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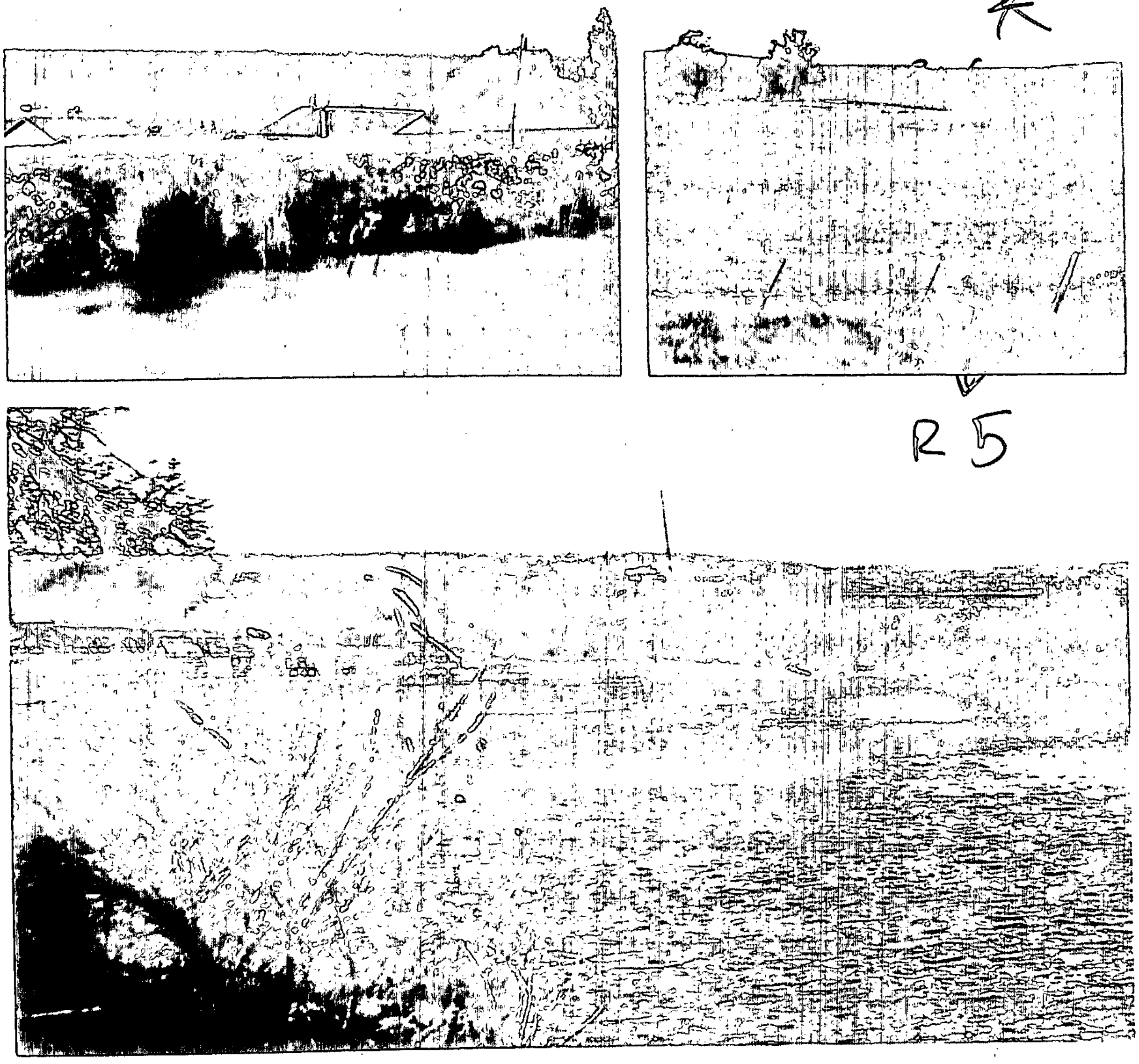
THE ECOLOGY OF THE SACRAMENTO-SAN JOAQUIN DELTA: A COMMUNITY PROFILE



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Fish and Wildlife Service
U.S. Department of the Interior
U.S. Environmental Protection Agency

CHAPTER 4. ZOOBENTHOS AND SUBSTRATES

4.1 PATTERNS OF ABUNDANCE

The zoobenthos of the delta is better understood than the zooplankton because the benthic community is dominated by only five species, although more than 82 species have been recorded (Table 4). Our understanding of the zoobenthos rests primarily on the monthly samples taken by California Department of Water Resources personnel at four stations within the delta. Two of these stations are in the western delta, in the main channel of the Sacramento River (in the center of the channel and along each bank) and in the center of a nearby flooded island (Sherman Lake). Two are in the

Table 4. Zoobenthos collected by California Department of Water Resources at four stations in the delta during monthly collections through 1984.

