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COLLEGE OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES
AGRICULTURAL EXPERIMENT STATION
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1 May 1995

Dr. Randall Brown
Department of Water Resources
3251 "S" Street
Sacramento, CA 95816

Re: DWR contract B-59636

Dear Randy,

Enclosed please find the 1994 annual report for our Suisun Marsh sampling (contract B-59636). The catches were dominated by introduced fishes and average fish per trawl was the lowest we have recorded, as were catches of several species. In fact, eight native fishes were represented by six or fewer individuals.

I would also like to call your attention to the fact that there were some errors in the data from 1989, 1990, and 1991 that we discovered this year. The present graphs and tables have been corrected. The changes in the data did not change the results (e.g. trends in fish abundances) in any substantial way.

As part 2 of our report we have included an analysis of the first year of our larval fish sampling. Like the trawls, these samples were dominated by introduced species, especially gobies. No splittail or Sacramento sucker larvae were collected, but we did find delta smelt and longfin smelt in low numbers.

Thank you for your continued support.

Sincerely,

Peter B. Moyle
Professor

cc: UC Davis office of Research

Randy - also enclosed is the final electrophoresis report. Sorry I forgot to send it earlier; I was waiting for your comments on the Nov. 28 draft!

Trends in Fish Populations of Suisun Marsh
January 1994 - December 1994

Annual Report For:
Contract B-59636
California Department of Water Resources
Central Division Sacramento, California
Attn: Dr. Randall Brown

Scott A. Matern, Lesa Meng, and Peter B. Moyle
Department of Wildlife and Fisheries Biology
University of California, Davis

PART 1: Suisun Marsh Fish Survey
January 1994 - December 1994

Introduction

In January 1979, the Department of Wildlife, Fisheries, and Conservation Biology began a monthly fish sampling program in Suisun Marsh. Through 1993 the program consisted of otter trawl collections made at 17 sites scattered throughout the sloughs of the marsh and supplementary sampling done with small beach seines in Suisun Slough. To better represent the entire marsh, we added additional sampling sites in the eastern marsh in 1994. These include two otter trawl sites each in Nurse and Denverton Sloughs and a new beach seining location in Denverton Slough. The first five years of data are summarized in Moyle et al. (1986) who noted strong seasonal trends in abundances and occurrences of species as well as the presence of groups of co-occurring species. A downward trend in total catch data was noted but regarded as inconclusive. Subsequent years were summarized my Meng et al. (1994) who found the assemblage structure to be less predictable than had been concluded in the shorter 1986 study. Instead, they recorded a distinct downward trend in abundance by all species except for two Asian gobies, whose numbers fluctuated wildly. This report summarizes and compares data from 1994 with earlier collection data.

Methods

<u>Study area:</u> Suisun Marsh is a large (about 34,000-ha) tidal marsh downstream of the confluence of the Sacramento and San Joaquin Rivers, one-third of which is tidally influenced while the remainder consists of diked wetlands managed to attract overwintering waterfowl. Salinities have ranged from 0 to nearly 17 parts per thousand in recent years; highest salinities occur in early fall of drought years and lowest salinities occur during periods of high river outflows in spring (Meng et al. 1994). We sampled two major habitat types in the marsh: small (7-10 m wide, 1-2 m deep) dead-end sloughs lined with tules and reeds and larger (100-150 m, 2-4 m deep) sloughs that are partially riprapped. Depth of the sloughs fluctuates more than 1 m during extreme tides, dewatering small sloughs by up to 75%.

<u>Field methods:</u> In 1994 sampling was conducted monthly at 17 to 21 sites (four sampling locations were added in the middle of the year) in nine sloughs. The small dead-end sloughs sampled were Peytonia, Boynton, Spring Branch, Goodyear, Nurse, and Denverton, the latter two added midway through 1994. Cutoff Slough is open at both ends but is otherwise similar to dead-end sloughs. Nurse Slough is intermediate in size between the other small sloughs and the larger sloughs but more closely resembles the habitat of the smaller sloughs. The large sloughs sampled were Suisun, and Montezuma. All samples were taken during the

day because Moyle et al. (1986) found no significant differences in catch between day and night samples.

The principal means of sampling was a four-seam otter trawl with a 1 X 2.5 m opening, a length of 5.3 m, and mesh sizes that tapered down to 6 mm stretch in the bag. At each sample site the trawl was towed for 5 min (small sloughs) or 10 min (larger sloughs) at about 4 km/hr. The longer periods were necessary in the larger sloughs because of small catches. Sampling was augmented by 10 m beach seines used in Suisun and, for the second half of 1994, Denverton sloughs. For each site tidal height was determined using a tide table and salinity, temperature, conductivity, and secchi depth were recorded. Biases in sampling, gear effectiveness, and other methodology were consistent over the course of the study, so comparisons should be unaffected. The only differences in 1994 were the addition of four otter trawl sites and one seining site.

Contents of each trawl or seine were placed into large washtubs of water. Fishes were identified, measured to the nearest mm standard length, and returned to the slough. We also recorded the abundance of several common macroinvertebrates. The shrimps *Crangon franciscorum* and *Palaemon macrodactylus* were counted while the opossum shrimp *Neomysis mercedis* was given an abundance ranking: 1 represented fewer than three individuals; 2, 3, and 4 represented 3-50, 51-200, 201-500 shrimp, respectively; and 5 represented more than 500 individuals. The index was necessary because most *N. mercedis* probably passed through the net.

A complete list of species captured is presented in Table 1.1.

Results

Environmental patterns. Until fall of 1983, outflows varied annually and seasonally and salinities, temperatures, and water transparencies reflected the shifting influences of saltwater intrusion and freshwater runoff. During the dry years from 1985 to 1992, however, salinities in Suisun Marsh stayed above two parts per thousand (ppt) for all months except three (February, March 1986 and March 1989) and the highest yearly averages recorded in our study were in 1991 and 1992 (Table 1.2, Table 1.3). The wet year of 1993 dramatically reduced the salinity of the marsh, resulting in monthly averages of less than 2 ppt. for February through June and a yearly average of of only 2.4 ppt. 1994 was a dry year and the average yearly salinity of the marsh rose to 4.3 ppt. (Table 1.3), a value still lower than for all drought years except 1986 (no fall sampling was conducted in 1989, resulting in artificially low average yearly salinity). Furthermore, monthly salinity averages were below 2 ppt. for February, March, and April (Table 1.2). These data are perhaps a reflection of current water management decisions in Suisun Marsh. Temperature regimes have shown no easily detectable changes (Table 1.2). Secchi depth (a measure of turbidity) decreased in response to the high outflows in 1986, rose during the remainder of the drought, and decreased again with the wet year of 1993 (Table 1.3) As expected, the dry year of 1994 saw an increase in transparency (Table 1.3), but other trends are difficult to discern.

General trends in fish abundance: The fishes and invertebrates collected by otter trawl in Suisun Marsh display two responses to changing physical conditions:

1. A general change in abundance across years - accelerated for several species in 1983. For most resident species this change has been a decline, the only exceptions being the yellowfin goby which reached its highest abundance in the marsh in 1993 and the shimofuri goby (formerly identified as the chameleon goby; Matern and Fleming, in press) which were introduced in the early 1980's and peaked in 1989.

2. A temporary change in abundance - for many species this occurred during a period of low salinity (1983 El Nino) and they returned to previous levels of abundance when salinity increased. Other species simply show the effect of wet versus dry years. The wet springs of 1991 and 1992 produced more young-of-the-year striped bass and splittail than previous years. Delta smelt, prickly sculpin, and yellowfin goby may have also benefitted from greater spring outflows; all of them increased during the wet year of 1993. The dry year of 1994 saw major declines in prickly sculpins and yellowfin gobies but a modest increase in delta smelt.

The overall change has been toward a less numerous, less diverse assemblage of fishes (Table 1.3) with a greater dominance by introduced species. In fact, the mean number of fish per trawl was the lowest ever in 1994 and consisted of 77% introduced fishes (Table 1.4). However, species composition was only 39% introduced species, reflecting the very low abundances of most native species. Eight of the native species collected were represented by six or fewer individuals (Table 1.4).

Delta smelt and longfin smelt: Straight-forward declines in abundance across years occurred in delta smelt and longfin smelt (Figure 1.1) Of the 458 delta smelt captured by otter trawling, all but 36 were captured before 1984. Though we only caught 16 delta smelt in our trawls and an additional five by seining in 1994 it was our best catch since 1982 and the third consecutive year of increased catches. Longfin smelt have declined and changed their pattern of occurrence in the marsh. From 1980 to 1983 longfin smelt passed through the marsh in the fall or winter during their upstream spawning migrations, but since 1984 most of the longfin smelt have been newly spawned outmigrants in the spring. In 1994, however, the longfin smelt we captured were taken in February (3), October (1), November (1), and December (1), suggesting a return to historic patterns of occurrence, although abundances are orders of magnitude lower than the early 1980's.

<u>Striped bass:</u> The most abundant fish, in all years but 1988, 1990, and 1993, was young-of-the-year striped bass. Catch of young-of-the-year striped bass has varied widely over the course of our study (Figure 1.2) ranging from an average of two fish per trawl in 1990 to 22 fish per trawl in 1981. In 1994 less than four young striped bass were caught per trawl. Striped bass greater than one year old, on the other hand, show less fluctuation in abundance and are clearly declining (Figure 1.2). Catches of older striped bass, which averaged two per trawl in 1980, have been below 0.5 per trawl for the last nine years and were 0.1 fish per trawl in 1994, the lowest level recorded in our study.

<u>Splittail:</u> Until 1981 splittail was the second most abundant fish in Suisun Marsh (Table 1.4). As with striped bass, longfin smelt, chinook salmon, and American shad, splittail increase their reproductive success in wet years (Daniels and Moyle 1983). The wet years of 1980 and 1982 and the wet spring of 1986 produced the greatest abundance of young-of-the-year splittail (Figure 1.3). Very little recruitment has occurred since 1986 and in subsequent years, except 1989 and 1991, adult splittail have outnumbered young-of-the-year in Suisun Marsh (Figure 1.3). Both young and adult splittail continued their three-year decline, hitting all-time lows in 1994.

We attempted to study the dietary habits of young-of-the-year splittail but found only one <u>Daphnia</u> spp. after examination of 30 stomachs. In addition, the proposed-for-listing status of the splittail constrained collection efforts.

<u>Yellowfin goby and shimofuri goby:</u> The yellowfin goby, an Asian exotic, peaked at six fish per trawl in 1984 and fluctuated between one and four fish per trawl until 1993, when a very high abundance of young-of-the-year pushed the average to 16 fish per trawl (Figure 1.4). In 1994, the catch plummeted to less than one fish per trawl. The shimofuri goby, another Asian introduction, was first captured in the marsh in 1985 and became the most abundant fish in our trawls by 1989 (Table 1.4). Based upon description given in Akihito and Sakamoto (1989), this species, *Tridentiger bifasciatus*, is different from the chameleon goby, *T. trigonocephalus*, found in the marine environments of the San Francisco Bay Estuary (Matern and Fleming, in press). This is the first occurrence of *T. bifasciatus* outside of Asia. The shimofuri goby appeared to peak in 1989 and then decline, causing us to question its long-term viability in Suisun Marsh. However, our shimofuri goby catches increased four-fold in 1994. After reaching the pumps of the State Water Project System in the upper estuary in 1987 (Raquel 1988), shimofuri gobies were transported over 500 km south to Pyramid Reservoir and were collected a year later from a creek downstream of the dam (Swift et al. 1993). This species spawns repeatedly throughout the spring and summer and its larvae were more abundant than all other species combined during our 1994 Suisun Marsh larval fish sampling.

Prickly sculpin, Pacific staghorn sculpin, and Sacramento sucker: Prickly scuplin show a strong response to outflow. Years of high outflow, even 1986, produced high abundances of young prickly sculpins. From 1991 to 1993 prickly sculpin abundances increased steadily to pre-drought levels, presumably due to increased springtime flows. Dry years, 1994 included, result in lower catches (Figure 1.5). These sculpins apparently breed within Suisun Marsh, but young are also carried down from upstream populations (Moyle 1976). This pattern is typical of other freshwater species such as splittail and Sacramento sucker. Staghorn sculpins, a marine species, hit an all-time low in 1983 and fluctuated since then (Figure 1.5). For the past three years catches of staghorn sculpins have been about 0.1 fish per trawl, approaching the all-time low. Sacramento suckers, like many native fishes, are in serious decline in Suisun Marsh. Catches for the past several years are an order of magnitude smaller than the high of 1.6 fish per trawl recorded in 1981, and 1994 was no exception (Figure 1.5). This species is long-lived and can wait several years between spawnings. No sucker larvae were collected during our 1994 Suisun Marsh larval fish sampling but perhaps the heavy rains of 1995 will promote successful recruitment.

Tule perch: Tule perch has been one of the most abundant species in the marsh (Table 1.4). Like all surfperches, tule perch are livebearers. They are year-round residents of the marsh. Tule perch populations peaked in 1981-1982 and again 1987-1988, followed by dramatic declines (Figure 1.6). Since 1988 the population has been very low and recent catches are among the lowest we have encountered. Low tule perch catches coincide with the overall decline of native fishes found in the smaller sloughs of Suisun Marsh.

Marine species: In 1992, three truly marine species were collected in the marsh: one California halibut (*Paralichthys californicus)*, two speckled sanddab (*Citharichthys stigmaeus*), and one bay pipefish *(Sygnathus leptorhynchus)*. The presence of these fishes indicates unusually high salinities in the marsh. When the marsh became less saline in 1993, none of these species were collected. However, with the increasing salinities of 1994, another bay pipefish was collected. In addition, another marine species, white croaker (*Genyonemus lineatus*), was collected for the first time in Suisun Marsh.

Invertebrates: The two shrimp species, *Palaemon macrodactylus* and *Crangon franciscorum* fluctuate widely within and across years in their abundances. Both species seemed to show a decline in abundance during periods of low salinity but the increased salinity of 1994 nevertheless saw a decrease in both species (Table 1.3, Figure 1.7). The introduced *P. macrodactylus* prefers fresher water than *C. franciscorum* and reached an all-time low in 1994. *C. franciscorum*, on the other hand, has not declined substantially from its average values for the past several years. Our catches of the oppossum shrimp (*Neomysis mercedis*) have shown only a small decline since the beginning of our study (Table 1.3, Figure 1.7). However, Orsi and Mecum (1994) reported the invasion of an Asian mysid (*Acanthomysis*) to the San Francisco Bay Estuary. We are not aware of its effects in Suisun Marsh.

