuary." Our analysis indicates that declarations (1)-(4) are true. Additionally, introductions of exotic organisms have altered the delta smelt's food supply, and water projects have adversely modified the delta smelt's habitat, distribution and probably abundance within the Estuary. While our analysis failed to determine the specific relationships between these threats and the smelt population, that is not crucial to determining whether delta smelt should be listed as threatened or endangered.

Major adverse habitat modifications include effects of changes in the character and position of the salinity gradient and exploitation through entrainment in diversions. Such population threats are likely to worsen or, at best, remain stable (Table 16). Trends in abundance of other species, such as striped bass,

Table 16. Probable Trend in Delta Smelt Population Threats. W = worse, S = Stable

| Threat | Trend |
|---|---|
| Inadequate Food Supply | S |
| Inadequate spawning stock | S or W |
| Entrainment Losses | W |
| Toxicity | ? |
| Delta outflows | W |
| Genetic dilution | S |
| Exotic introductions | S (if ship ballast discharges are controlled), W (if ship ballast discharges are not controlled) |
| Disease and parasites | S or W |

also point toward a general degradation of the delta smelt's habitat.

Thus, the delta smelt population trend, certain life history attributes, and environmental threats tend to support "listing". The most relevant issue, however, is whether the population is low enough that it is in danger of extinction. The scientific information is insufficient to make that determination. Unfortunately, it is a very complicated scientific determination, and no scientific study which we might implement will provide a conclusive answer in the next few years. Meanwhile the population might become extinct.

The Department of Fish and Game believes that the relatively stable, albeit low, population is not in imminent danger of extinction. One factor supporting this contention is that the population has historically rebounded quickly from levels nearly as low as present ones. While we cannot be certain that such rebounds will not happen again, the persistent low populations since 1983, the nature of the delta smelt's life history and distribution, and increasing threats to its habitat lead us to conclude that the delta smelt may well "become an endangered species in the forseeable future". Hence, based on the best scientific information available (Section 2074.6 CESA), the

Department believes that the most prudent action is to list the delta smelt as a Threatened Species.

## RECOMMENDATIONS

### Petitioned Action

1. The Commission should find that the petitioned action that is warranted is for the status of State Threatened.
2. The Commission should publish notice of its intent to amend Title 14 CCR 670.5 to add the delta smelt (Hypomesus transpacificus) to its list of Threatened and Endangered Species.

### Recovery and Management Actions

The Department's objective is the protection of a sufficient number of delta smelt to insure their long-term survival in their native habitat and range. In order to achieve recovery, the population must be protected, monitored, and shown to be self-sustaining. Annual monitoring and evaluation should be increased after input from interested parties. Recovery goals and reclassification criteria need to be established. When recovery goals have been met, the Department will make recommendations to the Commission regarding delisting this species.

The following actions have potential to achieve management and recovery objectives.

1. Improve species identification and fish handling procedures at the existing State and Federal Water Project diversions from the Delta. Such actions could reduce present entrainment losses to these major diversions.

2. Modify pumping strategies at the State and Federal Water project diversions to reduce entrainment losses during periods when delta smelt are most abundant.

3. Increase spring and summer delta outflows to maintain the entrapment zone and major delta smelt nursery in the Suisun Bay region where food supplies are greater than in the Delta and exposure to diversions is minimal.

4. Support regulations restricting ship ballast water discharges to eliminate or minimize new introductions of potentially harmful exotic species. S 2244 and HR 4214 currently being considered by the U.S. Congress would create such regulations.

5. Evaluate losses to agricultural diversions in the Delta. Screening these diversions probably would reduce entrainment and losses to local crop irrigation.

6. Remove water project diversions from the Delta. Moving the diversion intakes to the Sacramento River upstream from the major nursery area would do this and also provide benefits to other species which formerly made more use of the Delta.

7. Consider developing pond culture techniques for the purpose of creating "refuge" populations.

**Alternatives to the Petititioned Action**

If the Commission should choose not to list the Delta smelt, it is our opinion that this fish would be deprived of protection provided through recognition and formal consultation available to a listed species. When a species is listed as Threatened or Endangered, a higher degree of urgency is mandated, and protection and recovery receives more attention from the Department and other agencies than does a non-listed species.

In the absence of listing, it still would be possible to devise a management plan for this species. However, this Departmental status review indicates that the future existence of this species is already seriously threatened. Despite good intentions on the part of the Department and the Commission, promises of management and protection for a non-listed species do not have the weight of law behind them, and thus seldom receive high priority in the eyes of other agencies. Without the benefits of listing and the cooperation of other agencies in preservation and recovery actions, the species could decline further until the population is no longer viable, and is no longer able to exist in perpetuity. Eventually, extinction could occur.

Although the petitioner has requested listing of the Delta smelt as Endangered, the Department has made the recommendation and the Commission has the option to list this fish as Threatened instead. Under this option, the Delta smelt would receive the same special consideration and protection under CESA and the California Environmental Quality Act (CEQA) as if it were listed as Endangered. This Departmental status review indicates that the continued existence of the Delta smelt is seriously threatened throughout its range, and that this alternative is appropriate.

## PROTECTION AFFORDED BY LISTING

If listed, the Delta smelt will receive protection from take during development activities subject to CEQA and will be subject to formal consultation requirements under CESA. The species will also be eligible for the allocation of resources by government agencies to provide protection and recovery. During the CEQA environmental review process, listed species receive special consideration, and protection and mitigation measures can be implemented as terms of project approval. Species that are not listed do not readily receive protection. The status of listing provides a species with recognition by lead agencies and the public, and significantly greater consideration is given to the Department's recommendations resulting from project environmental review.

Listing this species increases the likelihood that State and Federal land and resource management agencies will allocate funds and personnel for protection and recovery actions that benefit the Delta smelt. With limited funding and a growing list of Threatened and Endangered species, priority has been and will continue to be given to species that are listed. Those that are not listed, although considered to be of concern, are rarely given serious consideration under these circumstances.

## ECONOMIC CONSIDERATIONS

The Department is not required to prepare an analysis of economic impacts per CESA Section 2074.6. The Department is to provide a report to the Commission "based upon the best scientific information available to the Department, which indicates whether the petitioned action is warranted, which includes a preliminary identification of the habitat that may be essential to continued existence of the species, and which recommends management activities and other recommendations for recovery of the species".

## REFERENCES


Arthur, J. F. and M. D. Ball. 1979. Factors influencing the entrapment of suspended material in the San Francisco Bay-Delta Estuary. In T.J. Conomos (ed.) San Francisco Bay the urbanized estuary. Pacific Division AAAS San Francisco Ca: 143-174.

Calhoun, A.J. 1953. Distribution of striped bass fry in relation to major water diversions. California Fish and Game 39(3): 279-299.

CDFG (California Department of Fish and Game). 1987. Factors affecting striped bass abundance in the Sacramento-San Joaquin River System. Interagency Ecological Study Program Technical Rept. 20:1-149.

--------. 1988. Striped bass egg and larva monitoring, and effects of flow regulation on the larval striped bass food chain, in the Sacramento-San Joaquin Estuary. Final Report to the State Water Resources Control Board. 120 p.

--------. 1989. Striped bass restoration and management plan for the Sacramento-San Joaquin estuary: Phase I. 39 p.

Chadwick, H.K. 1964. Annual abundance of young striped bass, Roccus saxatilis, in the Sacramento-San Joaquin Delta, California. California Fish and Game 50(2):69-99.

Edwards, S.R., and F.M. Nahhas. 1968. Some endoparasites of fishes from the Sacramento-San Joaquin Delta, California. Calif. Fish and Game, 54(4):247-256.

Erkkila, L.F., J.W. Moffett, O.B. Cope, B.R. Smith, and R.S. Nelson. 1950. Sacramento-San Joaquin Delta fishery resources: effects of Tracy pumping plant and delta cross channel. USFWS Spec. Sci. Rept. Fish 56. 109 p.

Fisher, F. 1973. Observations on the spawning of the Mississippi silversides, Menidia audens, Hay. California Fish and Game 59(4):315-316.

Foe, C. 1989. 1989 Rice season toxicity monitoring results. Memorandum October 19, 1989, California Regional Water Quality Control Board Central Valley Region:1-30 plus appendices.

Ganssle, D. 1966. Fishes and decapods of San Pablo and Suisun Bays, p. 64-94. In D.W. Kelley (ed.), Ecological studies of the Sacramento-San Joaquin Estuary. California Fish and Game, Fish Bull., (133) : 1-133.