- Platyhelminthes
  - Planaridae
    - *Dugesia tigrina* – intro to Europe + Japan. 426 Ball 1975.
    - unknown triclad A
    - unknown triclad B
- Nemertea
    - *Paleonermatea* sp.
  - Tetrastemmatidae
    - *Prostoma graecense*
- Nematoda
  - Eudorylaimus
    - *Eudorylaimus*
    - unknown
- Ectoprocta
  - Lophopodidae
    - *Pecinatella magnifica*
- Annelida
  - Oligochaeta
    - Enchytraeidae
      - unknown spp.
    - Lumbricidae
      - *Lumbriculus variabilis*
    - Naididae
      - *Chaetogaster limnaei*
      - *Dero digitata*
      - *Nais pardalis*
      - *Ophidonais serpentina*
      - *Pristina breviseta*
      - *Slavina appendiculata*
      - *Stylaria fossularis*
      - *Vejdovskyella intermedia*
      - *Wapsa mobilis*
    - Tubificidae
      - *Aulodrilus limnodius*
      - *Aulodrilus pluriseta*
      - *Bothrioneurum vejdovskyanum*
      - *Branchiura sowerbyi*
      - *Ilyodrilus frantzi*
      - *Ilyodrilus mastix*
      - *Ilyodrilus templetoni*
      - *Limnodrilus angustipenis*
      - *Limnodrilus hoffmeistri*
      - *Limnodrilus udekemianus*
      - *Peloscolex gabriellae*
      - *Psammoryctides californianus*
      - *Quistadrilus multisetosus*
      - *Spirosperma ferox*
  - Polychaeta
    - Nereidae
      - *Neanthes limnicola*
      - * *Neanthes succinea* = Nereis succinea
    - Sabellidae
      - * *Manyunkia speciosa*

(Continued)

* introduced

Table 5. (Concluded)

- Spionidae
  - ** Boccardia ligerica*
- Hirudinea
  - Erpobdillidae
    - *Dina parva*
  - Glossophonidae
    - *Sparganophilus eiseni*
    - *Helobdella triserialis*
- Mollusca
  - Pelecypoda
    - Corbicullidae
      - ** Corbicula fluminea*
    - Planorbidae
      - *Gyraulus* spp.
  - Gastropoda
    - Myidae
      - ** Mya arenaria*
    - Sphaeriidae
      - *Musculium* spp.
    - Unionidae
      - *Anodonta nuttalliana*
- Arthropoda
  - Arachnida
    - Unionicolidae
      - *Unionicola* sp.
  - Crustacea
    - Cladocera
      - Sididae
        - *Latona setifera*
        - *Sida cristallina*
      - Chydoridae
        - *Eurycercus lamellatus*
      - Daphnidae
        - *Daphnia pulex*
        - *Simocephalus serrulatus*
      - Leptodoridae
        - *Leptodora kindtii*
    - Ostracoda
      - Candonidae
        - *Candona* sp.
      - Cypridae
        - *Stenocypria longicomosa*
    - Copepoda
      - Ameiridae
        - *Nitocra* sp.
      - Temoridae
        - *Epischura nevadensis*
        - *Eurytemora* sp.
      - Centropagidae
        - *Osphranticum labronectum*
      - Cyclopidae
        - *Mesocyclops edax*
    - Isopoda
      - Sphaeromatidae
        - *Gnorimosphaeroma lutea*
    - Amphipoda
      - Asellidae
        - *Asellus occidentalis*
      - Corophidae
        - *Corophium spinicorne*
        - *Corophium stimpsoni*
      - Idoteidae
        - ** Synodotia laticauda* = Synidotea laevidorsalis an isopod
      - Talitridae
        - *Hyallela azteca*
    - Decapoda
      - Palaemonidae
        - ** Palaemon macrodactylus*
      - Xanthidae
        - ** Rithropanopeus harrisii*
  - Insecta (none are listed in Fowell + Hogue)
    - Chironomidae water midges
      - *Ablabesmyia* sp.
      - *Chironomus attenuatus*
      - *Cladotanytarsus* sp.
      - *Cryptochironomus* spp.
      - *Demicryptochironomus* sp.
      - *Harnischia curtilamellata*
      - *Micropsectra* sp.
      - *Monodiamesa* sp.
      - *Nanocladius distinctus*
      - *Paracladopelura* sp.
      - *Paratendipes* spp.
      - *Polypedilum* sp.
      - *Procladius* sp.
    - Coenagrionidae damselflies (narrow-winged)
      - *Zoniagrion exclamationis*
    - Gomphidae dragonflies (clubtails)
      - *Gomphus olivaceous*
    - Ephemeridae mayflies (burrowing)
      - *Hexagenia limbata*
    - Heptageniidae mayflies (stream)
      - *Heptagenia rosea*

central delta, in the main channel of the San Joaquin River (in the center and along each bank), and in the center of a flooded island (Frank's Tract). These stations cover the range of benthic habitats in the delta, from the most lotic and shallow with generally peaty-muck substrates to the most swiftly flowing riverine with substrates of constantly shifting sand.