Some exotic invertebrate species have entered the marsh since 1989 and their effects may move up the food chain. The copepod *Eurytemora affinis*, an important food organism for young fish, as been partially replaced by the Asian copepod *Pseudodiaptomus forbesi*. This copepod appears to be suitable food for young fish (Meng and Orsi 1991) but its abundance does not peak until late spring.

Another Asian invader is the clam *Potamocorbula amurensis*. This clam is very abundant near the mouth of Suisun Slough and has invaded into the upstream regions of Suisun Slough but has only rarely appeared in our samples of smaller sloughs. In 1994 we collected *P. amurensis* near the salinity control gates in Montezuma Slough.

Table 1.1. Fishes of Suisun Marsh.

COMMON	SCIENTIFIC	ABBREVIATION
American shad	Alosa sapidissima	ASH
bay pipefish	Syngnathus leptorhynchus	BYP
brown bullhead	Ictalurus nebulosus	BB
black crappie	Pomoxis nigromaculatus	BC
bluegill	Lepomis macrochirus	BG
black bullhead	Ictalurus melas	BLB
bigscale logperch	Percina macrolepida	BLP
California halibut	Paralichthys californicus	CHA
channel catfish	Ictalurus punctatus	CCF
chinook salmon	Oncorhynchus tshawytscha	KS
common carp	Cyprinus carpio	CP
delta smelt	Hypomesus transpacificus	DS
fathead minnow	Pimephales promelas	FHM
golden shiner	Notemigonus crysoleucas	GSH
goldfish	Carassius auratus	GF
hitch	Lavinia exilicauda	HCH
inland silverside	Menidia beryllina	MSS
longfin smelt	Spirinchus thaleichthys	LFS
mosquitofish	Gambusia affinis	MQF
northern anchovy	Engraulis mordax	NAC
Pacific herring	Clupea harengeus	PH
Pacific lamprey	Lampetra tridentata	PL
Pac. staghorn sculpin	Leptocottus armatus	STAG
plainfin midshipman	Porichthys notatus	MID

prickly sculpin	Cottus asper	SCP
rainbow trout	Oncorhynchus mykiss	RT
rainwater killifish	Lucania parva	RWK
Sacramento blackfish	Orthodon microlepitus	GB
Sacramento squawfish	Ptychocheilus grandis	SQ
Sacramento sucker	Catostomus occidentalis	SKR
shimofuri goby	Tridentiger bifasciatus	SG
shiner perch	Cymatogaster aggregata	SP
speckled sanddab	Citharichthys stigmaeus	DAB
splittail	Pogonichthys macrolepidotus	ST
starry flounder	Platichthys stellatus	SF
striped bass	Morone saxatilis	SB
surf smelt	Hypomesus pretiosus	SS
threadfin shad	Dorosoma petenense	TFS
threespine stickleback	Gasterosteus aculeatus	STBK
tule perch	Hysterocarpus traski	TP
white catfish	Ictalurus catus	WCF
white croaker	Genyonemus lineatus	WCK
white crappie	Pomoxis annularis	WC
white sturgeon	Acipenser transmontanus	WS
yellowfin goby	Acanthogobius flavimanus	YFG

Table 1.2. Mean salinity (parts per thousand), temperature (°C) and Secchi depth (cm) per month. Seventeen sites sampled in most months, recently increased to 21 sites. See previous reports for yearly data prior to 1989.

	1979-1983	1984-1988	1989	1990	1991	1992	1993	1994
Salinity (ppt)								
J	2.2	2.6	---	4.2	8.1	7.2	2.1	2.8
F	1.5	2.2	2.9	3.8	6.6	4.5	1.4	1.5
M	1.4	2.5	1.3	4.7	3.3	2.6	0.9	1.2
A	1.1	2.3	3.3	5.4	2.6	2.2	1.7	1.9
M	1.9	3.1	3.5	5.9	8.4	4.8	1.1	2.1
J	2.0	5.1	5.3	4.2	7.8	7.0	0.9	4.1
J	2.4	5.1	6.4	5.7	8.4	7.8	2.2	6.3
A	3.0	5.8	6.1	6.4	8.3	9.7	2.5	7.8
S	4.2	5.4	6.3	7.3	8.6	9.4	3.6	6.7
O	3.9	6.2	---	---	9.6	10.2	4.4	5.7
N	3.8	5.8	---	9.3	8.1	8.0	4.4	5.7
D	2.8	5.3	---	8.8	8.6	5.0	4.1	3.4
Temperature (°C)								
J	8.0	9.0	---	8.6	6.7	8.0	8.2	9.6
F	11.2	11.6	8.7	10.2	12.3	11.5	12.4	11.0
M	13.4	15.0	15.4	15.4	11.9	14.3	17.6	14.9
A	15.6	18.5	17.3	19.3	15.0	16.6	17.0	18.2
M	19.2	20.7	20.5	18.9	18.3	19.5	20.0	19.8
J	20.7	21.0	19.4	21.0	18.5	20.3	24.3	20.0
J	21.8	22.7	22.5	21.3	20.3	22.2	22.2	20.9
A	20.6	22.8	21.6	24.1	20.9	20.2	23.1	23.0
S	21.0	19.9	19.7	20.7	19.4	21.1	20.0	20.5
O	17.5	16.2	---	---	19.1	21.7	19.0	18.0
N	12.5	12.2	---	12.3	15.3	19.3	12.2	10.7
D	9.8	7.2	---	9.9	9.5	10.8	11.9	8.6
Secchi (cm)								
J	25.3	27.9	---	25.3	37.8	27.1	18.9	25.3
F	22.8	20.7	29.8	20.8	24.5	24.8	16.5	19.3
M	18.6	18.8	17.3	20.5	15.9	18.6	22.4	18.3
A	18.0	19.8	16.1	15.5	14.0	16.2	17.7	23.9
M	17.4	20.1	13.6	21.2	14.0	17.4	16.2	17.7
J	16.7	27.9	19.8	14.9	16.7	21.8	13.4	23.4
J	17.9	22.1	---	19.0	19.6	22.1	16.2	18.0
A	20.6	27.8	22.5	18.8	23.3	21.2	14.5	25.3
S	26.8	31.0	20.4	25.1	27.9	28.5	16.5	23.0
O	25.6	31.2	---	---	35.6	35.3	22.7	23.7
N	24.4	34.9	---	27.7	30.4	26.3	25.9	21.6
D	21.0	25.3	---	21.3	20.5	26.6	28.0	26.3

Table 1.3. Summary of Suisun Marsh data 1980-1993. Fish, Species, Crangon, and Palaemon are averages per trawl. Neomysis is an abundance index with 5=most abundant. Salinity (ppt), temperature (°C), and secchi (cm) are yearly averages.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Fish	59	39	37	33	23	28	23	17	24	11	18	20	26	10
Species	5	4	4	4	4	4	4	3	3	3	3	3	3	3
Crangon	60	43	33	39	12	68	58	32	66	25	43	13	46	27
Palaemon	22	8	10	11	15	12	24	8	15	7	4.3	3.4	4.7	3.0
Neomysis	2.8	2.4	3.3	3.3	3.0	2.8	2.6	2.2	2.6	2.2	1.7	1.7	2.1	2.0
Salinity	4.3	1.2	0.5	2.2	5.5	3.1	5.8	4.3	3.9	5.9	7.4	6.5	2.4	4.3
Temp	17.0	15.3	16.3	17.5	15.7	16.9	16.0	15.4	17.3	16.8	15.6	17.1	17.4	16.6
Secchi	22.3	20.2	20.2	27.1	28.7	18.9	25.3	26.3	19.9	21.3	23.4	23.8	19.1	22.3

Table 1.4. Total catch per year for species (and age categories) collected in Suisun Marsh January 1980-December 1994. Numbers are not adjusted for catch per unit effort. Approximately twice as many trawls were made in 1980 and 1981. See Table 1.1 for species represented by abbreviations.

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
ASH	36	153	8	2	5	8	5	8	6	1	16	3	6		4
BB	3	1	2	1	3	6	1								
BC	3	6	3	1		1	72	7	3						
BG	6	1	2	1			1								
BLB	1	1			9	14	5	1	1	1					2
BLP			10		1										
BYP													1		1
CCF	3		3		12	8	5	3	2		1				7
CHA												2	1		
CP	576	560	131	61	69	257	258	77	46	60	44	61	28	45	35
DAB													2		
DS	157	229	28	9		1			1	1	1	5	3	7	16
FHM	6	2				6	1			1					
GB	10	2	4	1											
GF	31	4	1		21	100	7	3	3	2			1	3	2
GSF	1	1													
GSH								2	1						
HCH	13	23	7		6	20	2	10	9		3	1	1		1
KS	12	19		10	1		13	1	1	1					
LFS	3263	831	1573	200	553	150	25	110	195	129	242	21	3	3	6
MID											2		1	1	4
MSS	25	50	6	2	18	128	7	16	21	8	13	18	7	3	15
MQF		4	2		4		1							1	1
NAC	13	154			1	15	1	5	5	2	2	3	22		
PH		24	3	3	5	34	1	6	40	1	7	49		1	4
PL		4	2				1	1			1		6		
RWK	3			1					1	3		2			
SBA	824	381	111	40	44	143	69	76	91	65	34	53	72	48	25
SBY	5044	8365	2528	3831	2242	2147	1879	1341	628	1053	349	1549	2610	919	767
SCP	1810	644	647	1137	125	74	362	51	112	38	11	83	137	242	68
SF	519	223	28	68	20	28	35	15	34	10	14	49	12	6	34
SG						2		45	284	1268	855	657	352	118	463
SKR	508	607	168	147	98	146	99	68	50	21	21	6	7	18	19
SQ	43	23	6	2	5	2	7	6	1						
SP	2	2									11				
SS	1	2													
STA	1982	721	165	74	81	82	100	302	116	46	54	85	73	35	36
STAG	354	369	31	9	39	98	54	40	96	76	52	162	18	14	19
STBK	2345	5264	954	311	41	51	206	664	70	150	141	581	137	65	48
STY	1630	1044	988	393	109	69	583	139	53	62	26	112	61	27	15
TFS	369	374	83	25	206	37	26	69	21	2	10	5	18	24	17
TP	1893	2364	1555	100	109	494	580	1219	1289	204	186	182	210	96	158
WC			8	1	1	3	11	8					1		
WCK															1
WCF	5	4	4	131	31	22	15	7	11		6	2	1	6	6
WS	4	1	3	8	5		1	1	2			1	1	1	1
YFG	1079	222	204	22	906	173	560	274	108	381	154	265	317	3261	174

Figures

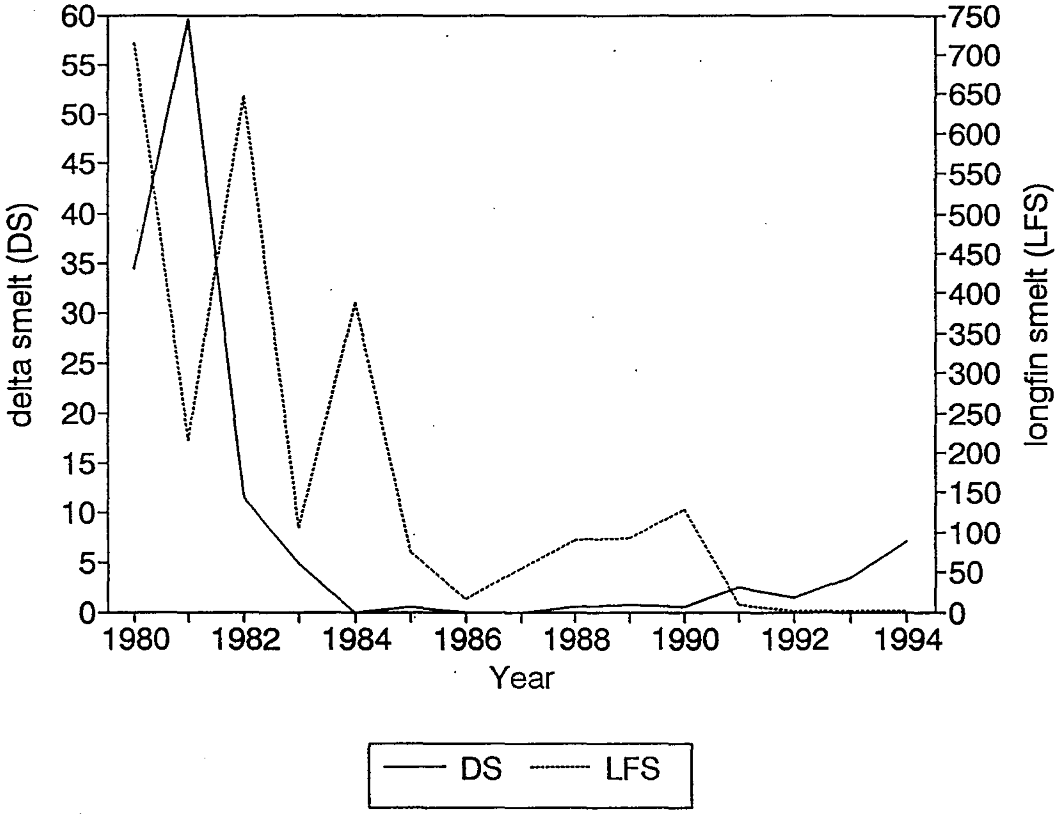

Figure 1.1. Mean catch per trawl (X 100) of delta smelt and longfin smelt in Suisun Marsh.