Hamada, K. 1961. Taxonomic and ecological studies of the genus Hypomesus of Japan. Mem. Fac. Fish. Hokkaido Univ. 9(1):1-56.

Hensley, G.H., and F.M. Nahhas. 1975. Parasites of fishes from the Sacramento-San Joaquin Delta, California. Calif. Fish and Game, 61(4):201-208.

Jung, M., J.A. Whipple, and M. Moser. 1984. Summary report of the Cooperative Striped Bass Study. Institute for Aquatic Resources, Santa Cruz, California. 117 p.

McAllister, D.E. 1963. A revision of the smelt family, Osmeridae. Bull. Natl. Mus. Canada 191. 53p

Meinz, M., and W.L. Mecum, 1977. A range extension for Mississippi silversides in California. California Fish and Game 63 (4) : 277-278.

Moyle, P.B. 1976. Inland Fishes of California. University of California Press, Berkeley. 405 p.

--------. 1980. Delta smelt. In D.S. Lee et al. (Eds.), Atlas of North American freshwater fishes. North Carolina Mus. Nat. Hist, Raleigh, NC: 123.

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

-------- MS. Life History and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Dept. of Wildlife and Fisheries Biology, University of California, Davis: 1-20.

Moyle, P.B., J.E. Williams, and E. Wikramanayake. 1990. Fish species of special concern of California. California Dept. Fish and Game, Inland Fisheries Division, Rancho Cordova. 221 p.

PGE (Pacific Gas and Electric Company). 1981a. Contra Costa Power Plant cooling water intake structures 316(b) demonstration. PGE, San Francisco, California.

---------. 1981b. Pittsburg Power Plant cooling water intake structures 316(b) demonstration. PGE, San Francisco, California.

Pickard, A., A. Baracco, and R. Kano. 1982. Occurrence, abundance, and size of fish at the Roaring River Slough intake, Suisun Marsh, California during the 1980-81 and the 1981-82 diversion seasons. Interagency Ecological Study Program Technical Rept. 3:1-14.

Pimm, S.L., H.L. Jones, and J. Diamond. 1988. On the risk of extinction. American Naturalist 132:757-785.

Radtke, L.D. 1966. Distribution of smelt, juvenile sturgeon, and starry flounder in the Sacramento-San Joaquin Delta with observation on food of sturgeon. In J.L. Turner and D.W. Kelley (ed.), Ecological studies of the Sacramento-San Joaquin Delta. California Fish and Game, Fish Bull. 136: 115-129.

Stevens, D.E. 1966. Food habits of striped bass, Roccus saxatilis, in the Sacramento-San Joaquin Delta. In J.L. Turner and D.W. Kelley (ed.), Ecological studies of the Sacramento-San Joaquin Delta. California Fish and Game, Fish Bull. 136:68-96.

-------- 1977. Striped bass (Morone saxatilis) monitoring techniques in the Sacramento-San Joaquin Estuary. In W. Van Winkle, (ed.) Proceedings of the conference on assessing the effects of power-plant-induced mortality on fish populations. Pergamon Press, New York, New York: 91-109.

Stevens, D.E., and L.W. Miller 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin River system. North American Journal of Fisheries Management 3:425-437.

Stevens, D.E., L.W. Miller and D.W. Kohlhorst MS. Where have California's striped bass gone? Unpublished manuscript California Fish and Game, Bay-Delta Project. Stockton, CA:1-27.

Thomas, J.L. 1967. The diet of juvenile and adult striped bass, Roccus saxatilis, in the Sacramento-San Joaquin River system. California Fish and Game 53 (1): 49-62.

Turner, J.L. 1966. Introduction to fisheries studies in the Sacramento-San Joaquin Delta. In J.L. Turner and D.W. Kelley (ed.). Ecological studies of the Sacramento-San Joaquin Delta. California Fish and Game, Fish Bull. 136:9-14.

*saxatilis*, in relation to river flow in the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society 101:442-452.

Wales, J.H. 1962. Introduction of pond smelt from Japan into California. Calif. Fish and Game 48(2):141-142.

Wang, J.C.S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary, Tech. Rept. No. 9.

## APPENDIX A

Section 2074.4 of the Fish and Game Code requires the Department of Fish and game to notify affected and interested parties and landowners and to solicit data and comments on petitions accepted by the Fish and Game Commission. To fulfill this requirement, the Department sent notices and/or copies of the petition to the following persons and organizations. Legal notices were placed in the newspapers indicated below:

### PERSONS/ORGS. RECEIVING DELTA SMELT PETITION AND/OR PUBLIC NOTICE

US Dept. of the Army
Sacramento District
Corps of Engineers
650 Capitol Mall
Sacramento, CA 95814-4794

Raymond E. Barsch, General Manager
State Reclamation Board
1416 Ninth Street, Room 455-6
Sacramento, CA 95814

Claire T. Dedrick, Exec. Officer
State Lands Commission
1807 13th Street
Sacramento, CA 95814

Tim Egan, President
California Waterfowl Assn.
3840 Rosin Court, Suite 200
Sacramento, CA 95834

Alan Pendleton, Exec. Director
SF Bay Conservation & Development Commission
30 Van Ness Ave., Suite 2011
San Francisco, CA 94102-6080

Monica Liquori, Exec. Director
Suisun Marsh Natural History Assn.
1171 Kellogg Street
Suisun, CA 94585

Peter Douglas, Exec. Director
California Coastal Commission
631 Howard Street
San Francisco, CA 94105

William H. Ivers, Director
Dept. of Boating and Waterways
1629 S Street
Sacramento, CA 95814

Peter Grenell, Executive Officer
State Coastal Conservancy
1330 Broadway, Suite 1100
Oakland, CA 94610

W. Don Maughan, Chairman
Water Resources Control Board
PO Box 100
Sacramento, CA 95801

Richard Spotts, Regional Rep.
Defenders of Wildlife
5604 Rosedale Way
Sacramento, CA 95822

Leland Lehman, President
Suisun Resource Conservation District
PO Box 426
Suisun, CA 94585

Rick Coleman
SF National Wildlife Refuge
PO Box 524
Newark, CA 94560

Huston Carlyle, Jr., Director
Office of Planning & Research
1400 10th Street
Sacramento, CA 95814

Orville Abbott, Exec. Officer
California Water Commission
1416 9th Street, Room 1104-4
Sacramento, CA 95814

Henry R. Agonia, Director
Dept. of Parks and Recreation
PO Box 942836
Sacramento, CA 94296-0001

David N. Kennedy, Director
Dept. of Water Resources
PO Box 942836
Sacramento, CA 94236-0001

Sacramento County
Board of Supervisors
700 H Street, Room 2450
Sacramento, CA 95814-1280

Bob McKay, President or
Elizabeth Wright, Exec. Secretary
California Wildlife Federation
1023 J Street, Suite 203
Sacramento, CA 95814

Sylvia McLaughlin, President
Save SF Bay Association
PO Box 925
Berkeley, CA 94701

Laurel Mayer, Vice President
The Nature Conservancy
Western Regional Office
785 Market Street, Third Floor
San Francisco, CA 94103

Lawrence Downing, President
Sierra Club
730 Polk Street
San Francisco, CA 94109

Richard Hubbard, Exec. Director
California Natural Res. Federation
2830 10th Street, Suite 4
Berkeley, CA 94710

Robert Nuzum, President
CA Assn. Resource Conservation Dist.
1072 Juanita Drive
Walnut Creek, CA 94595

Edward Hastey, State Director
Bureau of Land Management
Federal Office Bldg., Room E-2841
Sacramento, CA 95825

Department Chair
Dept. of Biological Sciences
CSU-Sacramento
6000 J Street
Sacramento, CA 95819

Contra Costa County
Board of Supervisors
651 Pine Street, Room 106
Martinez, CA 94553

Solano County
Board of Supervisors
Solano County Courthouse
Fairfield, CA 94533

Gerald Meral, Exec. Director
Planning & Conservation League
909 12th Street, Suite 203
Sacramento, CA 95814

Charles Sibley
Tiburon Center for Environ. Studies
SF State University
Box 855
Tiburon, CA 94920

Jerry Bogges, President
The Oceanic Society
SF Bay Chapter
Fort Mason center, Bldg. E
San Francisco, CA 94123

Sheila Byrne
Pacific Gas & Electric Company
TES/Moore Building
3400 Crow Canyon Road
San Ramon, CA 94583

Dr. John McCosker
California Academy of Sciences
Golden Gate Park
San Francisco, CA 94118

Michael Stroud, Head
Natural Resources Branch
US Dept. of the Navy, Western Div.
Nav. Facilities Eng. Command,
Code 243, PO Box 727
San Bruno, CA 94066