Zoobenthos density varies from year to year (Figure 35), with peak densities occurring in early or late summer. In the past, summertime densities have been as high as 100,000/m^2, but mean densities are usually between 10,000 and 40,000/m^2. The wet years from January 1982 to June 1984 led to temporary domination at all stations by freshwater species. The sudden salinity intrusion in July, because of abnormally low snowmelt, caused a sharp decline in zoobenthos density as the freshwater species declined faster than the brackish water species could spread or reproduce (California Department of Water Resources 1978-86a,b; see 1985 data).

4.2 SPECIES COMPOSITION

Species composition is more consistent than species abundance. Although 71 species were

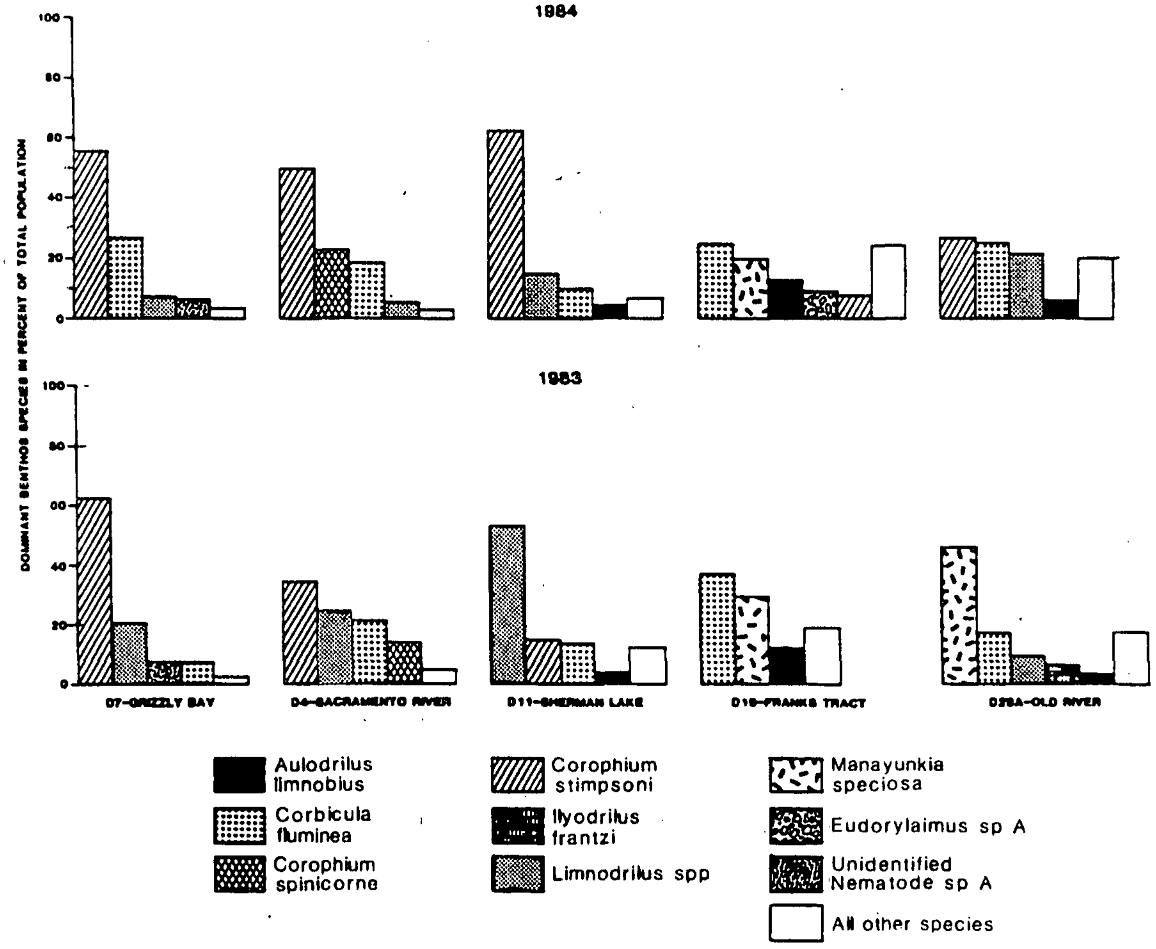

Figure 35. Variation across years in zoobenthos densities in the Sacramento-San Joaquin Delta. From California Department of Water Resources (1978-86a,b; 1985 data).

reported from the 1984 benthos samples, five species (*Corophium stimpsoni, C. spinicorne, Corbicula fluminea, Limnodrilis* spp., and *Manayunkia speciosa*) make up more than 90% of the individuals at most sites in most months of most years (California Department of Water Resources 1978-86a,b; see 1984 data). The domination of the zoobenthos by these five species makes the benthic community one of the most stable aspects of the delta. In addition, the species composition at one site differs from another site but is relatively constant across years (Figures 36, 37, 38, and 39). The distribution of each species seems to be largely determined by patterns of salinity and substrate (Hazel and Kelley 1966). Insects, particularly bloodworms (Chironomidae) are common in the river (Hazel and Kelley 1966), but are seldom found in the central or western delta sites (California Department of Water Resources 1978-86a,b; see 1981, 1982, 1983, 1984, 1985 data).