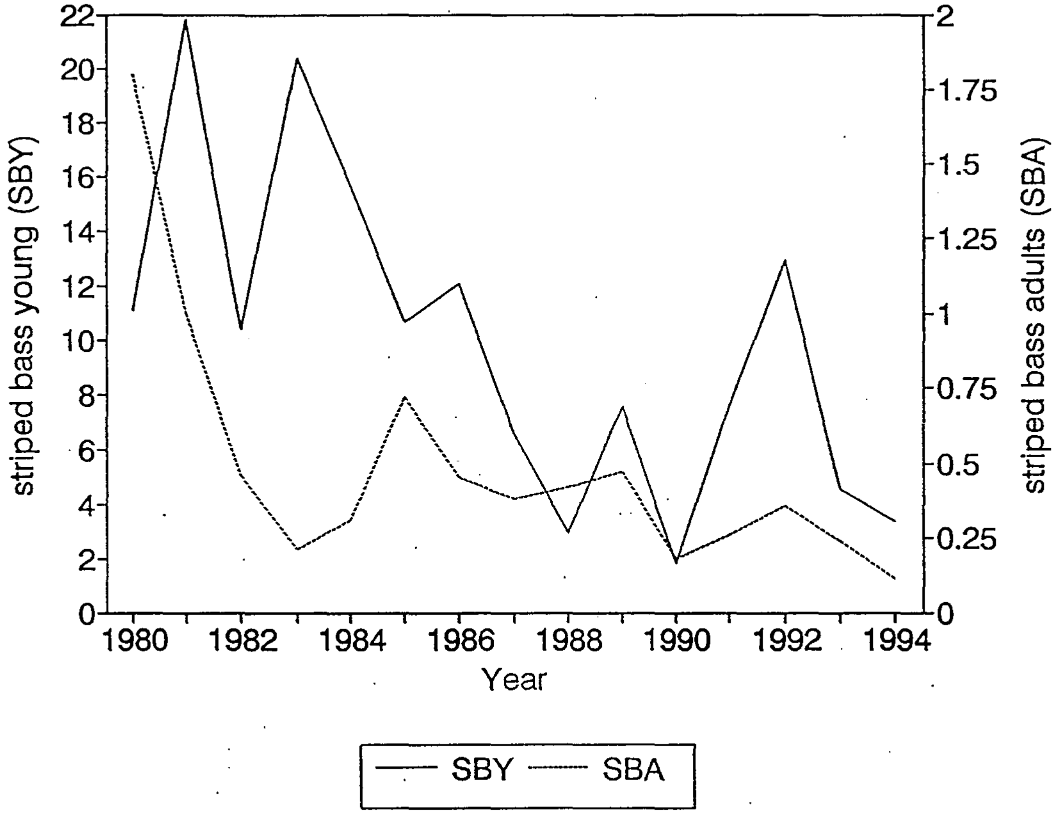

Figure 1.2. Mean catch per trawl of striped bass young (SBY) and striped bass adults (SBA) in Suisun Marsh.

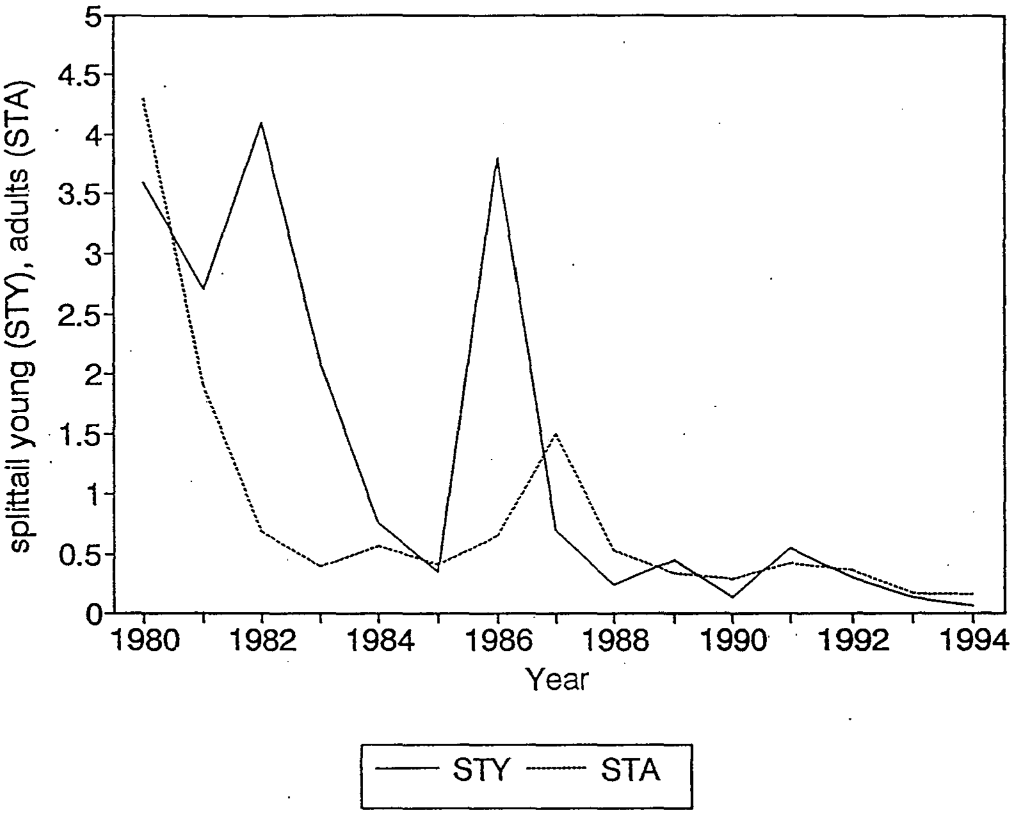

Figure 1.3. Mean catch per trawl of splittail young (STY) and splittail adults (STA) in Suisun Marsh.

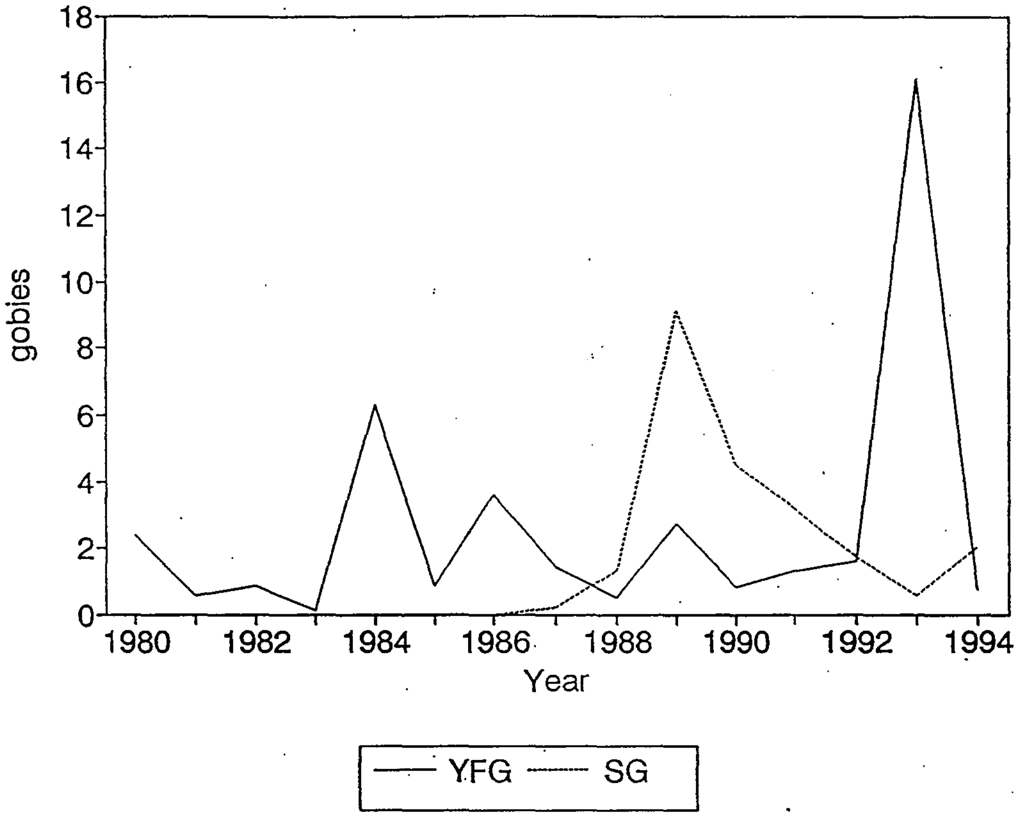

Figure 1.4. Mean catch per trawl of yellowfin goby (YFG) and shimofuri goby (SG) in Suisun Marsh.

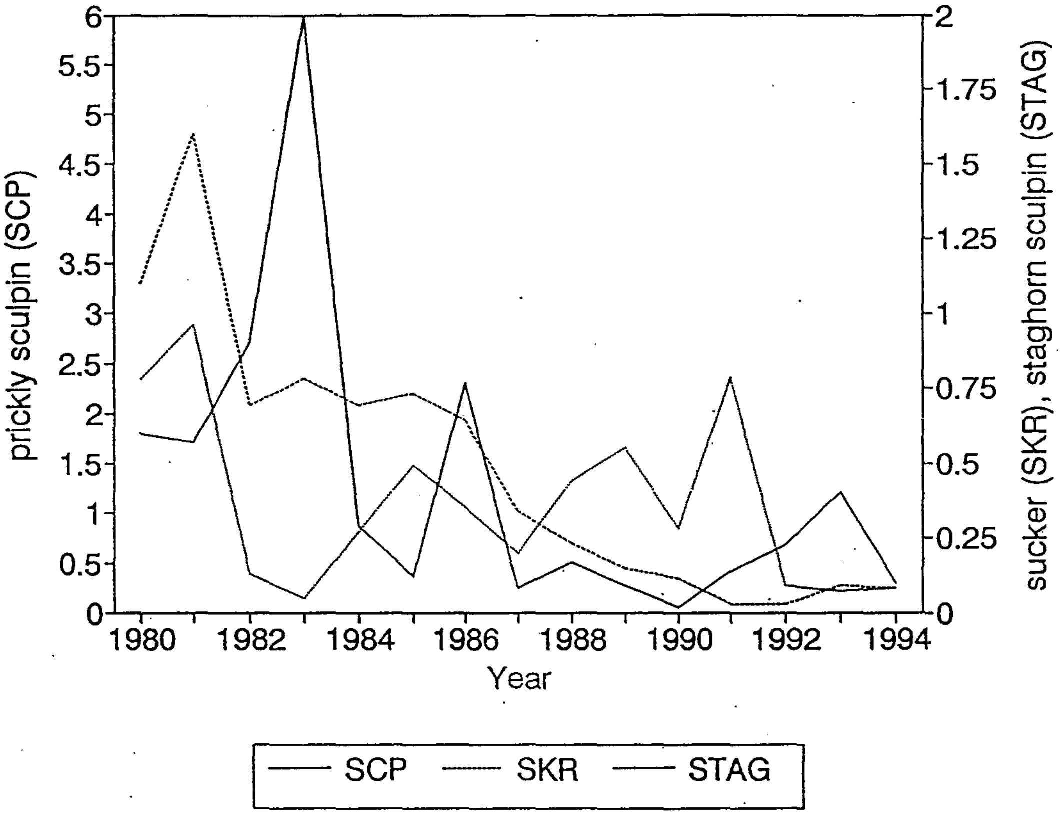

Figure 1.5. Mean catch per trawl of prickly sculpin (SCP), Sacramento sucker (SKR), and Pacific staghorn sculpin (STAG) in Suisun Marsh.

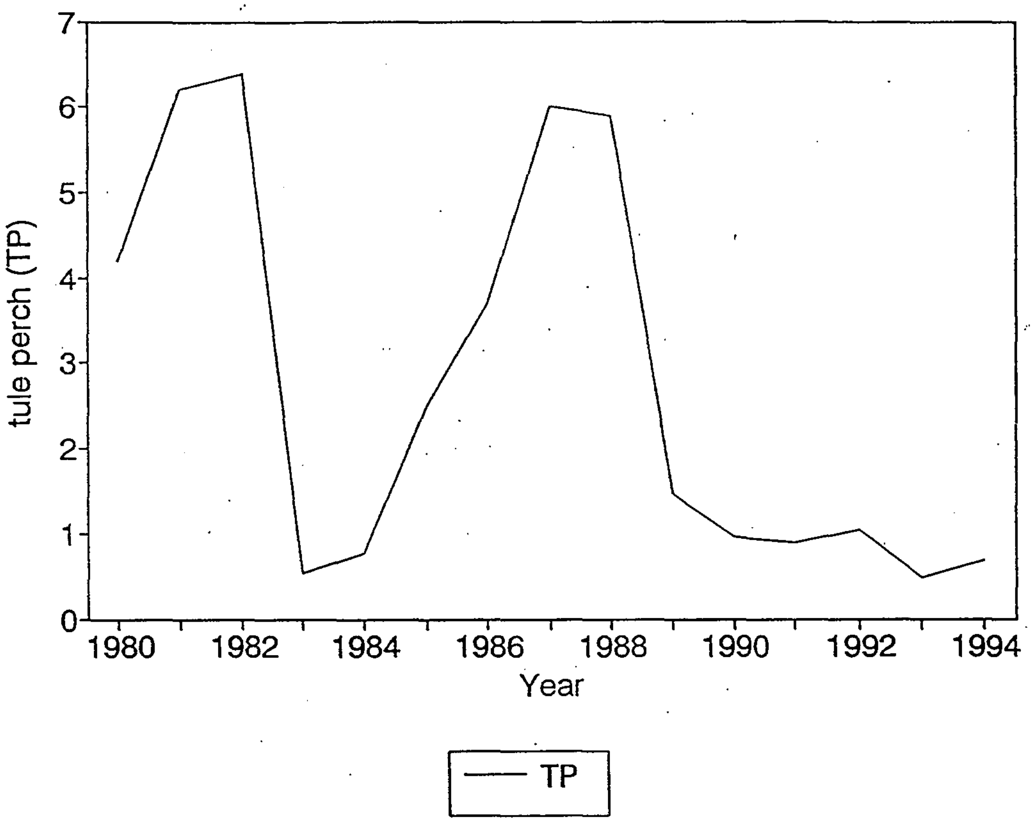

Figure 1.6. Mean catch per trawl of tule perch (TP) in Suisun Marsh.