Rolf Wallenstrom, Reg. Director
US Fish and Wildlife Service
Northwest Regional Office
500 NE Multnomah St., Suite 1692
Portland, OR 97232

Dr. Paul Ehrlich
Center for Conservation Biology
Stanford University
Stanford, CA 93405

Director
Museum of Vertebrate Zoology
UC Berkeley
Berkeley, CA 94720

Dr. Peter Moyle
Wildlife and Fisheries Biology
UC Davis
Davis, CA 95616

Kenneth R. Boyd
American Water Works Association
PO Box 2108
Livermore, CA 94550

Daniel Phelan
Bay Area League of Industrial Assns
155 Jackson #305
San Francisco, CA 94111

Scott Hodley
Bay Institute of San Francisco
10 Liberty Ship Way #120
Sausalito, CA 94965

Greg Mannesto
US Army Corps of Engineers
650 Capitol Mall
Sacramento, CA 95814

Robert Helwick, Senior Attorney
East Bay MUD
2130 Adeline Street
Oakland, CA 94607

David Stewart
Water Management Division
Environmental Protection Agency
215 Fremont Street
San Francisco, CA 94105

Martin Seldon
Federation of Fly Fishermen
PO Box 2393
Sunnyvale, CA 94807-2393

Ron Davis
CA Municipal Utility Assn.
1225 8th Street, Suite 440
Sacramento, CA 95814

Dan Taylor
National Audubon Society
555 Audubon Place
Sacramento, CA 95825

Department Chair
Dept. of Biology/Nat Resources
UC Berkeley
Berkeley, CA 94720

William H. Geyer
Consulting/Advocacy in CA Gov't.
1029 K Street, Suite 33
Sacramento, CA 95814

Robert T. Cockburn
Bay Area Dischargers Association
2130 Adeline Street
Oakland, CA 94607

Steven McAdam
SF Bay Conservation/Development
Commission
30 Van Ness Avenue
San Francisco, CA 94102

Austin Nelson
Contra Costa Water District
PO Box H20
Concord, CA 94524

Robert Baiocchi, Exec. Dir.
CA Sportfishing Protection Assn.
1859 Salider Way
Paradise, CA 95969

Thomas Graff
Environmental Defense Fund
5655 College Ave., Suite 304
Oakland, CA 94618

Don May
Friends of the Earth
2333 Elm Street
Long Beach, CA 90806

Ellen Johnck, Exec. Director
Bay Planning Coalition
666 Howard St., Suite 301
San Francisco, CA 94105

Association of Water Agencies
910 K Street, Suite 250
Sacramento, CA 95814-3577

Lori Smallwood-Wallack
CA Water Resources Association
1127 11th Street, Suite 602
Sacramento, CA 95814

Jane Darby, Water Chairperson
League of Women Voters of Redlands
309 Marcia Street
Redlands, CA 92373

Eric Johnson
Pacific Gas & Electric Company
3400 Crow Canyon Road
San Ramon, CA 94503

Mitch Ryan
Sen. John Garamendi's Office
State Capitol, Room 4081
Sacramento, CA 95814

John Coburn
State Water Contractors
555 Capitol Mall, Suite 575
Sacramento, CA 95814

John Beuttler
United Anglers of CA
2830 10th Street, Suite 4
Berkeley, CA 94710

Jim Arthur
US Bureau of Reclamation
2800 Cottage Way, Room 2137
Sacramento, CA 95825

Richard Oltman
US Geological Survey
2800 Cottage Way, Room W-2234
Sacramento, CA 95825

Laura King
Natural Resources Defense Council
90 New Montgomery, Suite 620
San Francisco, CA 94105

Bill Crooks, Executive Officer
Reg. Water Quality Control Board
3443 Routier Road
Sacramento, CA

Mike Valentine
State Lands Commission
1807 13th Street
Sacramento, CA 95814

Leo Winternitz
State Water Resources Control Board
Bay-Delta Program
901 P Street
Sacramento, CA 95814

Dr. Jack Williams
Fisheries Program Manager
US Bureau of Land Management
Division of Wildlife & Fisheries
18th and C Streets, NW
Washington, D.C. 20240

Martin Kjelson
US Fish and Wildlife Service
4001 Wilson Way
Stockton, CA 95205

Robert Hagan
Yolo Co. Flood Control & Water Conservation District
548 Oak Avenue
Davis, CA 95616

**NEWSPAPERS WHICH PUBLISHED THE DELTA SMELT LEGAL NOTICE**

Sacramento Bee
PO Box 15779
Sacramento, CA 95852

Fairfield Daily Republic
PO Box 47
Fairfield, CA 94533

San Francisco Chronicle
901 Mission Street
San Francisco, CA 94103

Contra Costa Times
PO Box 5088
Walnut Creek, CA 94596

Beginning June 22, 1990 the Department of Fish and Game circulated a draft report entitled **"Report to the Fish and Game Commission: A Status Review of the Delta Smelt (*Hypomesus transpacificus*) in California."** This report was prepared in accordance with Section 2074.6 of the Fish and Game Code. The draft report was provided to the following individuals and organizations that responded to a November 27, 1989 public notice to other individuals and organizations that the Department identified as interested parties and to the general public. The distribution of the draft report provided an opportunity for public review and comment before the Department submitted a final report to the Fish and Game Commission and ensured that the Department had access to the best scientific information.

Ms. Betsy Bolster
Inland Fisheries Division
DFG - Region 2

Dr. Dennis Murphy
Dept. Biological Sciences
Stanford University

Mr. Keith Taniguchi
Office of Endangered Species
USFWS

Dr. Don Erman
Dept. Forestry and Conservation
University of California, Berkeley

Ms. Carla Markmann
Chair, Conservation Committee
American Fisheries Society

Mr. Peter Moyle
Dept. of Fish & Wildlife
University of California Davis

Mr. George R. Baumli
State Water Contractors
555 Capitol Mall Suite 575

Mr. Harold Meyer
Water Resources Management, Inc.

Dr. Joe O'Connor
Aquatic Habitat Institute

Ms. Susan Joseph
Downey, Brand, Seymour and Rohwer
555 Capitol Mall, 10th Floor

Mr. David Beringer
Division of Water Rights
Water Resources Control Board

Mr. David Anderson
Department of Water Resources
Office of the Counsel

State Clearing House

Mr. Randy Brown
Department of Water Resources
Central District

Mr. Ken Lentz
US Bureau of Reclamation

Mr. Chris Bowman
Sacramento Bee

Ms. Diana Jacobs
State Lands Commission

Mr. Phil Hogan
Soil Conservation Service

Mr. Robert Schaefer
Mr. Wil Tully
Bureau of Reclamation

Mr. John Merz
Sacramento River Preservation Trust

Ms. Cay Goude
USFWS

Mr. Jim Canaday
Water Resources Control Board
Division of Water Rights

Mr. Barry Nelson
Save the Bay Association

Mr. William Davoren
Bay Institute of San Francisco

Mr. Robert Baiocchi
California Sportfishing Alliance

Mr. John Beuttler
United Anglers

Mr. Al Jahns
Merron, Reid, Sheehy
801 K Street #2100
Sacramento, CA 95814

Mr. Scott Hadley
Bay Institute

Mr. Richard Spotts
Defenders of Wildlife

Dr. C. David Vanicek
Department of Biological Sciences
CA State University - Sacramento

Mr. Aaron King
Assemblyman Dan Hauser's Office

Assemblyman William Campbell
State Capitol

Mr. Steven McAdam
San Francisco Bay Conservation and Development Commission

Mr. Greg Mannesto
U.S. Army Corps of Engineers

Mr. Robert Helwick
Senior Attorney
East Bay Municipal District

Mr. Thomas Graff
Environmental Defense Fund

Mr. David Stewart
EPA
Water Management Division

Ms. Susan LeFever
Friends of the River

Ms. Ellen Johnck
Bay Planning Coalition

Mr. Ron Davis
CA Municipal Utility Association

Mr. Gerald Meral
Planning and Conservation League

Associations of CA Water Agencies

Mr. Dan Taylor
National Audubon Society

Ms. Lori Smallwood
CA Water Resources Association

Ms. Jane Kay
San Francisco Examiner

Mr. Harold Gilliam
San Francisco Chronicle

Ms. Laura King
Natural Resources Defense Council

Mr. Eric Johnson
Pacific Gas and Electric
Company

Mr. Bill Crooks
Regional Water Quality Control
Board

Mr. Dave Beringer
Bay-Delta Unit
Division of Water Rights

Mr. Jim Arthur
US Bureau of Reclamation

Mr. Richard Oltman
US Geological Survey

STATE OF CALIFORNIA—THE RESOURCES AGENCY GEORGE DEUKMEJIAN, Governor

DEPARTMENT OF FISH AND GAME
1416 NINTH STREET
P.O BOX 944209
SACRAMENTO, CALIFORNIA 95814-2090

November 27, 1989

**PUBLIC NOTICE**

**TO WHOM IT MAY CONCERN:**

Pursuant to Section 2074.4 of the California Fish and Game Code (FGC), **NOTICE IS HEREBY GIVEN** that on **August 29, 1989** the California Fish and Game Commission accepted a petition from **Dr. Peter Moyle** to amend the official State list of endangered and threatened species (Section 670.2, 670.5, Title 14, California Code of Regulations) as follows:

| Species | Proposal |
|---|---|
| Delta smelt (*Hypomesus transpacificus*) | List as endangered |