Members of the genus *Corophium* are filter-feeders on detritus and use some detritus in the construction of tubes. During their summer peaks of abundance *Corophium* densities are regularly 25,000-35,000/m^2.

Corophium stimpsoni is the most abundant benthic animal in the delta (Hazel and Kelley 1966; California Department of Water Resources 1978-86a,b; see 1981, 1982, 1983, 1984 data) and was found in each of 25 samples collected throughout the delta. It was found on all substrates and in all locales, but was most common in the western half and most abundant on substrates of fine sand (Hazel and Kelley 1966). Within a channel *Corophium stimpsoni* shows a marked preference for the deeper, central portions (Hazel and Kelley 1966; Figure 40). *Corophium stimpsoni* appears to undergo a diel vertical migration similar to, but less extensive than that of *Neomysis*. Up to 10% of the population migrates

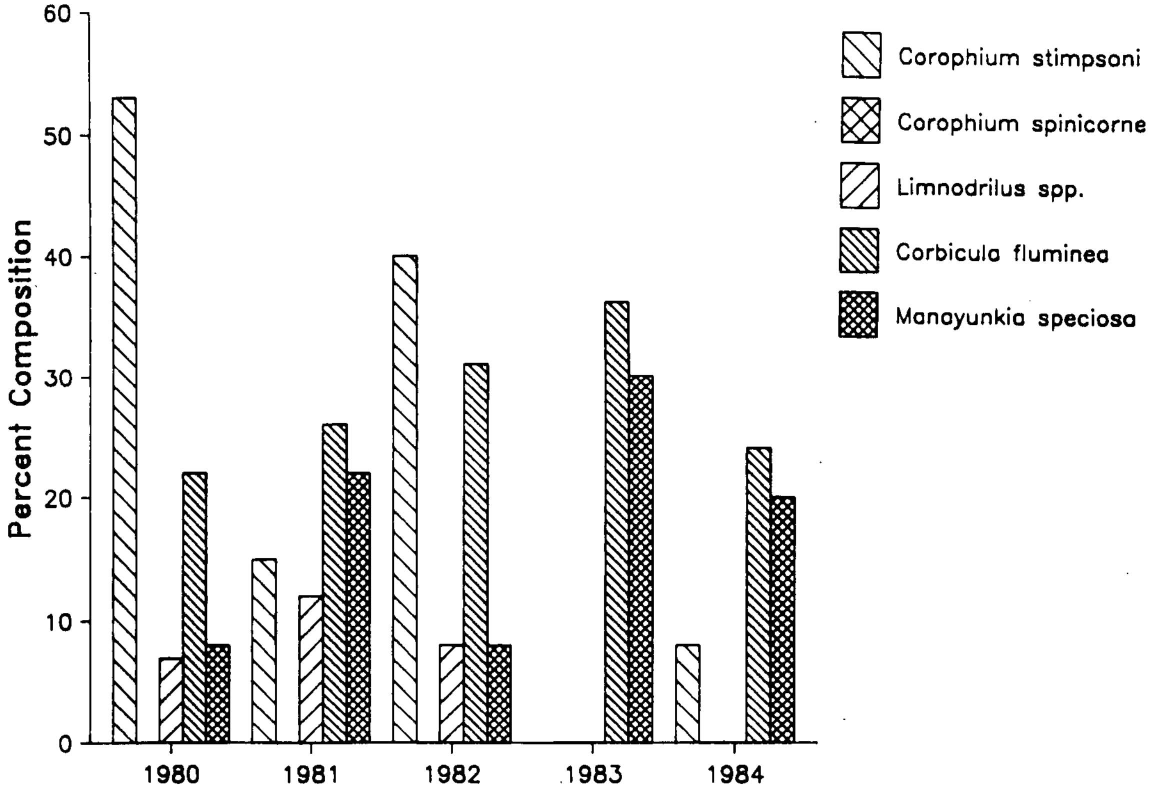

Figure 36. Dominant zoobenthos species across years at sampling sites in a flooded island on the San Joaquin River in the central delta.