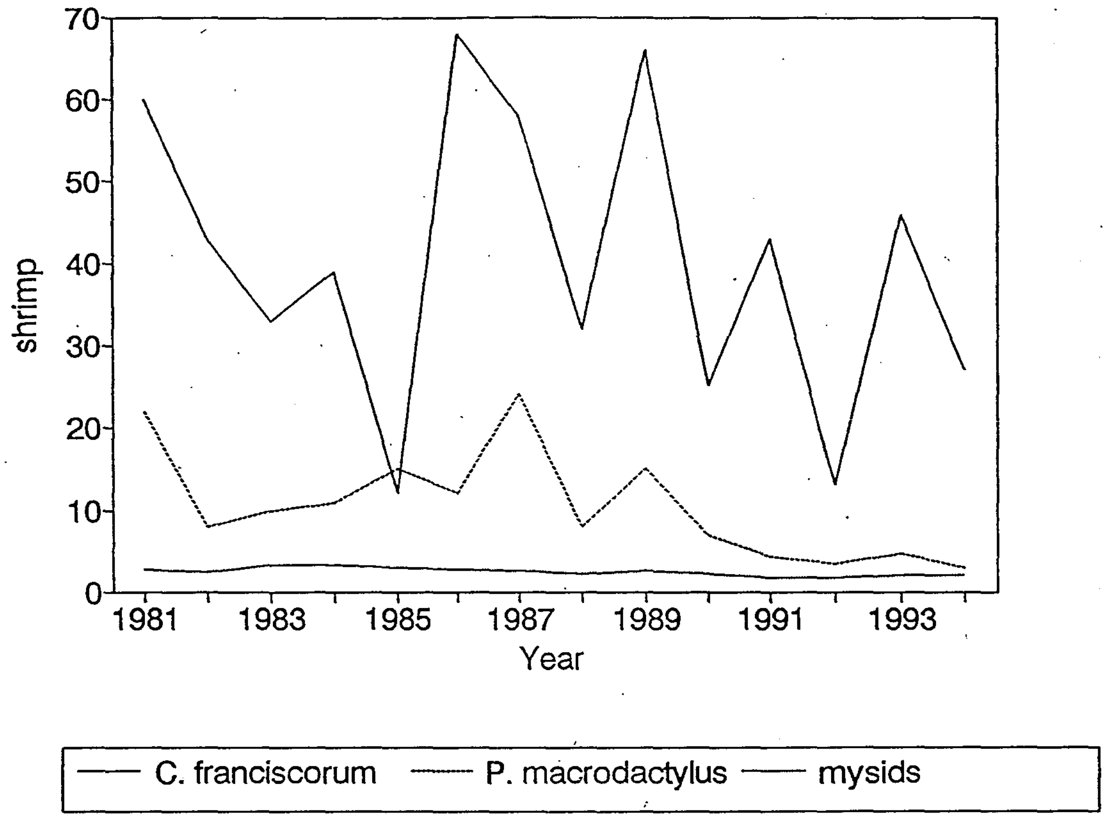

Figure 1.7. Mean catch per trawl of <u>Crangon franciscorum</u>, <u>Palaemon macrodactylus</u>, and mysid shrimps in Suisun Marsh.

Part 2: Suisun Marsh Larval Fish Survey
April 15-June 17, 1994

Introduction

The Department of Wildlife, Fish and Conservation Biology (formally Wildlife and Fisheries Biology) of the University of California, Davis, has sampled fish communities monthly in Suisun Marsh since January of 1979 with an otter trawl (Moyle et al. 1986; Meng et al. 1994). In April of 1994, the U.S. Fish and Wildlife Service began a cooperative study with the University to assess use of the marsh for fish spawning and rearing of larvae. Suisun Marsh contains most of the tidal wetlands remaining in the Sacramento-San Joaquin Estuary resembling those that existed before large-scale reclamation activities occurred (Meng and Moyle in press). Dead-end sloughs in the marsh are shallow, lined with tules and reeds, and appear to be good habitat for rearing of larval and juvenile fishes. The Estuary is carefully regulated because many native species are listed as endangered or threatened by the federal Endangered Species Act. The goals of our study were: (1) to augment our understanding of the adult fish communities of the marsh with information on other life history stages; (2) to determine what extent the relatively undisturbed habitat of the marsh is used by fish for spawning and rearing; and (3) to determine if special status species such as delta smelt, longfin smelt, and splittail are using the marsh for spawning and rearing.

Methods

We sampled the marsh weekly with a 505-micron mesh net (3 m long with a 0.525 m^2 mouth opening) mounted on a sled from April 15-June 17, 1994. We made three replicate tows in five sloughs: Suisun, Spring Branch (upper marsh), Nurse, Denverton (eastern marsh), and Cordelia (western marsh). Counts of larvae were low initially so we used 10-minute tows in all sloughs except Spring Branch. We used 5-minute tows in Spring Branch due to shallow depths and the limited portion of the slough we could reach in the boat. A flow meter was attached to the sled and samples were adjusted for amount of water that passed through the net.

Samples were preserved in 10% formaldehyde tinted with rose bengal to aid fish identification. The total number of fish in each sample was counted unless samples were very large. At the end of our sampling period, in June, we caught large numbers of gobies. If a jar contained more than 1000 larvae, the total number of fish were estimated to the nearest 100. An index of the total number of fish caught (adjusted fish) was developed by dividing the total number of fish (including estimates) by water sampled and multiplying by 1000. When more than 200 fish were caught in a replicate, only 200 were identified by random subsampling. The entire sample was laid out in pan marked into 16 equal squares and all fish contained within a square, chosen randomly, were identified. Numbers of species and families were not adjusted for effort, but a regression of adjusted fish versus total fish produced an r-squared of 0.98. Fish were identified to family (Wang 1986) and assigned a species category if only one species representative occurs in the marsh, e.g., inland silverside. Osmerids and cyprinids were taken to Dr. Johnson Wang for species identification and verification.

Results

In all sloughs, the greatest number of species and families were captured early in the study, but the greatest number of fish were captured late in the study (Table 2.1, Figure 2.1). There were 11 species-family categories: Gobiidae, Cottidae, striped bass, Cyprinidae, delta smelt, longfin smelt, Clupeidae, inland silverside, northern anchovy, threespine stickleback, and Pleuronectidae (Table 2.2 and 2.3). The maximum number of species-family categories (7) were captured in Cordelia Slough in April. Generally, 5-7 species-family categories were captured in April versus 3-4 in June for all sloughs. Catches in June were very large and dominated by gobies (Figure 2.1). The greatest number of fish were captured in Denverton Slough, where the maximum number of species-family categories was 5 (Figure 2.2). The smallest catches occurred in Cordelia Slough (Figure 2.2). Gobies, sculpins, and striped bass were the most abundant categories, whereas other categories were rare (Figure 2.3). Highest catches occurred on flood tides (Figure 2.4) and were significantly different from catches on other tides ($P < 0.0001$) even when adjusted for differences in the number of sampling events.

There were some environmental differences among the western (Cordelia Slough), eastern (Nurse and Denverton sloughs), and upper ends of the marsh (Spring Branch and Suisun sloughs) (Table 2.1). Salinities in the eastern and upper ends of the marsh were less than half those found in Cordelia Slough (4.9 ppt) (Table 2.1). The average temperature ranged from 19.2-19.6°C, with highest temperatures in Cordelia Slough and lowest temperatures in Suisun Slough (Table 2.1). Water clarity ranged from 15.1 cm in Spring Branch to 18.4 cm in Cordelia (Table 2.1).

We caught 10 families and at least 16 species. Gobies were not identified to species, but subsampling indicated we caught shimofuri gobies, yellowfin gobies, and longjaw mudsuckers *Gillichthys mirabilis*. The sculpin family was represented by staghorn sculpins and prickly sculpins. Cyprinids were not identified to species, but splittail were looked for and not found. Longfin smelt were captured in all sloughs and delta smelt were captured in all sloughs except Cordelia (Table 2.2, Figure 2.5). Most of the delta and longfin smelt were captured in April and May, except 1 delta smelt which was taken in June

(Table 2.3, Figure 2.6). The greatest number of delta smelt were taken in Nurse and Suisun sloughs, whereas longfin smelt catches were evenly distributed among sloughs (Table 2.2, Figure 2.5). Clupeids, Pacific herring, American shad, and threadfin shad, were the most abundant fish after gobies, sculpins, and striped bass and were taken in all months, in all sloughs (Table 2.2, 2.3, Figure 2.5, and 2.6). There were two peaks in clupeid abundance (Table 2.3 and Figure 2.6). The April peak was dominated by Pacific herring which spawn earlier than American and threadfin shad. The June peak was dominated by American shad.

Discussion

Results of our larval fish study generally followed results of the adult fish survey. Larval species and families were caught in the same proportions as adult fish. An exception was capture of several longjaw mudsucker larvae. We have only captured one longjaw mudsucker during the 16 years of the otter trawl survey (Moyle et al. 1986). Longjaw mudsuckers probably spawn downstream in higher salinities, then move up into the marsh on landward-flowing currents. From April 22-May 20, we captured 8 longjaw mudsucker larvae in the western end of the marsh in Cordelia Slough. It is unknown to what extent longjaw mudsuckers use the marsh for rearing. Capture of longjaw mudsucker larvae by California Fish and Game's larval survey indicate the pelagic larvae travel long distances (Kathy Hieb, CDFG, personal communication).

The upper and eastern portions of the marsh seemed to be better habitat for larval fish. The narrow, dead-end sloughs (Spring Branch and Denverton) and wide, upper end of Suisun Slough had the highest catches. Cordelia had the lowest catches, but greatest number of species reflecting its marine influence. Cordelia also differs from other sloughs sampled because it is deep with little shallow-water habitat. Delta smelt were found primarily in Nurse and Suisun, large sloughs with a more riverine nature. Longfin smelt were captured in equal proportions all over the marsh.

High catches on flood tides may indicate a mechanism of larval movement and dispersal. Significantly more fish were caught on flood tides, but sloughs were not sampled equally on all tides. A greater number of sampling events occurred in Suisun Slough on flood tides (16 versus 8 in Denverton and 11 in Spring Branch). The second largest number of fish (adjusted for effort) were captured in Suisun Slough (789 versus 1054 in Denverton and 725 in Spring Branch) and this may partly account for the higher flood-tide catches. When flood-tide catches are examined by species, the biggest difference appears to be the exceptionally high number of sculpins. Most fish larvae are planktonic, but prickly sculpins remain near the surface for 30-35 days (Wang 1986); this planktonic habit helps disperse the larvae and may partly explain our higher flood-tide catches.

The catches for 1994 reflect results of a very dry year with lower than average river flows. This year (1995) we began sampling on February 26th (6 weeks earlier) and we expect to see more families and special status species. Our earlier start date, the abundant precipitation, and high river flows should result in an increase in the number of species and families taken in 1995. An increase in numbers of fish other than gobies and sculpins may help clarify differences in catches due to tidal cycle. Our 1995 data will provide a valuable addition and contrast to data collected in 1994, a dry year.

Table 2.1 Data from Suisun Marsh larval fish survey conducted from April 15 to June 17, 1994. Weekly sampling occurred 3 times in April and June, and 4 times in May. Adj. Fish = Number of fish/flow * 1000. Max. Species = Maximum number of species-family categories caught. Temperature, salinity, and secchi are in °C, ppt, and cm, respectively.

Slough	April	May	June	All
Cordelia				
Total Fish	368	998	1886	3252
Adj. Fish	21.2	52.0	92.8	166
Max. Species	7	6	3	7
Temperature	18.2	18.8	22.0	19.6
Salinity	4.1	4.2	6.5	4.9
Secchi	21.4	16.4	17.7	18.4
Denverton				
Total Fish	969	2236	17600	20805
Adj. Fish	56.5	124.4	873.1	1054
Max. Species	5	4	4	5
Temperature	18.8	18.4	21.7	19.5
Salinity	1.7	1.7	2.8	2.1
Secchi	15	14.9	16.1	15.4
Nurse				
Total Fish	725	1452	6398	8575
Adj. Fish	36.9	75.8	326.1	439
Max. Species	5	6	3	6
Temperature	18.1	18.3	22.1	19.4
Salinity	1.1	1.4	3.0	1.8
Secchi	18.5	15.2	16.9	16.5
Spring Branch				
Total Fish	979	2195	5147	8321
Adj. Fish	74.3	191.0	459.2	725
Max. Species	6	5	3	6
Temperature	18.3	17.7	22.4	19.3
Salinity	1.3	1.7	2.7	1.9
Secchi	15.2	14.0	16.0	15.1
Suisun				
Total Fish	1409	1905	13300	16614
Adj. Fish	66.3	98.1	624.3	789
Max. Species	5	5	3	5
Temperature	18.0	18.6	21.2	19.2
Salinity	1.2	1.4	2.4	1.6
Secchi	16.0	14.2	18.1	16.0
All				
Total Fish	4450	8786	44331	57567
Adj. Fish	255.2	541.3	2376	3172
Max. Species	7	6	4	7
Temperature	18.3	18.3	22.0	19.4
Salinity	1.9	2.1	3.5	2.5
Secchi	17.9	15.0	17.0	16.3

Table 2.2 Families and species captured in five sloughs sampled by the Suisun Marsh larval fish survey in 1994. GOB = Gobiidae, SCP = Cottidae, SB = striped bass, CYP = Cyprinidae, DS = delta smelt, LFS = longfin smelt, HERR = Clupeidae, ATH = inland silverside, ANCH = northern anchovy, STBK = threespine stickleback, PLEU = Pleuronectidae.

Fish	Cordelia	Denverton	Nurse	Spring Branch	Suisun
GOB	2711	4338	4214	5590	4390
SCP	49	354	110	339	205
SB	48	100	81	85	52
CYP	2	4	3	5	5
DS		2	6	1	4
LFS	4	4	3	4	4
HERR	13	4	9	11	2
ATH	9	1	8	3	5
ANCH	4		1		
STBK	3		1	3	3
PLEU		1			

Table 2.3 Familes and species captured by month in the Suisun Marsh larval fish survey in 1994. Weekly sampling occurred 3 times in April and June and 4 times in May. GOB = Gobiidae, SCP = Cottidae, SB = striped bass, CYP = Cyprinidae, DS = delta smelt, LFS = longfin smelt, HERR = Clupeidae, ATH = inland silverside, ANCH = northern anchovy, STBK = threespine stickleback, PLEU = Pleuronectidae.