The California Endangered Species Act (FGC, Chapter 1.5, Section 2050 et seq.) requires that the Department of Fish and Game notify affected and interested parties that the Commission has accepted the petition for the purpose of receiving information and comments that will aid in evaluating the petition and determining whether or not the above proposal should be adopted by the Commission. If the above proposal includes adding a species to the list as endangered or threatened, the Commission's action has resulted in this species receiving the interim designation of "candidate species." The Department has 12 months to review the petition, evaluate the available information and report back to the Commission whether the petitioned action is warranted (FGC Section 2074.6). The Department's recommendation must be based on the best scientific information available to the Department. Therefore,

**NOTICE IS FURTHER GIVEN** that anyone with data or comments on the taxonomic status, ecology, biology, life history, management recommendations, distribution, abundance, threats, habitat that may be essential for the species or other factors related to the status of the above species, is hereby requested to provide such data or comments to:

Natural Heritage Division
California Department of Fish and Game
1416 Ninth Street, 12th Floor
Sacramento, CA 95814

Responses received by **January 17, 1990** will be included in the Department's final report to the Fish and Game Commission. If the Department concludes that the petitioned action is warranted, it will recommend that the Commission adopt the above proposal. If the Department concludes that the petitioned action is not warranted, it will recommend that the Commission not adopt the proposal. (If the petitioned action is to list a species as endangered or threatened and the Commission accepts the Department's recommendation to not adopt the proposal, the species will lose its candidate status.) Following receipt of the Department's report, the Commission will allow a 45-day public comment period prior to taking any action on the Department's recommendation.

**TICE IS FURTHER GIVEN** that any species above proposed to be added to the State list as endangered or threatened is a "candidate species" pursuant to Section 2074.2 (FGC) and, pursuant to Section 2085 (FGC), may not be taken or possessed except as provided by Section 2080, et seq. of the FGC or other applicable statutes.

Susan A. Cochrane, Chief
Natural Heritage Division

(916) 324-8348

June 22, 1990

To Whom It May Concern:

The enclosed draft report represents the Department of Fish and Game's analysis and response to a petition to list the Delta Smelt as an endangered species. The Department has determined that the Delta Smelt meets criteria set forth in the California Endangered Species Act of 1984 for listing as a threatened species. This draft report is being provided to all individuals and organizations that responded to our public notices earlier in the review process. We are providing another opportunity for the public to comment on this matter before the Department transmits a final report to the Fish and Game Commission for receipt at their August 3, 1990 meeting. Your comments must reach this office by July 18, 1990 to be included in our final status report. The Commission will conduct a hearing on the Departments recommendation and take public testimony at their August 31, 1990 meeting in Sacramento.

Thank you for your interest in this matter.

Sincerely,

Susan A. Cochrane, Chief
Natural Heritagae Division

CALIFORNIA DEPARTMENT OF FISH AND GAME
NOTICE OF AVAILABILITY OF REPORTS

NOTICE IS HEREBY GIVEN that a draft report prepared by the Department of Fish and Game, pursuant to Section 2074.6 of the Fish and Game Code, in response to a petition to list the delta smelt (Hypomesus transpacificus) as an endangered species, is available for review and comment at the Natural Heritage Division Office, 1220 "S" Street, Sacramento, CA 95814, phone (916) 324-0561.

The Fish and Game Commission will receive the Department's final report at their August 3, 1990 meeting. The Commission will conduct a hearing on the Department's recommendation and take public testimony at their August 31, 1990 meeting in Sacramento.

Department of Fish and Game
Inland Fisheries Division

Robert R. Rawstron

June 29, 1990

Robert R. Rawstron, Chief

## Appendix B. Summary of Public Comments on Draft Status Review

A draft of this report was released on June 22 for public comment. The cover letter from Susan A. Cochrane, Chief Natural Heritage Division specified that comments must reach the Department by July 18, 1990 to be included in the final status report. Comments were received from the following individuals and organizations: 1) State Water Contractors (SWC), 2) McDonough, Holland and Allen, attorneys for Central Valley Project Water Association (CVPWA), 3) Downey, Brand, Seymour, and Rohwer (DBSR), attorneys representing more than twelve reclamation districts which siphon or pump water from delta channels, 4) California Central Valley Flood Control Association (CCVFCA), 5) The Planning and Conservation League (PCL), 6) Drs. Bruce Herbold and Peter Moyle (HM), 7) The Department of Water Resources (DWR), and 8) Dr. Dallas Weaver, Scientific Hatcheries (DW).

Concerns were expressed in the following general areas:

- adequacy of available information for purposes of depicting the delta smelt population trend and status (SWC, CVPWA),
- verification of the taxonomic status of the species (SWC, CVPWA),

- adequacy of data regarding the diet of delta smelt (SWC, CVPWA),

- resolution on the timing and distribution of spawning, mechanisms of larval transport, and reproductive potential (SWC, CVPWA),

- resolution on distribution within the Estuary (SWC, CVPWA),

- weak linkage between abundance and factors potentially controlling abundance (SWC, CVPWA, DWR),

- need for stronger technical foundation in support of listing and management recommendations (SWC, CVPWA, DWR),

- increased cost of water associated with screening agricultural diversions and the question of screen effectiveness on fish as small as delta smelt (DSBR, CCVFCA, DWR),

- predation by birds should be considered as a potential mortality factor (DW),

- changes in carbon-nitrogen-phosphorus ratios due to sewage treatment may affect productivity of the food chain (DW),

- water diversion is the cause of the situation and consideration should be given to upgrading the listing to Endangered (PCL, HM).

We believe that some of these concerns have merit. In some cases they are consistent with statements in our draft text and in some cases we have modified the present text in response. Conversely, we also disagree with some of the comments and stand by our original analysis. Taken individually or collectively, the technical comments do not change conclusions about the status of the smelt population or the factors affecting it.

The SWC, CVPWA and DWR point to apparent discrepancies between certain conclusions reached in the report and the recommendations. The Department believes that those apparent discrepancies are due to the draft report's failure to explain adequately the logical basis for recommendations and that there is no discrepancy between conclusions about the status of the smelt population and the recommendations.

The most essential conclusions are that the Delta smelt population fluctuated widely in abundance from 1959 through 1982, but has been consistently at or below previous minimum levels since 1983; the causes for their low abundance are uncertain, although a number of impacts and likely threats are evident; and scientific information is insufficient to determine the minimum viable population size. In this regard, despite their technical comments, the SWC concede that there is "ample evidence to suggest that delta smelt are at a relatively low level of abundance and therefore represent a species of concern" (p. 9 Attachment 1, July 18, 1990 letter from George Baumli to Susan Cochrane), and DWR states that "it is clear that the population has been low and relatively stable for the past several years" (July 19, 1990 memorandum from Robert G. Potter to Susan Cochrane). The central issue, therefore, is whether the delta smelt is truly likely to become an endangered species in the foreseeable future and deserving of Threatened status.

The Department disagrees with PCL and HM and agrees with the SWC, CVPWA and DWR that based on available evidence there is a measure of uncertainty regarding endangerment (page 88, this report). We believe that at least three alternative conclusions about the population's status merit careful consideration. These are:

1. Some set of circumstances has caused the recent consistent low abundance levels but not permanently reduced habitat carrying capacity, so recovery may occur spontaneously.

2. Habitat degradation has permanently reduced this population to a low but stable level.

3. Habitat degradation has caused the population to fall to a low, temporarily stable level, but increasing habitat stress is likely to cause the population to decrease further.

The first alternative would clearly not warrant listing the smelt. The second would warrant listing only if the present population level is close to the minimum viable population size. At first glance, that seems unlikely considering the rapid historical increases from similar levels, but subsequent habitat degradation may have affected population viability. The third could warrant listing as threatened, depending on the likely consequences of a further decline.