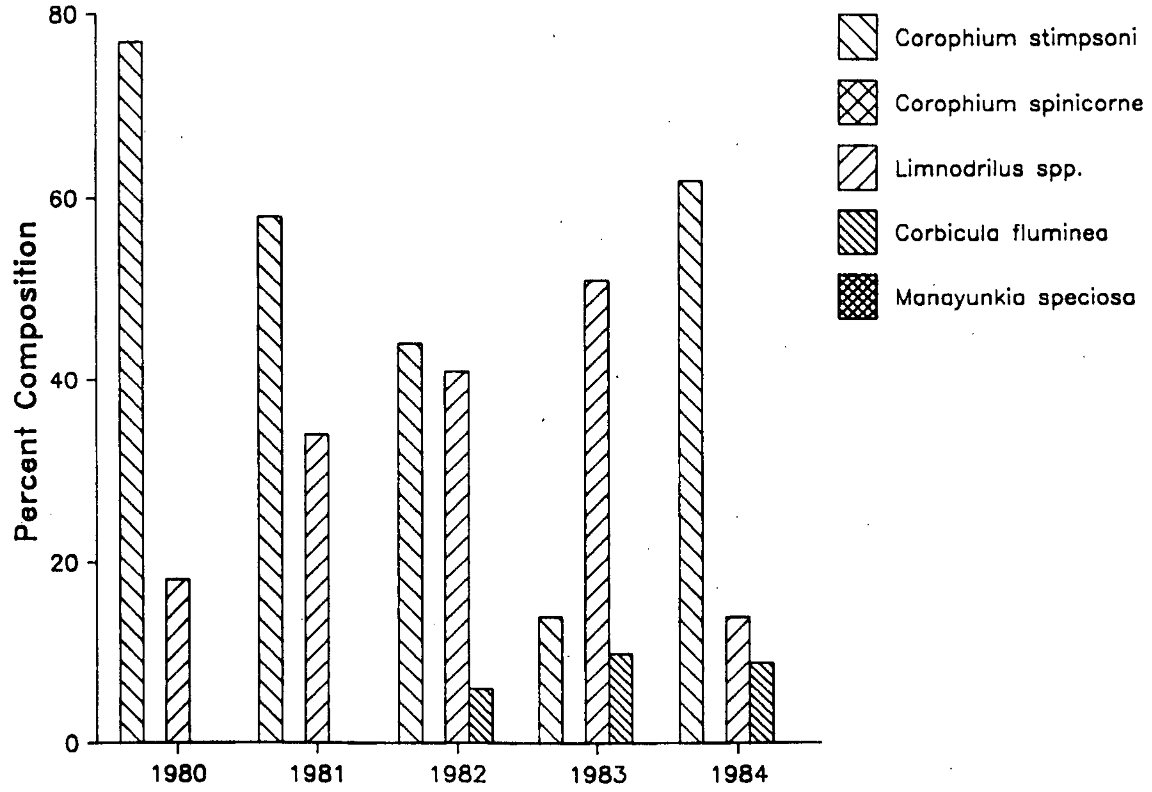

Figure 37. Dominant zoobenthos species across years at sampling sites in a flooded island in the western delta.

into the water column at midnight (Siegfried et al. 1978). Vertical migrations may serve in distributing young *Corophium* downstream. In samples taken from 1980 to 1984 (California Department of Water Resources 1978-86a,b; See 1983, 1984 data), *Corophium stimpsoni* was found regularly at each site but dominated the western sites (Figures 37 and 38).

Corophium spinicorne is a tube dwelling amphipod whose distribution in the delta is almost the complement to that of its congener; it is most frequently found on substrates of peat, cobble, or larger objects while *C. stimpsoni* is usually found on sandy substrates. Like *C. stimpsoni*, *C. spinicorne* is found at all locales in the delta (Hazel and Kelley 1966), but where one is abundant the other is usually rare. *C. spinicorne* is most common on the shallower edges of channels, frequently attached to pilings or riprap. *C. spinicorne* increases in abundance when conductivities increase, whereas *C. stimpsoni* declines at conductivities greater than 5,000 μsiemens/cm (Markmann 1986). In collections made since 1980 by the California Department of Water Resources, *C. spinicorne* has seldom dominated any site (Figures 36, 37, 38, and 39), but this is partly an artifact of its habit of building tubes on solid objects, which results in low capture rates by the Peterson dredge.

Both species of *Corophium* undergo two generations per year, although only one population peak is apparent. An overwintering population begins reproduction in the early spring. The subsequent generation begins to appear in March, grows rapidly through the summer, and produces the next overwintering generation in late summer (Siegfried et al. 1978). Before reproducing, the overwintering population grows larger than the summer population. Fecundity is a logarithmic function of size in *Corophium*, so the overwintering population can produce more young, in a shorter time, than the summer