Fish	April	May	June	All
GOB	3373	7573	10297	21243
SCP	913	136	8	1057
SB	100	251	15	366
CYP	10	8	1	19
DS	6	6	1	13
LFS	10	9		19
HERR	21	6	12	39
ATH	8	10	8	26
ANCH	2		3	5
STBK	3	4	3	10
PLEU	1			1
ALL	4447	8003	10348	22798

Figures

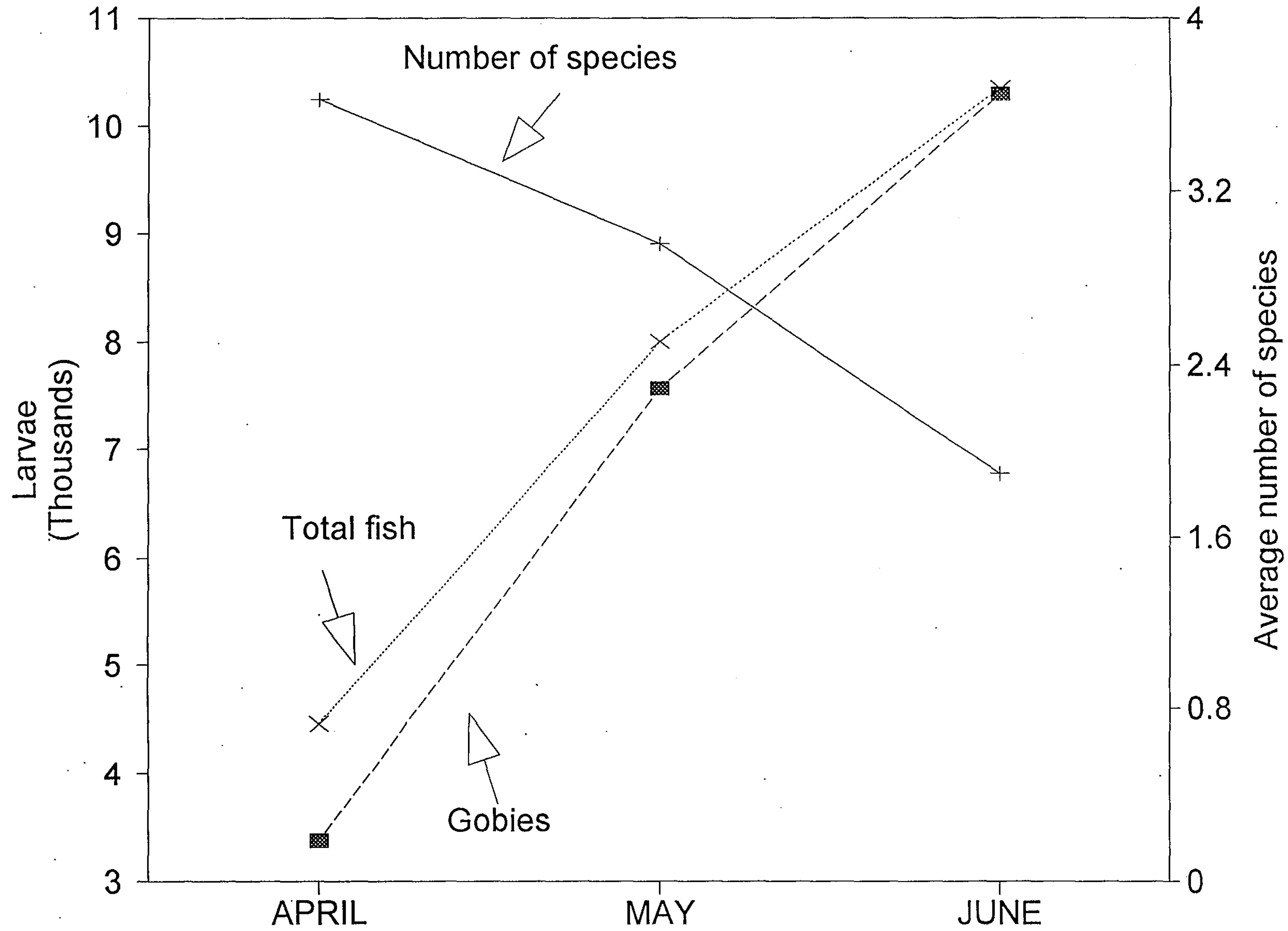

Figure 2.1 Species-family categories (number of species) vs. total fish & gobies by month.

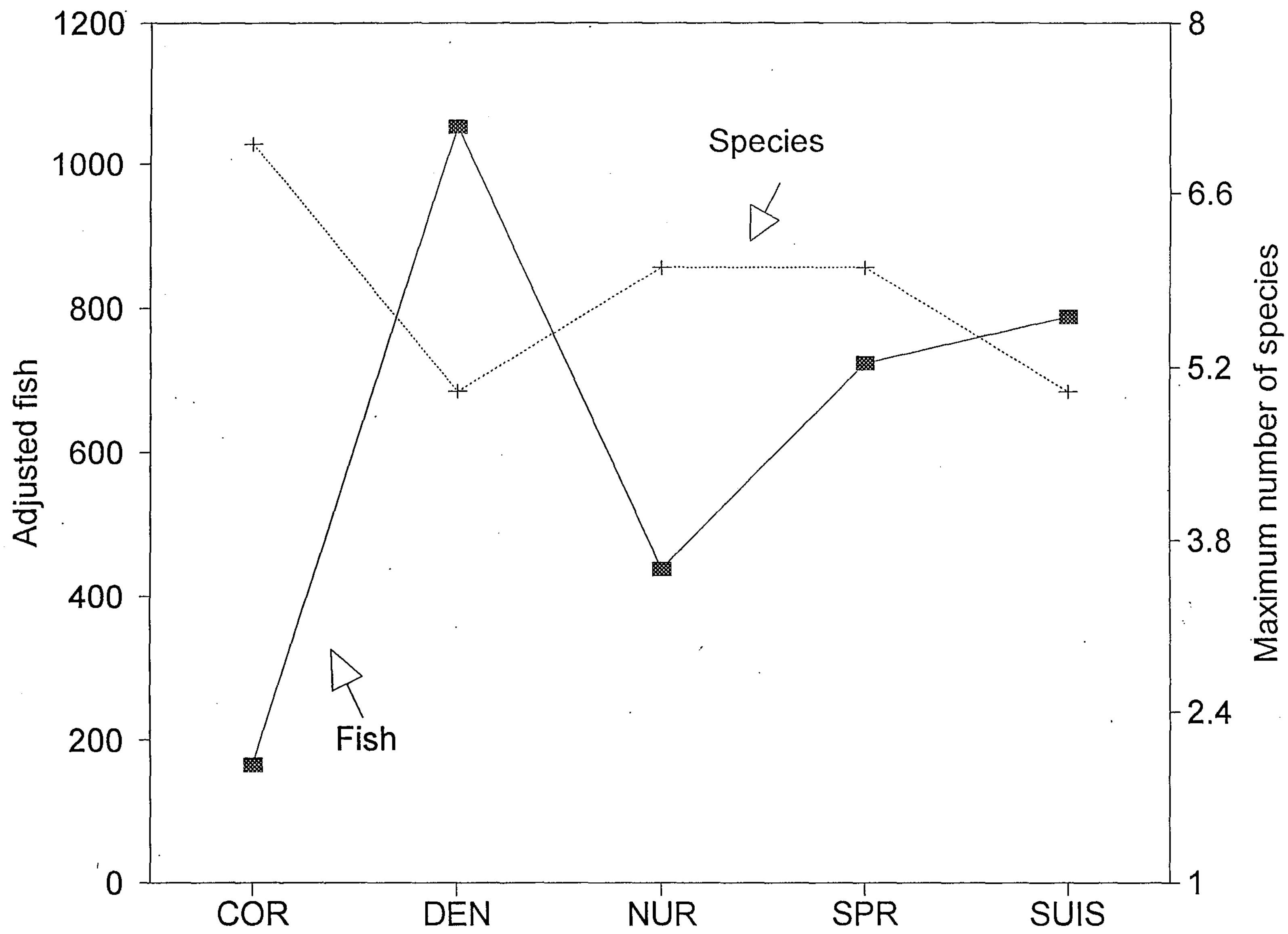

Figure 2.2 Adjusted fish (fish/flow*1000) & maximum number of species-family categories by slough.

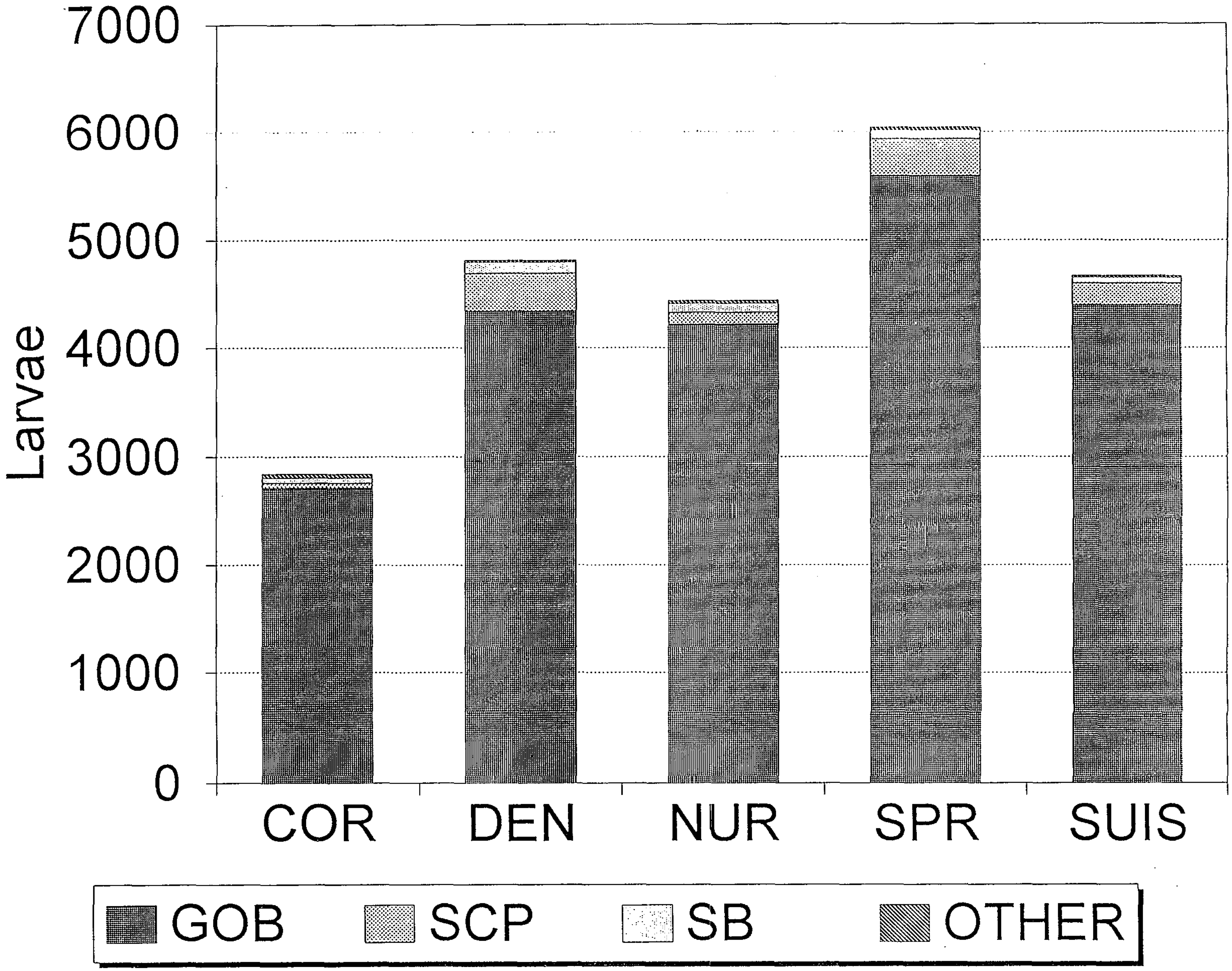

Figure 2.3 Gobies (GOB), sculpins (SCP), striped bass (SB) & other species by slough.

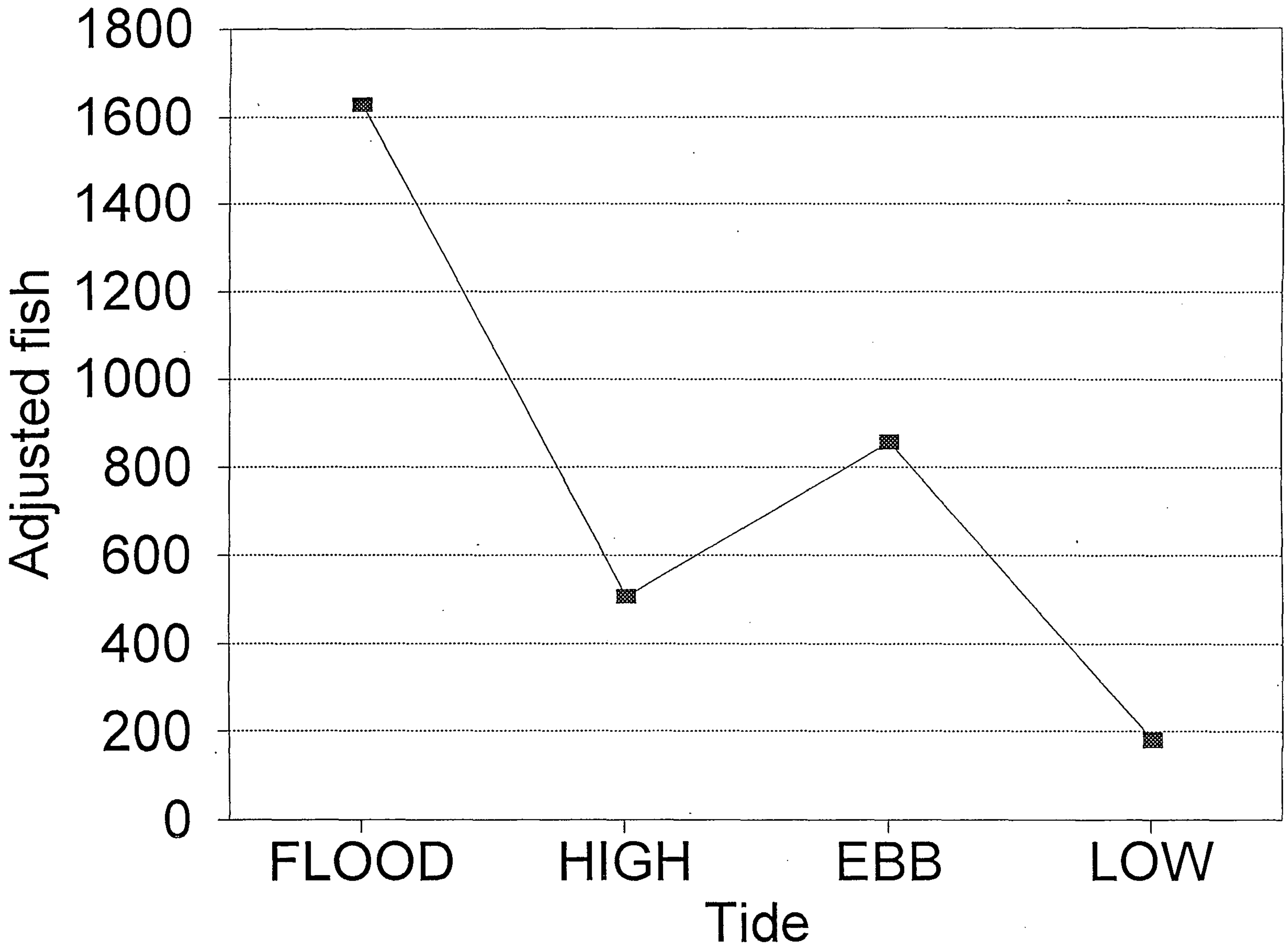

Figure 2.4 Adjusted number of fish by tidal cycle.