While none of the alternatives can be ruled out, the Department concluded that the third is sufficiently likely and warrants listing the smelt as threatened. Specific supporting reasons are:

1. The general degradation of phytoplankton, zooplankton and several species of fish including delta smelt, in the Delta and Suisun Bay.

2. The association of some of these changes with water development, with reverse flows and losses in project diversions causing particularly important effects.

3. Those water development effects will increase unless specific mitigative actions are taken.

4. The rapid changes associated with accidental introductions of invertebrates which probably haven't stabilized yet.

5. The vulnerability of delta smelt to extinction due to their limited distribution, and life history characteristics.

6. The uncertainty about factors controlling the abundance of smelt, which leads to an inability to conclude that smelt are unlikely to be harmed by further changes.

7. Each additional year of depressed populations makes it more difficult to rationalize the situation as reflecting temporary habitat degradation.

The SWC, CVPWA and DWR all advocate comprehensive studies as an alternative to listing. The Department recommends that such studies should be part of the recovery and management actions, rather than a substitute for listing. The Department's reasons are:

1. The status of this resource is much better defined by past programs than the SWC and CVPWA believe it is.

2. Management actions are warranted now due to risks posed by continuing environmental changes, and

3. Experience indicates that conclusive results will not be achieved quickly by proposed studies.

In addition to studies, DWR advanced two management recommendations as follows:

- The species list for the 1986 DFG-DWR agreement to offset DWR's direct Delta pumping impacts be expanded from striped bass, chinook salmon, and steelhead, to include Delta smelt. This action would result in funds being made available to develop projects to offset DWR's entrainment losses.

- The present DFG/DWR/USBR negotiations to develop an agreement to offset CVP/SWP indirect Delta impacts be expanded to include Delta smelt. (The negotiations presently focus on striped bass and chinook salmon).

The Department considers these helpful, but not specific enough. They would logically lead to consideration of the specific measures included in our recommendations. The lack of certainty as to the cause of the decline creates uncertainty as to the measures which should be undertaken to increase the population. The Department has chosen to recommend a series of habitat improvement measures related to the life history of smelt. The Department is confident that the recommended measures would improve habitat quality in the Delta and Suisun Bay and have a high probability of increasing smelt abundance.

Proposals to modify CVP/SWP pumping strategies to reduce entrainment losses, and to augment Delta outflow, have drawn specific criticism, considering the lack of strong relationships between entrainment losses, outflow and smelt abundance found during the analysis. While strong, long-term relationships do not exist, the Department considers the drain of present water diversions on the delta smelt population to be a significant factor inhibiting their recovery and flow augmentation is worth considering, at least as a vehicle to reduce such losses. Greater flows would reduce these losses by transporting the smelt population downstream away from the diversions.

In response to concerns about screening delta agricultural diversions we have modified our draft recommendation to include an initial evaluation phase.

Appendix C. Delta smelt abundance indices for the townet survey for the years 1959-1965 and 1969-1989

| Year | Survey 1 | Survey 2 | Mean |
|---|---|---|---|
| 1959 | 0.1 | 22.2 | 11.1 |
| 1960 | 21.6 | 26.0 | 23.8 |
| 1961 | 18.9 | 17.0 | 18.0 |
| 1962 | 20.3 | 26.5 | 23.5 |
| 1963 | 1.3 | 2.1 | 1.7 |
| 1964 | 11.4 | 36.4 | 23.9 |
| 1965 | 6.4 | 5.3 | 5.9 |
| 1969 | 3.7 | 1.2 | 2.7 |
| 1970 | 20.3 | 43.4 | 31.9 |
| 1971 | 8.9 | 15.8 | 12.4 |
| 1972 | 9.2 | 12.8 | 11.0 |
| 1973 | 21.5 | 21.0 | 21.2 |
| 1974 | 12.0 | 13.8 | 13.0 |
| 1975 | 7.0 | 16.7 | 11.9 |
| 1976 | 63.0 | 38.2 | 50.6 |
| 1977 | 12.5 | 37.1 | 24.8 |
| 1978 | 23.0 | 102.0 | 62.5 |
| 1979 | 6.4 | 19.9 | 13.2 |
| 1980 | 14.7 | 16.9 | 15.8 |
| 1981 | 19.1 | 20.5 | 19.9 |
| 1982 | 7.0 | 14.3 | 10.6 |
| 1983 | 3.3 | 2.5 | 2.9 |
| 1984 | 1.3 | 1.2 | 1.3 |
| 1985 | 0.8 | 0.9 | 0.9 |
| 1986 | 7.4 | 8.3 | 7.8 |
| 1987 | 0.4 | 2.4 | 1.4 |
| 1988 | 0.5 | 1.8 | 1.2 |
| 1989 | 3.6 | 0.8 | 2.2 |
| [illegible] | 2.2 | 2.3 | 2.3 |

Appendix D. Weight Factors used for Midwater Trawl Survey Data.

| Area | Midwater Trawl Stations | Acre ft. |
| --- | --- | --- |
| 1 | 336-339 | 81,000 |
| 2 | 320 | 28,000 |
| 3 | 321-326 | 113,000 |
| 4 | 327-329 | 65,000 |
| 5 | 330-335 | 122,000 |
| 6 | 317-319 | 59,000 |
| 7 | 312-316 | 102,000 |
| 8 | 303-311 | 185,000 |
| 9 | 301-302 | 30,000 |
| 10 | 340 | 48,000 |
| 11 | 401-402,404-408 | 160,000 |
| 12 | 409-419 | 140,000 |
| 13 | 501-520 | 180,000 |
| 14 | 601-606,608 | 50,000 |
| 15 | 702-711 | 120,000 |
| 16 | 801-815 | 140,000 |
| 17 | 901-915,918,919 | 200,000 |

Appendix E. Regression search of potential effects of March to June environmental variables on the summer townet survey abundance index for delta smelt. See appendix H for Key to variable names.