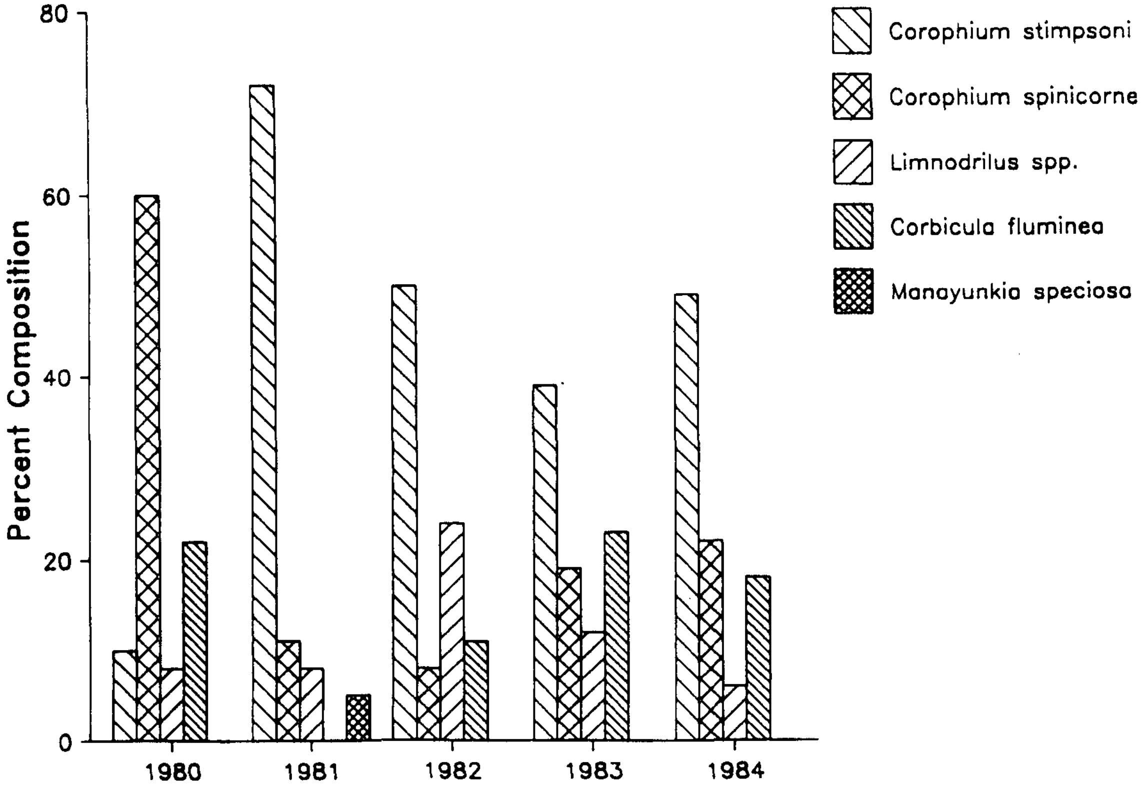

Figure 38. Dominant zoobenthos species across years at sampling sites in the main channel of the Sacramento River in the western delta.

generation (Siegfried et al. 1978). These life history tactics are very similar to those of *Neomysis mercedis*.

Annelid worms of the genus *Limnodrilis* are more euryhaline than other members of the benthic community. They frequently dominate samples from Grizzly Bay, downstream of the delta, as well as freshwater sites in the central delta. Brackish waters of the western delta support the greatest densities (California Department of Water Resources 1982) and appear optimal for their growth and reproduction. The densities and reproductive output of *Limnodrilis* spp. are lower at times of higher salinity (California Department of Water Resources 1982). On the other hand, during the wet year of 1983 when conductivity in the delta never exceeded 200 μsiemens/cm, *Limnodrilis* declined in relative abundance (California Department of Water Resources 1978-86a,b; see 1984 data). *Limnodrilis* lives in burrows as deep as 18 cm, and the lower reaches of these burrows may serve as a refuge for the worm when sudden salinity changes occur at the surface. The ability of these worms to survive low oxygen conditions within their burrows and to use the burrows as buffers against environmental change may explain their greater abundance in Suisun Bay where salinities change frequently and in parts of the southeastern delta where anoxic conditions may regularly occur. Thus, these worms tend to be most abundant in areas which support few other species. If high flows remove *Limnodrilis* from channels they seem to readily recolonize from nearby populations, but they do not appear to use river currents or tidal flow to distribute their young.

The Asian clam *Corbicula fluminea* (perhaps synonymous with *C. manilensis*), introduced into the Columbia River in 1938, had invaded the Sacramento River by 1945 (Gleason 1984). It is now the most widespread and abundant freshwater clam in the