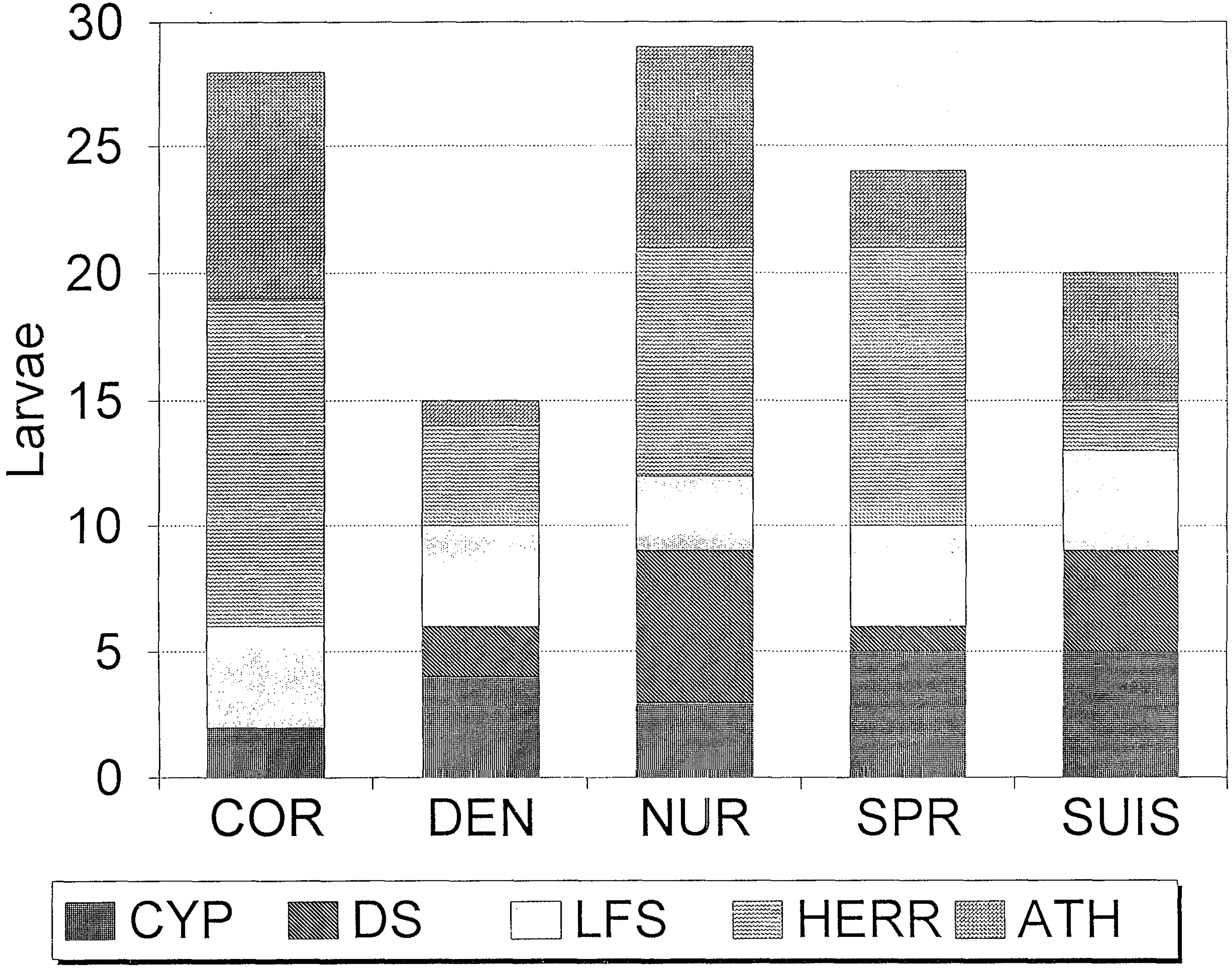

Figure 2.5 Cyprinids (CYP), delta smelt (DS), longfin smelt (LFS), Clupeids (HERR) & silversides (ATH) by slough.

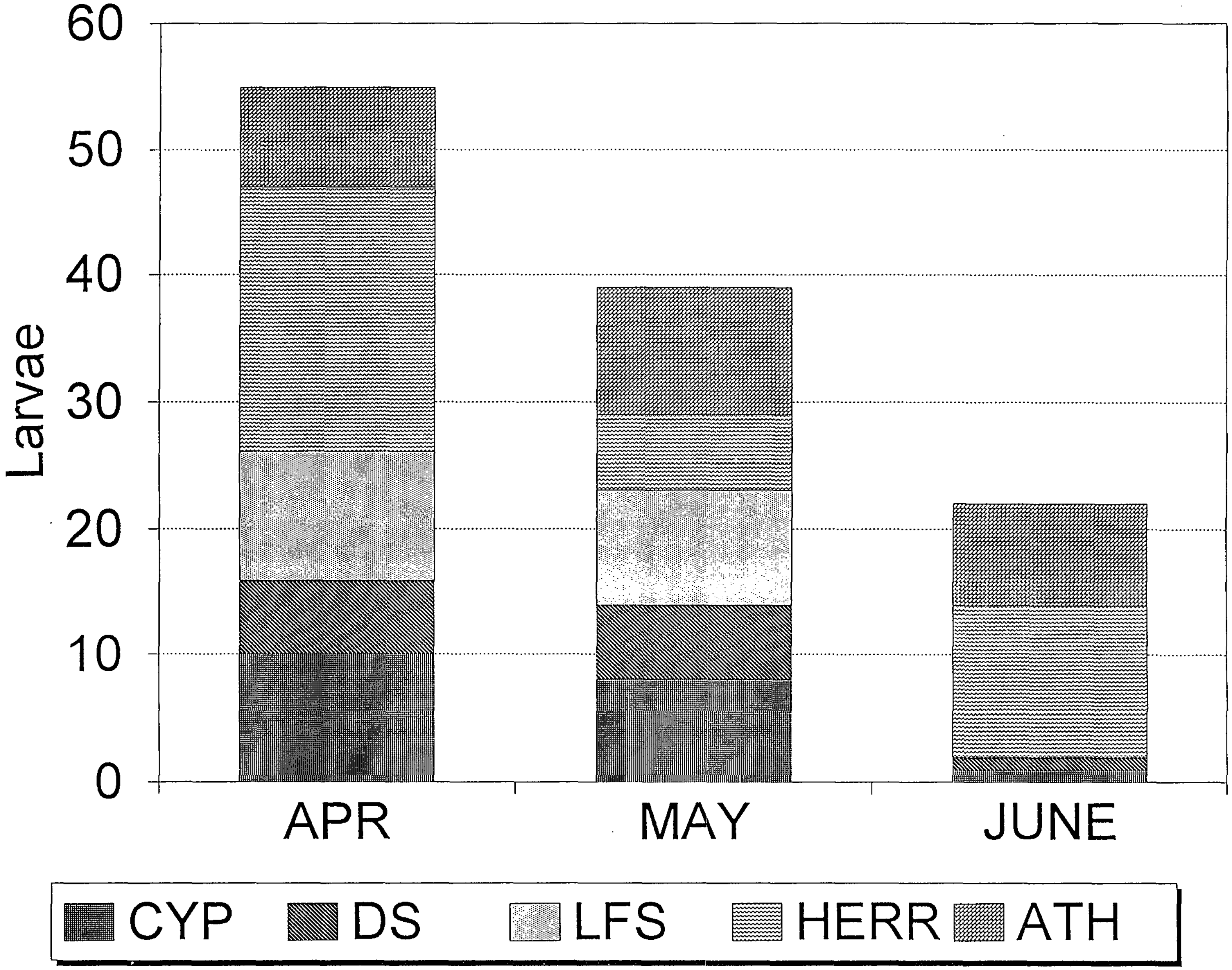

Figure 2.6 Cyprinids (CYP), delta smelt (DS), longfin smelt (LFS), Clupeids (HERR) & silversides (ATH) by month.

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Electrophoretic identification of smelt of the genus *Hypomesus* from the Sacramento-San Joaquin Delta

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University of California, Davis

May, 1995

Final report to the California Department of Water Resources

The delta smelt (Hypomesus transpacificus) is endemic to the Sacramento-San Joaquin estuary and has greatly reduced populations (Moyle et al. 1992). It has consequently been listed as a threatened species by both the U. S. Fish and Wildlife Service and by the California Fish and Game Commission. A potential threat to the recovery of delta smelt populations is the invasion of the estuary of a similar species, the wakasagi (H. nipponensis). The wakasagi was introduced into California from Japan in 1959 as a forage fish in reservoirs, including reservoirs that drain into the Sacramento River (Wales 1962; Moyle 1976). Wakasagi were not detected in the estuary until recently (ca. 1992). Presumably, they invaded from Folsom Reservoir on the American River, in which they were first captured in 1989 (D. P. Lee, Calif. Dept. of Fish and Game, pers. comm.). How wakasagi got into Folsom Reservoir is not known but the most likely route is from Jenkinsson Reservoir (El Dorado Co.) upstream, one of the original introduction sites. Stanley et al. (in press) investigated the genetic similarities of delta smelt and wakasagi using electrophoretic techniques and concluded that the two species were genetically so distinct that introgressive hybridization between them was unlikely. The study also indicated that electrophoretic techniques could be used to reliably distinguish the two species.

In 1994, wakasagi were collected at the Tracy Fish Facility of the State Water Project, raising a number of questions: (1) Were many of the smelt identified as delta smelt, especially small (<30 mm SL) individuals, actually wakasagi? (2) What proportion of the smelt being counted as 'take' under the state and federal endangered species acts were actually wakasagi? (3) Is there any evidence of hybridization and introgression between the two species? (4) Can available morphometric and meristic characteristics be used to reliably distinguish small individuals of the two species? The purpose of this study is to provide at least partial answers to the above questions by genetic analysis of individual smelt collected at various locations in the Delta in 1994, as well as from Almanor and Folsom reservoirs. Sweetnam (1995) addressed the question of identifying characteristics, using the smelt identified electrophoretically in this study.

Methods

Samples of Hypomesus spp. were collected from Almanor and Folsom reservoirs, from Delta channels (Sacramento River by Decker Island, Barker Slough, Mokolumne River), and from the state and federal pumping plants in the south Delta. The fish were collected in June and July, 1994, using various techniques, by the California Department of Fish and Game. Personnel assigned each fish an identification (delta smelt, wakasagi, or unknown smelt) and stored the samples immediately on dry ice until they could be delivered to the laboratory at the University of California, Davis (UCD). Upon arrival at UCD, all samples were assigned catalog numbers and stored at -80C. Fish received ranged in total length from two to eight centimeters, with the majority falling towards the lower end of the range. All but the largest fish were transferred to individual numbered vials; large individuals were stored in the plastic bags in which they arrived.

An initial survey of ten individuals using eye, body-wall muscle and liver tissues separately indicated that differences could be resolved consistently for eight of the 13 loci identified by Stanley et al. (in press) as fixed for different alleles in delta smelt and wakasagi. Liver tissue produced the best activity for all loci and resulted in minimal destruction of characters important to morphological identification. Degree of destruction was a concern because of the desire to preserve these samples as voucher specimens and the relatively small size of the fish; therefore liver was used exclusively for the remainder of this study.

Samples were thawed in room temperature tap water and an incision was made along the ventral surface between the pelvic and pectoral fins. All liver tissue was removed and placed in separately labeled microcentrifuge tubes, homogenized in grinding buffer (Selander et al. 1971), and centrifuged for three minutes. This tissue was also stored at -80C. After the liver tissue was removed, the smelt were refrozen and returned to the California Department of Fish and Game, where the fish were used to develop characteristics for identifying the two species in the field (Sweetnam 1995).

Methods of horizontal starch-gel electrophoresis followed general procedures in Murphy et al. (1990). Liver tissue from positively identified delta smelt and wakasagi were used as standards on all gels. Electromorphs were identified for all loci relative to the most common allele in delta smelt which was designated as medium; other alleles were identified as either fast or slow. Due presumably to the small size of the liver samples it was not possible to positively genotype all individuals for all loci. Any locus for which an individual's identification was ambiguous was run at least twice, and dropped for that individual if we still could not confidently resolve the bands. Blank cells in Table 2 reflect these difficulties. Table 1 identifies the eight enzyme systems investigated and buffer systems utilized in this study.

Table 1. ENZYME SYSTEMS EXAMINED AND BUFFERS USED.

Enzyme (EC number)	Locus	Buffer System[a]
Aspartate aminotransferase (2.6.1.1)	sAAT-1*	Tris-HCl
Adenosine deaminase (3.5.4.4)	ADA-1*	Tris-HCl
Glycerol-3-phosphate dehydrogenase (1.1.1.8)	G3PDH-1*	T.C.II
Glucose-6-phosphate isomerase (5.3.1.9)	GPI-A*	T.C.II
L-Iditol dehydrogenase (1.1.1.14)	s-IDDH-1*	T.C.II
Isocitrate dehydrogenase (1.1.1.42)	IDHP-1*	T.C.II
Mannose-6-phosphate isomerase (5.3.1.8)	MPI-1*	T.C.II
Tripeptide aminopeptidase[b] (3.4.-.-)	PEPB-1	Tris-HCl

[a] Buffer Tris-HCl = discontinuous borate-tris-hydrochloric acid, pH 8.5; T.C.II = Tris-citrate, pH 8.0. Solutions are from Selander et al. (1971) and Murphy et al. (1990).