N=16 REGRESSION MODELS FOR DEPENDENT VARIABLE: TNS_IND MODEL: MODEL1

| NUMBER IN MODEL | R-SQUARE | ADJUSTED R-SQUARE | SSE | C(P) | VARIABLES IN MODEL |
|---|---|---|---|---|---|
| 1 | 0.00245546 | -.06879772 | 4445.9463 | 0.126004 | MR_J_FT |
| 1 | 0.00918957 | -.06158261 | 4415.9331 | 0.0441457 | DAY_REVS |
| 1 | 0.01253711 | -.05799595 | 4401.0135 | 0.00345339 | LMJN_OT2 |
| 1 | 0.01280421 | -.05770977 | 4399.8230 | .000206564 | LMJN_OUT |
| 1 | 0.07543021 | 0.00938952 | 4120.7058 | -0.761066 | MJN_EXP |
| 1 | 0.07861687 | 0.01280379 | 4106.5033 | -0.799802 | MJN_COP |
| 1 | 0.18925268 | 0.13134216 | 3613.4216 | -2.1447 | MJN_WT |
| 2 | 0.00918957 | -.14324280 | 4415.9331 | 2.044146 | MR_J_FT DAY_REVS |
| 2 | 0.01286260 | -.13900470 | 4399.5628 | 1.999497 | LMJN_OT2 DAY_REVS |
| 2 | 0.01312179 | -.13870563 | 4398.4076 | 1.996346 | LMJN_OUT DAY_REVS |
| 2 | 0.01320068 | -.13861460 | 4398.0560 | 1.995387 | LMJN_OUT LMJN_OT2 |
| 2 | 0.01612688 | -.13523821 | 4385.0143 | 1.959817 | LMJN_OT2 MR_J_FT |
| 2 | 0.01624085 | -.13510671 | 4384.5063 | 1.958431 | LMJN_OUT MR_J_FT |
| 2 | 0.07582923 | -.06635089 | 4118.9275 | 1.234084 | MR_J_FT MJN_EXP |
| 2 | 0.07861957 | -.06313127 | 4106.4912 | 1.200165 | MR_J_FT MJN_COP |
| 2 | 0.08363359 | -.05734586 | 4084.1443 | 1.139215 | LMJN_OUT MJN_EXP |
| 2 | 0.08412034 | -.05678422 | 4081.9749 | 1.133298 | LMJN_OUT MJN_COP |
| 2 | 0.08465013 | -.05617293 | 4079.6137 | 1.126858 | LMJN_OT2 MJN_EXP |
| 2 | 0.08472391 | -.05608780 | 4079.2849 | 1.125961 | LMJN_OT2 MJN_COP |
| 2 | 0.09867377 | -.03999180 | 4017.1118 | 0.956389 | MJN_COP MJN_EXP |
| 2 | 0.10366083 | -.03423751 | 3994.8851 | 0.895767 | MJN_COP DAY_REVS |
| 2 | 0.11678410 | -.01909527 | 3936.3961 | 0.736242 | MJN_EXP DAY_REVS |
| 2 | 0.19818343 | 0.07482704 | 3573.6082 | -0.253236 | MJN_COP MJN_WT |
| 2 | 0.23032862 | 0.11191764 | 3430.3407 | -0.643988 | MJN_WT MJN_EXP |
| 2 | 0.24841852 | 0.13279060 | 3349.7160 | -0.863886 | MJN_WT DAY_REVS |
| 2 | 0.26355320 | 0.15025369 | 3282.2624 | -1.0479 | MR_J_FT MJN_WT |
| 2 | 0.27339677 | 0.16161165 | 3238.3907 | -1.1675 | LMJN_OT2 MJN_WT |
| 2 | 0.27615854 | 0.16479831 | 3226.0818 | -1.2011 | LMJN_OUT MJN_WT |
| 3 | 0.01376476 | -.23279405 | 4395.5420 | 3.988530 | LMJN_OUT LMJN_OT2 DAY_REVS |
| 3 | 0.01620227 | -.22974717 | 4384.6783 | 3.958900 | LMJN_OT2 MR_J_FT DAY_REVS |
| 3 | 0.01624333 | -.22969583 | 4384.4953 | 3.958401 | LMJN_OUT LMJN_OT2 MR_J_FT |
| 3 | 0.01635567 | -.22955517 | 4383.9937 | 3.957033 | LMJN_OUT MR_J_FT DAY_REVS |
| 3 | 0.09103191 | -.13621011 | 4051.1708 | 3.049282 | LMJN_OUT LMJN_OT2 MJN_COP |
| 3 | 0.09227006 | -.13466242 | 4045.6525 | 3.034231 | LMJN_OUT MR_J_FT MJN_COP |
| 3 | 0.09440191 | -.13199761 | 4036.1511 | 3.008317 | LMJN_OT2 MR_J_FT MJN_COP |
| 3 | 0.09830425 | -.12711969 | 4018.7588 | 2.960881 | LMJN_OUT LMJN_OT2 MJN_EXP |
| 3 | 0.09945417 | -.12568229 | 4013.6337 | 2.946902 | MR_J_FT MJN_COP MJN_EXP |
| 3 | 0.10405786 | -.11992768 | 3993.1156 | 2.890941 | LMJN_OUT MR_J_FT MJN_EXP |
| 3 | 0.10407978 | -.11990027 | 3993.0179 | 2.890674 | LMJN_OUT MJN_COP MJN_EXP |
| 3 | 0.10506134 | -.11867333 | 3988.6432 | 2.878743 | LMJN_OT2 MJN_COP MJN_EXP |
| 3 | 0.10912856 | -.11358930 | 3970.5160 | 2.829302 | LMJN_OT2 MR_J_FT MJN_EXP |
| 3 | 0.11010825 | -.11236468 | 3966.1496 | 2.817393 | LMJN_OT2 MJN_COP DAY_REVS |
| 3 | 0.11104587 | -.11119266 | 3961.9708 | 2.805995 | LMJN_OUT MJN_COP DAY_REVS |
| 3 | 0.11671103 | -.10411121 | 3936.7218 | 2.737131 | MR_J_FT MJN_COP DAY_REVS |
| 3 | 0.13234922 | -.08456348 | 3867.0241 | 2.547035 | LMJN_OT2 MJN_EXP DAY_REVS |
| 3 | 0.13521623 | -.08097971 | 3854.2461 | 2.512184 | LMJN_OUT MJN_EXP DAY_REVS |
| 3 | 0.14131462 | -.07335673 | 3827.0663 | 2.438053 | MJN_COP MJN_EXP DAY_REVS |
| 3 | 0.16007633 | -.04990458 | 3743.4474 | 2.209988 | MR_J_FT MJN_EXP DAY_REVS |
| 3 | 0.23074451 | 0.03843063 | 3428.4871 | 1.350956 | MJN_COP MJN_WT MJN_EXP |
| 3 | 0.26162025 | 0.07702532 | 3290.8773 | 0.975635 | MJN_COP MJN_WT DAY_REVS |
| 3 | 0.26528200 | 0.08160251 | 3274.5573 | 0.931124 | MR_J_FT MJN_COP MJN_WT |
| 3 | 0.27343085 | 0.09178857 | 3238.2388 | 0.832068 | LMJN_OT2 MJN_COP MJN_WT |
| 3 | 0.27545584 | 0.09431980 | 3229.2136 | 0.807452 | MR_J_FT MJN_WT MJN_EXP |
| 3 | 0.27589325 | 0.09486656 | 3227.2641 | 0.802135 | LMJN_OT2 MJN_WT DAY_REVS |
| 3 | 0.27642018 | 0.09552522 | 3224.9157 | 0.795730 | LMJN_OUT MJN_COP MJN_WT |
| 3 | 0.27849796 | 0.09812244 | 3215.6552 | 0.770473 | LMJN_OUT MJN_WT DAY_REVS |
| 3 | 0.28085861 | 0.10107326 | 3205.1341 | 0.741777 | LMJN_OT2 MR_J_FT MJN_WT |
| 3 | 0.28206293 | 0.10257866 | 3199.7666 | 0.727137 | MR_J_FT MJN_WT DAY_REVS |
| 3 | 0.28209759 | 0.10262199 | 3199.6121 | 0.726716 | LMJN_OUT LMJN_OT2 MJN_WT |
| 3 | 0.28338380 | 0.10422975 | 3193.8796 | 0.711081 | LMJN_OUT MR_J_FT MJN_WT |
| 3 | 0.30087076 | 0.12608844 | 3115.9421 | 0.498512 | LMJN_OT2 MJN_WT MJN_EXP |
| 3 | 0.30091448 | 0.12614311 | 3115.7472 | 0.497981 | LMJN_OUT MJN_WT MJN_EXP |
| 3 | 0.33438849 | 0.16798562 | 2966.5573 | 0.0910754 | MJN_WT MJN_EXP DAY_REVS |

Appendix F. Regression search of potential effects of March to June environmental variables on the fall midwater trawl abundance index for delta smelt. See appendix H for Key to variable names.