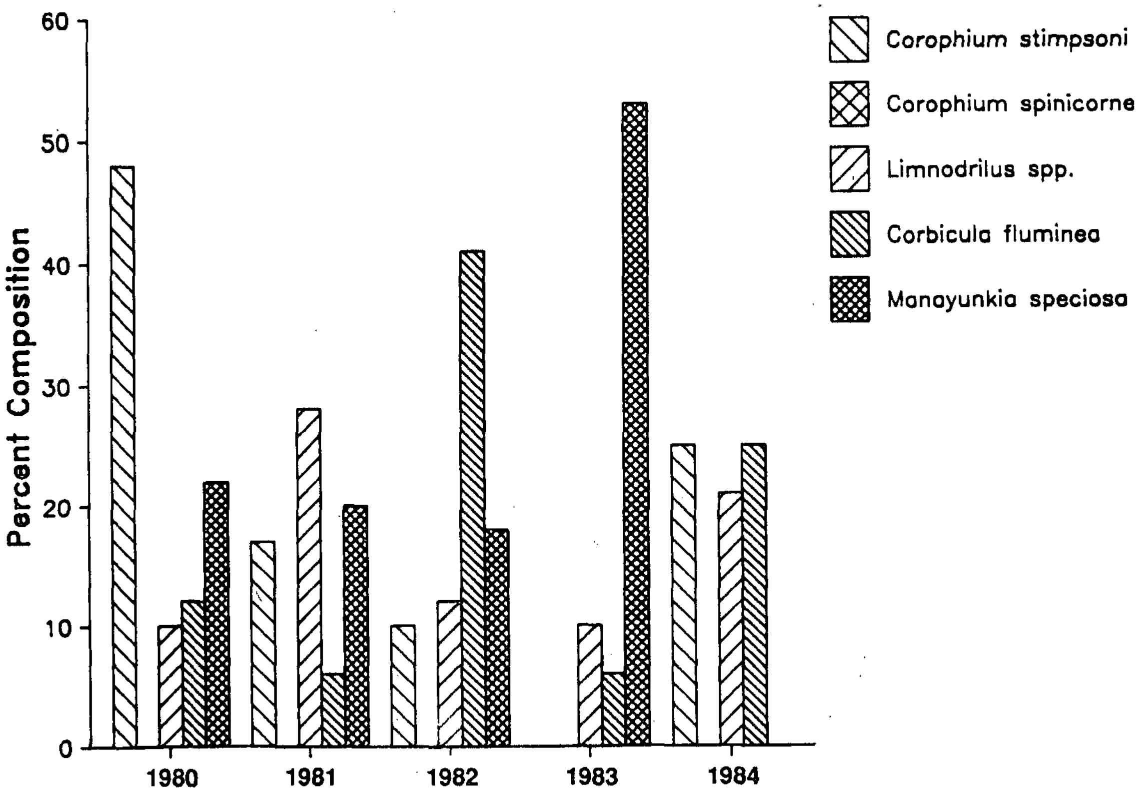

Figure 39. Dominant zoobenthos species across years at sampling sites in the main channel of the San Joaquin River in the central delta.

state. Reproduction is tied to temperature: eggs only develop when water temperature is between 16 and 24 °C. These temperatures typically occur only in the spring and fall, and *Corbicula* reproduction is, correspondingly, bimodal. Fecundity can be as great as 8,000 young/yr. Young leave the parent's mantle cavity in a relatively well-developed state, attaching themselves to the bottom soon after emergence. Colonies of *Corophium* frequently harbor high densities of young clams (Eng 1979). Two thousand clams/m^2 is a common density estimate, but densities of up to 20,000/m^2 have been recorded (Gleason 1984).

Corbicula usually reproduce in the late spring or early summer, but in the central delta there is often another reproductive peak in the late fall. High flows in the spring carry young clams downstream to the upper reaches of Suisun Bay, but high fall salinities and scouring flows of the following spring appear to prevent the establishment of large adult populations in the western delta (Markmann 1986). The fall bout of reproduction in the central delta takes place when flows are lower and young clams probably settle out of the water column near the adults.

Growth is apparently controlled by temperature via its effect on phytoplankton densities. Laboratory studies have shown that *Corbicula* can grow through winter temperatures of the delta if chlorophyll *a* concentrations are sufficiently high (Foe and Knight 1985). However, low temperatures coincide with decreased insolation and residence time to limit algal growth. Thus, in nature, *Corbicula* are not observed to grow at temperatures below 15 °C.

In the Sacramento-San Joaquin Delta *Corbicula fluminea* is usually the third most abundant form of zoobenthos. It is present at all sample sites but is