[b] Peptidase substrate = Leu-Gly-Gly

Results

283 fish were examined electrophoretically; 235 were from the Delta while 48 were from Folsom and Almanor Reservoirs (Table 2, Appendix). Of the 232 smelt from the Delta for which electrophoretic identifications could be made, 216 (93%) were delta smelt, 13 (6%) were wakasagi, and 2 (1%) were hybrids. The majority of the wakasagi came from Barker Slough (4) and Mokelumne River (6), while one of the hybrids was also from the Mokolumne River. The remaining wakasagi and hybrid were collected from the state and federal pumping plants (Table 2). In all, 4 (2%) of the 184 smelt collected from the pumping plants were either wakasagi or hybrids.

Of the 13 wakasagi from the Delta, 11 had been identified by CDFG biologists as unknown and two as delta smelt; both hybrids were initially identified as unknown. Of the 42 fish from the estuary identified as unknown, 29 were delta smelt, 11 were wakasagi and two were hybrids. All 48 smelt collected from the two reservoirs were electrophoretically identified as wakasagi.

Both hybrids were first generation crosses between the two parent species. There was no evidence of genetic introgression between the species; the two hybrids carried one allele from each parent species at each locus (Appendix). If introgression were occuring, mixture of alleles would not be so regular.

As a result of the large number of smelt analyzed, additional rare alleles were discovered at four loci in delta smelt and three in wakasagi (Appendix). Ten new alleles were observed in the delta smelt and four in wakasagi. Stanley et al. (in press) found delta smelt and wagasaki to have fixed differences in alleles at all eight loci included in this investigation. That study only looked at 30 individuals of each species, while this investigation included more than 200 delta smelt and more than 50 wakasagi. Because in all but one case (GPI) the newly uncovered variants were only present in one individual of each species, our ability to electrophoretically identify individuals to species was not affected.

Table 2. Comparative identification of Hypomesus species from the Sacramento-San Joaquin estuary and two upstream reservoirs using morphological and electrophoretic techniques. Abbreviations are DS = delta smelt, WG = wakasagi; UNK = unknown; HYBR = hybrid.

Location	Total fish	Field identification			Electrophoretic identification			
		DS	WG	UNK	DS	WG	HYBR	Non
Decker Is.	17	17	0	0	17	0	0	0
Barker Sl.	27	0	0	27	23	4	0	0
Mokolumne R.	7	0	0	7	0	6	1	0
SWP pumps	153	151	0	2	150	1	0	1
CVP pumps	31	25	0	6	26	2	1	2
Delta total	**235**	**192**	**0**	**42**	**216**	**13**	**2**	**3**
Folsom Res.	13	0	14	0	0	13	0	0
Almanor Res.	35	31	25	10	0	35	0	0
Reservoir total	**49**	**31**	**39**	**10**	**0**	**48**	**0**	**0**
Total	283	192	49	42	217	62	2	3

*Probably from mislabelled sample.

Discussion

This study confirms that wakasagi have indeed invaded the Sacramento-San Joaquin estuary and have hybridized with delta smelt. The invasion is not surprising because wakasagi have been present in the drainage since 1959. They were collected from the American River below Folsom Reservoir in 1992 (L. Brown, USGS, pers. comm.). Presumably, their presence in the estuary was not confirmed sooner because of their rarity and because of lack of intensive studies of delta smelt until recently. Their continued rarity may indicate that they are poorly adapted for conditions in the Delta. In their native Japan they live in freshwater lakes and spawn in inlet streams. However, their hybridization with delta smelt does indicate that spawning has taken place in the Delta.

Wakasagi appear to be concentrated in a few areas within the Delta (e.g., Barker Slough, Mokolumne River). The Mokolumne River fish are particularly interesting because all seven fish collected from this area were either wakasagi or hybrids. In Barker Slough 15% of the smelt collected were wakasagi, as opposed to 2% of the smelt from the SWP and CVP pumping stations, which could be regarded as a sample from the entire Delta population of smelt. Barker Slough and connected Lindsey and Cache sloughs are the first major sloughs to diverge from the Sacramento River so may be more subject to invasion of wakasagi moving downstream from the reservoirs.

Interspecific and even intergeneric hybrids in fishes are common and usually occur when (1) one of the two species is rare compared to the other species, so choices of mates are limited, (2) when the two species spawn in proximity to one another and the gametes become mixed as a result and (3) when one of the two species is an invading species (Hubbs 1955). Situations promoting hybridization are also more likely to occur in disturbed habitats. In the Delta, virtually all these conditions exist for the two smelt species, so hybridization is not surprising. However, the presence of hybridization does not mean that gene exchange or introgression is taking place between the two species. Hybrid fishes are usually either sterile, have low survival rates compared to the parent species, or have low reproductive success if they survive and are fertile (Moyle and Cech 1988). The lack of any evidence for introgression between the two species despite presumably frequent invasion of the Delta by wakasagi indicates this is unlikely to be a problem in the future. However, if the Delta environment becomes increasingly unfavorable to delta smelt, hybridization could become more frequent, accelerating the decline of the species.

At the present time, however, delta smelt are still the principal <u>Hypomesus</u> species in the estuary. Therefore almost all of the smelt being captured in sampling programs or in the pumps of the CVP and SWP are delta smelt. This means that estimates of delta smelt abundance trends and status continue to have the same reliability they have had previously. It is obvious that future sampling efforts in the Delta will have to account for the relative abundances of the two species. The most reliable morphological means to distinguish individuals of the two species in the field seems to be number of chromatophores on the isthmus of the 'chin' (Sweetnam 1995). Eventually, experienced workers should be able to distinquish larger individuals (<20 mm SL) of the species quickly. One indication of this is that a majority of the wakasagi used in this study were initially identified as "unknown" indicating some doubt about classifying them as the much more abundant delta smelt.

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Appendix
~~Table 2:~~ Summary of results for electrophoretic analysis of 283 smelt.

CATALOG #	G3PDH	IDDH	IDHP	GPI	MPI	ADA	AAT	PEPB	LOCAL	DWR ID	ALLOZYME ID
17212	M	M	M	MF	M	M	M	M	DI	DS	DS
17214	M	M	M	M	M	M	M	M	DI	DS	DS
17215	M	M		M	M	M	M	M	DI	DS	DS
17216	M	M	M	M	M	M	M	M	DI	DS	DS
17217	M	M	M	M	M	M	M	M	DI	DS	DS
17218	M	M	M	M	M	M	M	M	DI	DS	DS
17219	M	M	M		M	M	M	M	DI	DS	DS
17220	M	M	M		M	M	M	M	DI	DS	DS
17221	M		MS-	M	M	M	M	M	DI	DS	DS
17222	M	M	M		M	M	M	M	DI	DS	DS
17223	M	M	MF	M	M	M	M	M	DI	DS	DS
17224	M	M	M	M	M	M	M	M	DI	DS	DS
17225	M	M	M	M	M	M	M	M	DI	DS	DS
17226	M	M		M	M	M	M	M	DI	DS	DS
17227	M	M	M		M	M	M	M	DI	DS	DS
17228	M	M	M		M	M	M	M	DI	DS	DS
17229	M	M	M		M	M	M	M	DI	DS	DS
17230	M	M	M		M	M	M	M	DI	DS	DS
17239	M	M	M	M	M	M	M	M	SWP	DS	DS
17240	M	M	M	M	M	M	M	M	SWP	DS	DS
17241	M	M	M	M	M	M	M	M	SWP	DS	DS
17242	M	M	M	M	M	M	M	M	SWP	DS	DS
17243		M	M	M	M	M	M	M	SWP	DS	DS
17244	M	M	M	M	M	M	M	M	SWP	DS	DS
17245	M	M	M	M	M	M	M	M	SWP	DS	DS
17246				M	M	M	M	M	SWP	DS	DS
17247	M		M	M	M	M	M	M	SWP	DS	DS
17248	M	M	M	M	M	M	M	M	SWP	DS	DS
17249				M					SWP	DS	DS
17250	M		M	M	M	M	M	M	SWP	DS	DS
17251	M	M	M	M	M	M	M	M	SWP	DS	DS
17252	M	M	M	M	M	M	M	M	SWP	DS	DS

Locality abbreviations: DI = Decker Island; SWP = State Water Project; CVP = Central Valley Project; F = Folsom Res.; BS = Barker Slough; A = Almanor Res.; MR = Mokelumne River
ID abbreviations: DS = Delta Smelt; WG = Japanese Smelt; UK = Unknown

Appendix ~~Table 2~~: Summary of results for electrophoretic analysis of 283 smelt.

CATALOG #	G3PDH	IDDH	IDHP	GPI	MPI	ADA	AAT	PEPB	LOCAL	DWR ID	ALLOZYME ID
17253	M	M	MF	M	M	M	M	M	SWP	DS	DS
17254	M	M	M	M	M	M	M	M	SWP	DS	DS
17255	M	M	M	M	M	M	M	M	SWP	DS	DS
17256	M	M	M	M	M	M	M	M	SWP	DS	DS
17257	M	M	M	MS+	M	M	M	M	SWP	DS	DS
17258	M		M	M	M	M	M	M	SWP	DS	DS
17259			M	M	M	M	M	M	SWP	DS	DS
17260	M	M	M	M	M	M	M	M	SWP	DS	DS
17261	M	M	M	M	M	M	M	M	SWP	DS	DS
17262	M	M	MF	M	M	M	M	M	SWP	DS	DS
17263	M	M	M	M	M	M	M	M	SWP	DS	DS
17264	M		M	M	M	M	M	M	SWP	DS	DS
17265	M	M	MF	M	M	M	M	M	SWP	DS	DS
17266	M	M	M	M		M	M	M	SWP	DS	DS
17267	M	M	M	M	M	M	M	M	SWP	DS	DS
17268	M	M	MS-	M		M	M	M	SWP	DS	DS
17269	M	M	M	M	M	M	M	M	SWP	DS	DS
17270	M	M	M	M	M	M	M	M	SWP	DS	DS
17271	M	M	M	M	M	M	M	M	SWP	DS	DS
17272	M	M	M	M	MM-	M	M	M	SWP	UK	DS
17273	M	M	M		M	M	M	M	SWP	DS	DS
17274	M	M	M	M	M	M	M	M	SWP	DS	DS
17275	M	M	M	M	M	M	M	M	SWP	DS	DS
17276	M	M	M	M	M	M	M	M	SWP	DS	DS
17277	M		M	M	M	M	M	M	SWP	DS	DS
17278	M	M	M	M	M	M	M	M	SWP	DS	DS
17279	M	M	M	M	M	M	M	M	SWP	DS	DS
17280	M	M	M	M	M	M	M	M	SWP	DS	DS
17281	M	M	M	M	M		M	M	SWP	DS	DS
17282	M		M	M	M	M	M	M	SWP	DS	DS
17283	M	M	M	M	M	M	M	M	SWP	DS	DS
17284	M		MF	M	M	M	M	M	SWP	DS	DS

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ID abbreviations: DS = Delta Smelt; WG = Japanese Smelt; UK = Unknown

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CATALOG #	G3PDH	IDDH	IDHP	GPI	MPI	ADA	AAT	PEPB	LOCAL	DWR ID	ALLOZYME ID
17285	M		M	M	M	M	M	M	CVP	DS	DS
17286	M	M	M	M	M	M	M	M	CVP	DS	DS
17287				M				M	CVP	DS	DS
17288	M		M	M	M	M	M	M	CVP	DS	DS
17289	M		M	M		M	M	M	CVP	DS	DS
17290	M	M	M	M	M	M	M	M	CVP	DS	DS
17291			M	M		M	M	M	CVP	DS	DS
17292	M		M	M	M	M	M	M	CVP	DS	DS
17294						M	M		CVP	UK	DS
17295	M	M	M	M	M	M	M	M	CVP	UK	DS
17296	MS	MF		MS	MS	MS	MS		CVP	UK	HYBRID
17297									CVP	UK	
17298	M		M	M	M	M	M	M	CVP	UK	DS
17299	M	M	M	M	M	M	M	M	SWP	DS	DS
17300	M	M	M	M	M	M	M	M	SWP	DS	DS
17301	M		M	M	M	M	M	M	SWP	DS	DS
17302	M	M	M		M	M	M	M	SWP	DS	DS
17303				M	M	M	M	M	SWP	DS	DS
17304	M	M	M	M	M	M	M	M	SWP	DS	DS
17305	M	M	MF	M	M	M	M	M	SWP	DS	DS
17306	M	M	M	M	M	M	M	M	SWP	DS	DS
17307	M	M	M	M	M	M	M	M	SWP	DS	DS
17308	M	M	M	M	M	M	M	M	SWP	DS	DS
17309	M	M	M	M	M	M	M	M	SWP	DS	DS
17310	M	M	M	M	M	M	M	M	SWP	DS	DS
17311	M	M	M	M	M	M	M	M	SWP	DS	DS
17312	M		M	M	M	M	M	M	SWP	DS	DS
17313	M		M	M		M	M	M	SWP	DS	DS
17314	M	M	M	M	M	M	M	M	SWP	DS	DS
17315	M	M	M	M	M	M	M	M	SWP	DS	DS
17316	M		M	M	M	M	M	M	SWP	DS	DS
17317	M	M	M	M	M	M	M	M	SWP	DS	DS

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ID abbreviations: DS = Delta Smelt; WG = Japanese Smelt; UK = Unknown

Table 2: Summary of results for electrophoretic analysis of 283 smelt.