N=14 REGRESSION MODELS FOR DEPENDENT VARIABLE: MWT_IND MODEL: MODEL1

| NUMBER IN MODEL | R-SQUARE | ADJUSTED R-SQUARE | SSE | C(P) | VARIABLES IN MODEL |
|---|---|---|---|---|---|
| 1 | 0.00014336 | -.08317803 | 2920645.8 | 25.430383 | LMJN_OT2 |
| 1 | 0.00085631 | -.08240566 | 2918562.5 | 25.405119 | LMJN_OUT |
| 1 | 0.00249623 | -.08062909 | 2913772.2 | 25.347008 | DAY_REVS |
| 1 | 0.00398817 | -.07901282 | 2909414.1 | 25.294140 | MJN_EXP |
| 1 | 0.01024312 | -.07223662 | 2891143.0 | 25.072493 | MR_J_FT |
| 1 | 0.15752201 | 0.08731551 | 2460932.0 | 19.853598 | MJN_COP |
| 1 | 0.30782448 | 0.25014319 | 2021888.9 | 14.527560 | MJN_WT |
| 2 | 0.00261506 | -.17872766 | 2913425.1 | 27.342797 | LMJN_OUT DAY_REVS |
| 2 | 0.00388605 | -.17722558 | 2909712.4 | 27.297759 | LMJN_OT2 DAY_REVS |
| 2 | 0.00414336 | -.17692148 | 2908960.8 | 27.288641 | LMJN_OT2 MJN_EXP |
| 2 | 0.00471141 | -.17625015 | 2907301.5 | 27.268512 | MJN_EXP DAY_REVS |
| 2 | 0.00497157 | -.17594269 | 2906541.5 | 27.259293 | LMJN_OUT MJN_EXP |
| 2 | 0.01024325 | -.16971253 | 2891142.6 | 27.072489 | MR_J_FT DAY_REVS |
| 2 | 0.01533291 | -.16369747 | 2876275.4 | 26.892134 | LMJN_OUT MR_J_FT |
| 2 | 0.01740101 | -.16125335 | 2870234.3 | 26.818850 | MR_J_FT MJN_EXP |
| 2 | 0.02046772 | -.15762906 | 2861276.3 | 26.710180 | LMJN_OT2 MR_J_FT |
| 2 | 0.11181617 | -.04967180 | 2594441.6 | 23.473205 | LMJN_OUT LMJN_OT2 |
| 2 | 0.15782147 | 0.00469810 | 2460057.2 | 21.842986 | MJN_COP DAY_REVS |
| 2 | 0.16523995 | 0.01346540 | 2438387.4 | 21.580109 | LMJN_OT2 MJN_COP |
| 2 | 0.17041767 | 0.01958451 | 2423262.9 | 21.396634 | LMJN_OUT MJN_COP |
| 2 | 0.20420359 | 0.05951333 | 2324572.1 | 20.199414 | MR_J_FT MJN_COP |
| 2 | 0.21899222 | 0.07699080 | 2281373.6 | 19.675372 | MJN_COP MJN_EXP |
| 2 | 0.31695692 | 0.19276727 | 1995212.4 | 16.203948 | MJN_WT MJN_EXP |
| 2 | 0.32616822 | 0.20365336 | 1968305.6 | 15.877541 | MJN_WT DAY_REVS |
| 2 | 0.32638517 | 0.20390974 | 1967671.9 | 15.869853 | MR_J_FT MJN_WT |
| 2 | 0.33487614 | 0.21394453 | 1942869.2 | 15.568972 | MJN_COP MJN_WT |
| 2 | 0.33694797 | 0.21639306 | 1936817.3 | 15.495555 | LMJN_OUT MJN_WT |
| 2 | 0.34287576 | 0.22339862 | 1919501.8 | 15.285502 | LMJN_OT2 MJN_WT |
| 3 | 0.00496994 | -.29353907 | 2906546.3 | 29.259351 | LMJN_OT2 MJN_EXP DAY_REVS |
| 3 | 0.00497666 | -.29353034 | 2906526.7 | 29.259113 | LMJN_OUT MJN_EXP DAY_REVS |
| 3 | 0.01863274 | -.27577743 | 2866636.4 | 28.775203 | LMJN_OUT MR_J_FT DAY_REVS |
| 3 | 0.02118697 | -.27245694 | 2859175.3 | 28.684693 | MR_J_FT MJN_EXP DAY_REVS |
| 3 | 0.02510041 | -.26736946 | 2847743.9 | 28.546018 | LMJN_OUT MR_J_FT MJN_EXP |
| 3 | 0.02767892 | -.26401740 | 2840211.9 | 28.454648 | LMJN_OT2 MR_J_FT DAY_REVS |
| 3 | 0.03257719 | -.25764965 | 2825903.8 | 28.281075 | LMJN_OT2 MR_J_FT MJN_EXP |
| 3 | 0.12622952 | -.13590162 | 2552339.3 | 24.962461 | LMJN_OUT LMJN_OT2 DAY_REVS |
| 3 | 0.17316716 | -.07488269 | 2415231.5 | 23.299204 | LMJN_OUT LMJN_OT2 MR_J_FT |
| 3 | 0.17906853 | -.06721092 | 2397993.2 | 23.090087 | LMJN_OUT LMJN_OT2 MJN_EXP |
| 3 | 0.18625393 | -.05786989 | 2377004.2 | 22.835469 | LMJN_OT2 MJN_COP DAY_REVS |
| 3 | 0.20229296 | -.03701916 | 2330153.2 | 22.267118 | LMJN_OUT MJN_COP DAY_REVS |
| 3 | 0.20895398 | -.02835982 | 2310695.9 | 22.031082 | LMJN_OUT MR_J_FT MJN_COP |
| 3 | 0.21723206 | -.01759832 | 2286515.1 | 21.737744 | LMJN_OT2 MR_J_FT MJN_COP |
| 3 | 0.22625222 | -.00587211 | 2260166.6 | 21.418111 | MJN_COP MJN_EXP DAY_REVS |
| 3 | 0.23358763 | 0.00366392 | 2238739.4 | 21.158177 | MR_J_FT MJN_COP DAY_REVS |
| 3 | 0.23487803 | 0.00534144 | 2234970.1 | 21.112451 | LMJN_OT2 MJN_COP MJN_EXP |
| 3 | 0.24073285 | 0.01295271 | 2217867.8 | 20.904983 | LMJN_OUT MJN_COP MJN_EXP |
| 3 | 0.26236440 | 0.04107372 | 2154680.7 | 20.138459 | MR_J_FT MJN_COP MJN_EXP |
| 3 | 0.32890932 | 0.12758212 | 1960298.7 | 17.780409 | MJN_WT MJN_EXP DAY_REVS |
| 3 | 0.33375731 | 0.13388450 | 1946137.4 | 17.608618 | MR_J_FT MJN_WT DAY_REVS |
| 3 | 0.33736038 | 0.13856849 | 1935612.6 | 17.480942 | LMJN_OUT MR_J_FT MJN_WT |
| 3 | 0.33743693 | 0.13866801 | 1935389.0 | 17.478229 | LMJN_OUT MJN_WT DAY_REVS |
| 3 | 0.33779659 | 0.13913557 | 1934338.4 | 17.465484 | MR_J_FT MJN_COP MJN_WT |
| 3 | 0.34287576 | 0.14573849 | 1919501.8 | 17.285502 | LMJN_OT2 MR_J_FT MJN_WT |
| 3 | 0.34288982 | 0.14575676 | 1919460.8 | 17.285004 | LMJN_OT2 MJN_WT DAY_REVS |
| 3 | 0.34714188 | 0.15128444 | 1907040.2 | 17.134330 | LMJN_OUT MJN_COP MJN_WT |
| 3 | 0.34993780 | 0.15491913 | 1898873.2 | 17.035255 | MR_J_FT MJN_WT MJN_EXP |
| 3 | 0.35160616 | 0.15708801 | 1893999.8 | 16.976136 | LMJN_OUT MJN_WT MJN_EXP |
| 3 | 0.35227786 | 0.15796122 | 1892037.7 | 16.952334 | LMJN_OT2 MJN_COP MJN_WT |
| 3 | 0.35452653 | 0.16088449 | 1885469.2 | 16.872651 | MJN_COP MJN_WT DAY_REVS |
| 3 | 0.35668859 | 0.16369517 | 1879153.7 | 16.796037 | LMJN_OT2 MJN_WT MJN_EXP |
| 3 | 0.39365370 | 0.21174981 | 1771176.2 | 15.486162 | MJN_COP MJN_WT MJN_EXP |
| 3 | 0.43054898 | 0.25971367 | 1663402.8 | 14.178760 | LMJN_OUT LMJN_OT2 MJN_WT |
| 3 | 0.44276665 | 0.27559664 | 1627714.2 | 13.745822 | LMJN_OUT LMJN_OT2 MJN_COP |

Appendix G. Regression search of potential effects of July to October environmental variables on the fall midwater trawl abundance index for delta smelt. See appendix H for Key to variable names.

N=14 REGRESSION MODELS FOR DEPENDENT VARIABLE: MWT_IND MODEL: MODEL1

| NUMBER IN MODEL | R-SQUARE | ADJUSTED R-SQUARE | SSE | C(P) | VARIABLES IN MODEL |
|---|---|---|---|---|---|
| 1 | 0.00130751 | -.08191686 | 2917244.5 | 28.059097 | LJ_O_OT2 |
| 1 | 0.00303352 | -.08004702 | 2912202.7 | 27.993321 | J_O_EXP |
| 1 | 0.00353265 | -.07950629 | 2910744.7 | 27.974300 | LJ_O_OUT |
| 1 | 0.00571686 | -.07714007 | 2904364.5 | 27.891062 | JL_OFT |
| 1 | 0.03338527 | -.04716596 | 2823543.3 | 26.836649 | DAY_REVP |
| 1 | 0.25866386 | 0.19688585 | 2165490.2 | 18.251524 | JL_O_COP |
| 1 | 0.36666982 | 0.31389231 | 1849997.9 | 14.135532 | JO_WT |
| 2 | 0.00416421 | -.17689684 | 2908899.9 | 29.950232 | LJ_O_OT2 J_O_EXP |
| 2 | 0.00612686 | -.17457734 | 2903166.8 | 29.875437 | J_O_EXP JL_OFT |
| 2 | 0.00641868 | -.17423247 | 2902314.4 | 29.864316 | LJ_O_OUT J_O_EXP |
| 2 | 0.01694467 | -.16179267 | 2871567.4 | 29.463182 | LJ_O_OT2 JL_OFT |
| 2 | 0.02384620 | -.15363630 | 2851407.5 | 29.200172 | LJ_O_OUT JL_OFT |
| 2 | 0.03911606 | -.13559011 | 2806803.3 | 28.618254 | J_O_EXP DAY_REVP |
| 2 | 0.04152319 | -.13274532 | 2799771.9 | 28.526521 | LJ_O_OUT DAY_REVP |
| 2 | 0.04255564 | -.13152516 | 2796756.1 | 28.487176 | JL_OFT DAY_REVP |
| 2 | 0.04948508 | -.12333582 | 2776514.7 | 28.223102 | LJ_O_OT2 DAY_REVP |
| 2 | 0.26318064 | 0.12921348 | 2152296.4 | 20.079394 | JL_O_COP JL_OFT |
| 2 | 0.26445781 | 0.13072287 | 2148565.7 | 20.030722 | JL_O_COP J_O_EXP |
| 2 | 0.26531810 | 0.13173957 | 2146052.7 | 19.997938 | LJ_O_OT2 JL_O_COP |
| 2 | 0.26691795 | 0.13363030 | 2141379.4 | 19.936969 | LJ_O_OUT LJ_O_OT2 |
| 2 | 0.26859214 | 0.13560889 | 2136489.0 | 19.873167 | LJ_O_OUT JL_O_COP |
| 2 | 0.31324298 | 0.18837807 | 2006061.1 | 18.171572 | JL_O_COP DAY_REVP |
| 2 | 0.36701013 | 0.25192106 | 1849003.8 | 16.122564 | JO_WT DAY_REVP |
| 2 | 0.36713721 | 0.25207125 | 1848632.6 | 16.117721 | JO_WT J_O_EXP |
| 2 | 0.37098812 | 0.25662232 | 1837383.8 | 15.970967 | LJ_O_OUT JO_WT |
| 2 | 0.37199556 | 0.25781294 | 1834441.0 | 15.932574 | LJ_O_OT2 JO_WT |
| 2 | 0.37826357 | 0.26522058 | 1816131.8 | 15.693707 | JO_WT JL_OFT |
| 2 | 0.69578315 | 0.64047099 | 888636.8 | 3.593377 | JL_O_COP JO_WT |
| 3 | 0.01861599 | -.27579921 | 2866685.3 | 31.399490 | LJ_O_OT2 J_O_EXP JL_OFT |
| 3 | 0.02641678 | -.26565819 | 2843898.7 | 31.102210 | LJ_O_OUT J_O_EXP JL_OFT |
| 3 | 0.04333182 | -.24366863 | 2794488.8 | 30.457596 | LJ_O_OUT JL_OFT DAY_REVP |
| 3 | 0.04948922 | -.23566401 | 2776502.6 | 30.222944 | LJ_O_OT2 JL_OFT DAY_REVP |
| 3 | 0.08124338 | -.19438361 | 2683746.7 | 29.012827 | LJ_O_OUT J_O_EXP DAY_REVP |
| 3 | 0.08699869 | -.18690170 | 2666935.1 | 28.793499 | J_O_EXP JL_OFT DAY_REVP |
| 3 | 0.10105707 | -.16862581 | 2625869.7 | 28.257749 | LJ_O_OT2 J_O_EXP DAY_REVP |
| 3 | 0.26560361 | 0.04528469 | 2145218.7 | 21.987057 | JL_O_COP J_O_EXP JL_OFT |
| 3 | 0.27059762 | 0.05177691 | 2130630.9 | 21.796741 | LJ_O_OT2 JL_O_COP J_O_EXP |
| 3 | 0.27207674 | 0.05369976 | 2126310.3 | 21.740373 | LJ_O_OUT LJ_O_OT2 JL_OFT |
| 3 | 0.27409046 | 0.05631760 | 2120428.1 | 21.663632 | LJ_O_OUT JL_O_COP J_O_EXP |
| 3 | 0.28798367 | 0.07437877 | 2079845.1 | 21.134177 | LJ_O_OT2 JL_O_COP JL_OFT |
| 3 | 0.29533035 | 0.08392946 | 2058385.0 | 20.854203 | LJ_O_OUT JL_O_COP JL_OFT |
| 3 | 0.31995144 | 0.11593687 | 1986465.2 | 19.915920 | LJ_O_OUT JL_O_COP DAY_REVP |
| 3 | 0.32121710 | 0.11758223 | 1982768.2 | 19.867687 | JL_O_COP J_O_EXP DAY_REVP |
| 3 | 0.32180560 | 0.11834728 | 1981049.1 | 19.845260 | JL_O_COP JL_OFT DAY_REVP |
| 3 | 0.32573019 | 0.12344924 | 1969585.1 | 19.695698 | LJ_O_OT2 JL_O_COP DAY_REVP |
| 3 | 0.36717777 | 0.17733109 | 1848514.1 | 18.116175 | JO_WT J_O_EXP DAY_REVP |
| 3 | 0.37146369 | 0.18290279 | 1835994.7 | 17.952843 | LJ_O_OUT JO_WT J_O_EXP |
| 3 | 0.37216045 | 0.18380859 | 1833959.4 | 17.926290 | LJ_O_OUT JO_WT DAY_REVP |
| 3 | 0.37238843 | 0.18410495 | 1833293.5 | 17.917603 | LJ_O_OT2 JO_WT J_O_EXP |
| 3 | 0.37388822 | 0.18605468 | 1828912.5 | 17.860447 | LJ_O_OT2 JO_WT DAY_REVP |
| 3 | 0.37947638 | 0.19331930 | 1812589.1 | 17.647488 | JO_WT J_O_EXP JL_OFT |
| 3 | 0.38020262 | 0.19426341 | 1810467.7 | 17.619812 | JO_WT JL_OFT DAY_REVP |
| 3 | 0.40937631 | 0.23218921 | 1725249.5 | 16.508034 | LJ_O_OUT LJ_O_OT2 JO_WT |
| 3 | 0.40963462 | 0.23252501 | 1724494.9 | 16.498190 | LJ_O_OUT LJ_O_OT2 J_O_EXP |
| 3 | 0.42150144 | 0.24795187 | 1689831.2 | 16.045959 | LJ_O_OUT JO_WT JL_OFT |
| 3 | 0.42446933 | 0.25181013 | 1681161.8 | 15.932855 | LJ_O_OT2 JO_WT JL_OFT |
| 3 | 0.43376093 | 0.26388922 | 1654020.4 | 15.578762 | LJ_O_OUT LJ_O_OT2 JL_O_COP |
| 3 | 0.43547960 | 0.26612348 | 1649000.1 | 15.513266 | LJ_O_OUT LJ_O_OT2 DAY_REVP |
| 3 | 0.69580992 | 0.60455290 | 888558.6 | 5.592357 | JL_O_COP JO_WT J_O_EXP |
| 3 | 0.69621217 | 0.60507582 | 887383.6 | 5.577028 | JL_O_COP JO_WT DAY_REVP |
| 3 | 0.69679479 | 0.60583323 | 885681.8 | 5.554825 | LJ_O_OT2 JL_O_COP JO_WT |
| 3 | 0.69680044 | 0.60584057 | 885665.3 | 5.554609 | LJ_O_OUT JL_O_COP JO_WT |
| 3 | 0.71429518 | 0.62858374 | 834562.8 | 4.887903 | JL_O_COP JO_WT JL_OFT |

Appendix H. Key to the variables used in regression search of environmental variables affecting delta smelt abundance.

## March-June Variables

| | |
|---|---|
| LMJN_OUT= | $Log_{10}$ Mean March-June Delta outflow. |
| LMJN_OT2= | $Log_{10}$ Mean March-June Delta outflow squared. |
| DAY_REVS= | Number of March-June days of reverse flow. |
| MJN_EXP= | Mean March-June water project exports. |
| MR_J_FT= | Mean Maximum March-June Sacramento River Temperature at Freeport. |
| MJN_COP= | Mean March-June copepod density/$m^3$ exclusive of Sinocalanus and nauplii. |
| MJN_WT= | Mean March-June water transparency (secchi). |

## July-October Variables

| | |
|---|---|
| LJ_O_OUT= | $Log_{10}$ mean July-October Delta outflow. |
| LJ_O_OT2= | $Log_{10}$ mean July-October Delta outflow squared. |
| DAY_REVF= | Number of July-October days of reverse flows. |
| J_O_EXP= | Mean July-October water project exports. |
| J_OFT= | Mean July-October maximum Sacramento River temperature at Freeport. |
| JL_O_COP= | Mean July-October copepod density/$m^3$ exclusive ofSinocalnus and nauplii. |
| JO_WT= | Mean July-October water transparency (secchi). |