CATALOG #	G3PDH	IDDH	IDHP	GPI	MPI	ADA	AAT	PEPB	LOCAL	DWR ID	ALLOZYME ID
17318	M		M	M		M	M	M	SWP	DS	DS
17319	M	M	M	M	M	M	M	M	SWP	DS	DS
17320	M	M	M	M	M	M	M	M	SWP	DS	DS
17321	M	M	M	M	M	M	M	M	SWP	DS	DS
17322	M	M	M	MS+	M	M	M	M	SWP	DS	DS
17323	M	M	M	M	M	M	M	M	SWP	DS	DS
17324	M	M	M	M	M	M	M	M	SWP	DS	DS
17325									SWP	DS	
17326	M	M	M	M	M	M	M	M	SWP	DS	DS
17327	M	M	M	M	M	M	M	M	SWP	DS	DS
17328	M	M	M	M	M	M	M	M	SWP	DS	DS
17329	M	M	M	M		M	M	M	SWP	DS	DS
17330	M	M	M	M	M	M	M	M	SWP	DS	DS
17331	M	M	M	M	M	M	M	M	SWP	DS	DS
17332									SWP	DS	
17333	M	M	M	M	M	M	M	M	SWP	DS	DS
17334				M			M	M	SWP	DS	DS
17335	M		M	M		M	M	M	SWP	DS	DS
17336	M	M	M	M	M	M	M	M	SWP	DS	DS
17337	M	M	M	M	M	M	M	M	SWP	DS	DS
17338	M	M	M	M	M	M	M	M	SWP	DS	DS
17339	M	M	M	M	M	M	M	M	SWP	DS	DS
17340	M	M	M	M	M	M	M	M	SWP	DS	DS
17341	M	M	M	M	M	M	M	M	SWP	DS	DS
17342	M			M		M			SWP	DS	DS
17343	M	M	M	M	M	M	M	M	SWP	DS	DS
17344	M	M	M	M	M	M	M	M	SWP	DS	DS
17345	M		M	M	M	M	M	M	SWP	DS	DS
17346	M	M	M	M	M	M	M	M	SWP	DS	DS
17347	M	M	M	M	M	M	M	M	SWP	DS	DS
17348	M	M	M	M	M	M	M	M	SWP	DS	DS
17349	M	M	M	M	M	M	M	M	SWP	DS	DS

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ID abbreviations: DS = Delta Smelt; WG = Japanese Smelt; UK = Unknown

Table 2: Summary of results for electrophoretic analysis of 283 smelt.

CATALOG #	G3PDH	IDDH	IDHP	GPI	MPI	ADA	AAT	PEPB	LOCAL	DWR ID	ALLOZYME ID
17350	M	M	M	M		M	M	M	SWP	DS	DS
17351		M	M	M	M	M	M	M	SWP	DS	DS
17352	M	M	M	M	M	M	M	M	SWP	DS	DS
17353	M	M	M	M	M	M	M	M	SWP	DS	DS
17354	M	M	M	M	M	M	M	M	SWP	DS	DS
17355	M	M	M	M	M	M	M	M	SWP	DS	DS
17356	M	M	M	M	M	M	M	M	SWP	DS	DS
17357	M	M	M	M	M	M	M	M	SWP	DS	DS
17358	M	M	M	M	M	M	M	M	SWP	DS	DS
17359	M	M	M	M	M	M	M	M	SWP	DS	DS
17360	M	M	M	M	M	M	M	M	SWP	DS	DS
17361	M	M	M	MF	M	M	M	M	SWP	DS	DS
17362	M	M	M	M	M	M	M	M	SWP	DS	DS
17363	M	M	MF	M	M	M	M	M	SWP	DS	DS
17364	M	M	M	M	M	M	M	M	SWP	DS	DS
17365	M	M	M	M	M	M	M	M	SWP	DS	DS
17366	M	M	M	M	M	M	M	M	SWP	DS	DS
17367	M	M	M	M	M	M	M	M	SWP	DS	DS
17368	M	M	M	MF	M	M	M	M	SWP	DS	DS
17369	M	M	M	M	M	M	M	M	SWP	DS	DS
17370	M	M	M	M		M	M	M	SWP	DS	DS
17371	M		M	M	M	M	M	M	SWP	DS	DS
17372	M		M	M	M	M	M	M	SWP	DS	DS
17373	M	M	M	M	M	M	M	M	SWP	DS	DS
17374	M	M	M	M	M	M	M	M	SWP	DS	DS
17375	S	F	S	S	S	S	S	F	SWP	DS	WG
17376	M	M	M	M	M	M	M	M	SWP	DS	DS
17377	M	M	M	M	M	M	M	MS	SWP	DS	DS
17378	M	M	M	M	M	M	M	M	CVP	DS	DS
17379	M	M	M	M	M	M	M	M	CVP	DS	DS
17380	M	M	M	M	M	M	M	M	CVP	DS	DS
17381	M		M	M	M	M	M	M	CVP	DS	DS

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Table 2: Summary of results for electrophoretic analysis of 283 smelt.

CATALOG #	G3PDH	IDDH	IDHP	GPI	MPI	ADA	AAT	PEPB	LOCAL	DWR ID	ALLOZYME ID
17382	M	M	M	M	M	M	M	M	SWP	DS	DS
17383	M	M	M	M	M	M	M	M	CVP	DS	DS
17384	M	M	MF	M	M	M	M	M	SWP	UK	DS
17385	S	F	S	S	S	S	S	FF-	CVP	UK	WG
17386	S	F	S	MS	S	S	S	F	CVP	DS	WG
17387	M	M	M	M	M	M	M	M	CVP	UK	DS
17388	M	M	M	M	M	M	M	M	CVP	DS	DS
17389	M	M	M	M	M	M	M	M	CVP	DS	DS
17390	M	M	M	M	M	M	M	M	CVP	DS	DS
17391	M		M	M	M	M	M	M	CVP	DS	DS
17392	M	M	M	M	M	M	M	MM+	CVP	DS	DS
17393	M	M	M	M	M		M	M	CVP	DS	DS
17394	M	M	M	M	M	M	M	M	CVP	DS	DS
17395	M	M	M	M	M	M	M	M	CVP	DS	DS
17396	M	M	M	M	M	M	M	M	CVP	DS	DS
17397	M	M	M	M	M	M	M	M	CVP	DS	DS
17398	M	M	M	M	M	M	M	M	SWP	DS	DS
17399	M	M	M	M	M	M	M	M	SWP	DS	DS
17400	M	M	M	M	M	M	M	M	SWP	DS	DS
17401	M	M	M	M	M	M	M	M	SWP	DS	DS
17402	M	M	M	M	M	M	M	MS	SWP	DS	DS
17403	M	M	M	M	M	M	M	M	SWP	DS	DS
17404	M	M	M	M	M	M	M		SWP	DS	DS
17405	M	M	M	M	M	M	M		SWP	DS	DS
17406	M	M	M	M	M	M	M	M	SWP	DS	DS
17407	M	M	M	M	M	M	M	M	SWP	DS	DS
17408	M	M	M	M	M	M	M	M	SWP	DS	DS
17409	M	M	M	M	M	M	M	MM+	SWP	DS	DS
17410	M	M	M	M	M	M	M	M	SWP	DS	DS
17411	M	M	MS-	M	M	M	M	M	SWP	DS	DS
17412	M	M	M	M	M	M	M	M	SWP	DS	DS
17413	M	M	M	M	M	M	M	M	SWP	DS	DS

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ID abbreviations: DS = Delta Smelt; WG = Japanese Smelt; UK = Unknown

Table 2. Summary of results for electrophoretic analysis of 283 smelt.

CATALOG #	G3PDH	IDDH	IDHP	GPI	MPI	ADA	AAT	PEPB	LOCAL	DWR ID	ALLOZYME ID
17414	M	M	M	M	M	M	M	M	SWP	DS	DS
17415	M	M	M	M	M	M	M	M	SWP	DS	DS
17416	M	M	M	M	M	M	M	M	SWP	DS	DS
17417	M	M	M	M	M	M	M	M	SWP	DS	DS
17418	M	M	M	M	M	M	M	M	SWP	DS	DS
17419	M	M	M	M	M	M	M	M	SWP	DS	DS
17420	M	M	MF	M	M	M	M	M	SWP	DS	DS
17421	M	M	M	M	M	M	M	M	SWP	DS	DS
17422	S		S		S	S		F	F	WG	WG
17423	S	F	S	MS	S	S	S	F	F	WG	WG
17424	S	F	S	S	S	S	S	FF-	F	WG	WG
17425	S	F	S	S	S	S	S	F	F	WG	WG
17426	S	F	S	S	S	S	S	FF-	F	WG	WG
17427	S	F	S	S	S	S	S	F	F	WG	WG
17428	S	F	S	S	S	SS-	S	F	F	WG	WG
17429	S	F		S	S	S	S	F	F	WG	WG
17430	S	F		S	S	S	S	FF-	F	WG	WG
17431	S	F		S	S	S	S	FF+	F	WG	WG
17432	S		S	S	S	S	S		F	WG	WG
17433	S	F	S	S	S	S	S	FF-	F	WG	WG
17434	S	F		S	S	S	S	FF-	F	WG	WG
17435	M	M	M	M	M	M	M	M	F	WG	DS
17436	M	M	M		M	M	M	M	BS	UK	DS
17437	M	M	M	MM+	M	M	M	M	BS	UK	DS
17438	S	F	S	S	S	S	S	F	BS	UK	WG
17439	M	M	M	M	M	M	M	M	BS	UK	DS
17440	M	M	M	M	M	M	M	M	BS	UK	DS
17441	M	M	M	M	M	M	M	M	BS	UK	DS
17442	M	M	M	M	M	M	M	M	BS	UK	DS
17443	M		M	M	M	M	M	M	BS	UK	DS
17444	M	M	M	MF+	M	M	M	M	BS	UK	DS
17445	M	M	MF	M	M	M	M	M	BS	UK	DS

Locality abbreviations: DI = Decker Island; SWP = State Water Project; CVP = Central Valley Project; F = Folsom Res.; BS = Barker Slough; A = Almanor Res.; MR = Mokelumne River
ID abbreviations: DS = Delta Smelt; WG = Japanese Smelt; UK = Unknown

Table 2: Summary of results for electrophoretic analysis of 283 smelt.

CATALOG #	G3PDH	IDDH	IDHP	GPI	MPI	ADA	AAT	PEPB	LOCAL	DWR ID	ALLOZYME ID
17446	M	M	M	M	M	M	M	M	BS	UK	DS
17447	M	M	M	M	M	M	M	M	BS	UK	DS
17448	S	F	S	MS	S	SS-	S	F	BS	UK	WG
17449	M	M	M	M	M	M	M	M	BS	UK	DS
17450	M	M	M	M	M	M	M	M	BS	UK	DS
17451	M	M	M	M	M	M	M	M	BS	UK	DS
17452	S	F	S	S	S	S	S	FF-	BS	UK	WG
17453	M	M	M	M	M		M	M	BS	UK	DS
17454	M	M	M	M	M	M	M	M	BS	UK	DS
17455	M	M	M	M	M	M	M	M	BS	UK	DS
17456	S	F	S	MS	S	S	S	FF-	BS	UK	WG
17457	M	M	MS--	M	M	M	M	M	BS	UK	DS
17458	S	F		S	S	S	S	FF-	A	WG	WG
17459	S		S			S	S		A	WG	WG
17460	S	F		S	S	S	S	F	A	WG	WG
17461			S	S		S	S		A	WG	WG
17462				S	S	S		FF-	A	WG	WG
17463	S	F	S	S	S	S			A	WG	WG
17464	S		S	MS	S	S	S	F	A	WG	WG
17465	S	F	S	S	S	S	S	FF-	A	WG	WG
17466	S		S	S	S	S	S	FF+	A	WG	WG
17467	S	F	S	MS	S	S	S		A	WG	WG
17468	S	F	S	MS	S	S	S		A	WG	WG
17488	M	M	M	M	M	M	M	M	BS	UK	DS
17489	M	M	M	M	M	M	M	M	BS	UK	DS
17490	M	M	M	M	M	M	M	M	BS	UK	DS
17491	M		M	M	M	M	M	M	BS	UK	DS
17492	M	M	MF	M	M	M	M	M	BS	UK	DS
17493	S	F	S	MS	S	S	S	FF-	MR	UK	WG
17494	S	F	S	S	S	S	S	FF-	MR	UK	WG
17495	S	F		S	S	S	S	FF-	MR	UK	WG
17496	S	F		S	S	S	S	F	MR	UK	WG

Locality abbreviations: DI = Decker Island; SWP = State Water Project; CVP = Central Valley Project; F = Folsom Res.; BS = Barker Slough; A = Almanor Res.; MR = Mokelumne River

ID abbreviations: DS = Delta Smelt; WG = Japanese Smelt; UK = Unknown

~~Table 2~~: Summary of results for electrophoretic analysis of 283 smelt.

CATALOG #	G3PDH	IDDH	IDHP	GPI	MPI	ADA	AAT	PEPB	LOCAL	DWR ID	ALLOZYME ID
17497	S	F	S	S	S	S	S	F-	MR	UK	WG
17498	S	F	S	S	S	S	S	FF+	MR	UK	WG
17499	MS	MM+	MS	MS	MS	MS	MS	MF	MR	UK	HYBRID
17500	S	F	S	S	S	S	S	FF-	A	WG	WG
17501	S	F	S	MS	S	S	S	FF-	A	WG	WG
17502	S	F	S	S	S	S	S	F-	A	WG	WG
17503	S	F	S	S	S	S	S	F	A	WG	WG
17504	S	F	S	S	S	S	S	F	A	WG	WG
17505	S	F	S	S	S	S	S	F	A	WG	WG
17506	S	F	S	S	S	S	S	F	A	WG	WG
17507	S	F	S	S	S	S	S	FF-	A	WG	WG
17508	S	F	S	S	S	S	S	FF-	A	WG	WG
17509	S	F	S	S	S	SS-	S	F	A	WG	WG
17510		F			S	S	S	F	A	WG	WG
17511	S	F		S	S	S	S	FF-	A	WG	WG
17512	S	F	S	S	S	S	S	FF-	A	WG	WG
17513		F	S	MS	S	S	S	FF-	A	WG	WG
17514	S	F	S	S	S	S	S	FF+	A	UK	WG
17515	S	F		S	S	SS-	S	F	A	UK	WG
17516	S	F		S	S	SS-	S	F	A	UK	WG
17517	S	F	S	S	S	S	S		A	UK	WG
17518	S	F		S	S	S	S	FF-	A	UK	WG
17519	S	F		S	S	S	S	FF-	A	UK	WG
17520	S	F	S	S	S	S	S	F	A	UK	WG
17521	S	F	S	S	S	S	S	FF-	A	UK	WG
17522	S	F	S	S	S	S	S	F	A	UK	WG
17523	S	F	S	S	S	S	S	F	A	UK	WG

Locality abbreviations: DI = Decker Island; SWP = State Water Project; CVP = Central Valley Project; F = Folsom Res.; BS = Barker Slough; A = Almanor Res.; MR = Mokelumne River
ID abbreviations: DS = Delta Smelt; WG = Japanese Smelt; UK = Unknown