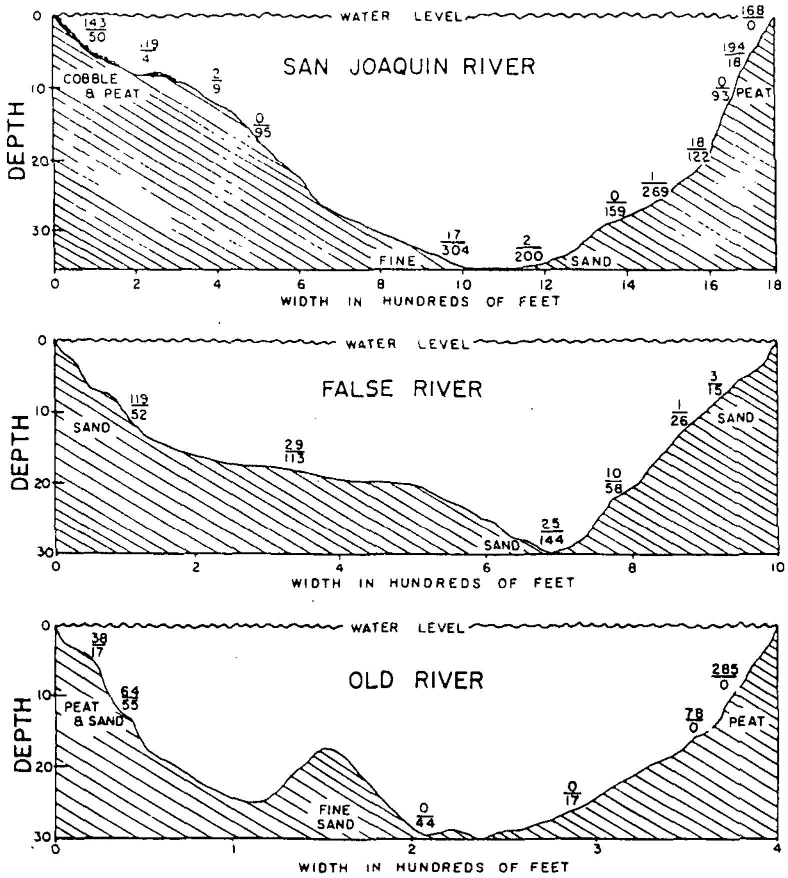

Figure 40. Segregation by depth of two species of *Corophium* in the channel of the Sacramento River. Modified from Hazel and Kelley (1966).

most abundant in the more freshwater, interior sites (California Department of Water Resources 1978-86a,b; see 1985 data). In 1983, an extraordinarily wet year, *Corbicula* rose to be the second most common genus of zoobenthos and increased in relative abundance at the western sampling sites (California Department of Water Resources 1978-86a,b; see 1984 data). Thus, freshwater flows seem to promote the abundance and spread of this species.

The polychaete worm *Manayunkia speciosa* is the most strictly freshwater inhabitant of the five dominant benthic species. Unlike other members of the benthos, *Manayunkia speciosa* is found only in the eastern portions of the delta. The requirement for freshwater makes *Manayunkia* unusual among polychaetes, which are predominantly marine worms. During the exceptionally high outflow conditions of 1983, *Manayunkia speciosa* became extremely abundant. During the 1976-77 drought, the western delta was temporarily invaded by polychaete species typical of the more saline bay waters and *Manayunkia speciosa* abundance in the eastern delta declined (Markmann 1986).

Manayunkia speciosa constructs mucus-and-silt tubes and lives in dense colonies of 2,000/m^2 to 50,000/m^2. Adults are hermaphrodites. Eggs are produced either sexually or asexually and mature within the parental tube. Dispersal appears to be a simple matter of the young crawling out of the parent's tube after hatching and then building their own tube nearby (Markmann 1986). In the

Sacramento-San Joaquin Delta, *Manayunkia speciosa* apparently only breeds in the spring. Its requirements for freshwater and silty substrates restrict *Manayunkia speciosa* to low-velocity waterways of the eastern delta.

CHAPTER 5. EPIFAUNA

Larger, more mobile animals that live on rather than in the substrate are not well sampled by any procedures used to monitor the delta. Although *Corbicula* could often be included in this category, the epibenthos is otherwise composed of arthropods. In the more saline waters of the western delta, the epibenthos consists largely of a native shrimp, *Crangon franciscorum*, an introduced shrimp, *Palaemon macrodactylus*, and an introduced crab, *Rithropaenopeus harrisii.* Further upstream the epibenthos is made up of insects (Markmann 1986): Gomphidae, Ephemeridae, Chironomidae, etc. The most widely distributed and economically important member of the epifauna is the signal crayfish *(Pasifastacus leniusculus)*. The red swamp crayfish (*Procambarus clarki*) is also reported to be widely distributed in the delta (Hazel and Kelley 1966).

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Pasifastacus leniusculus var. *leniusculus* was first found in California in San Francisco in 1898 and was apparently introduced from Oregon (Riegel 1959). A commercial harvest of signal crayfish in the delta began in 1970. Today, annual commercial landings in the delta average 500,000 pounds (Kimsey et al. 1982). *P. leniusculus* is tolerant of salinities up to 17 ppt and can be found in the upper reaches of the San Francisco Bay complex.

The two common caridean shrimp of the western delta are ecologically similar (Sitts 1978). *Crangon (=Crago) franciscorum* feeds predominantly on *Neomysis mercedis* and has its densest populations in the same areas in which *N. mercedis* is most abundant (Siegfried 1980). Formerly, *C. franciscorum* supported a large commercial catch in San Francisco Bay (Bonnot 1932), but now it is only taken in small quantities for bait (Siegfried 1980). *Palaemon macrodactylus* was introduced to San Francisco Bay sometime in the 1950's, probably by the dumping of water ballast from ships returning from Korea (Newman 1963; Siegfried 1980). The diet of *P. macrodactylus* also consists largely of *N. mercedis*, but the peak abundance of *P. macrodactylus* is downstream of the overlapping peaks of *C. franciscorum* and *N. mercedis* (Siegfried 1980). Both caridean shrimp show the same sort of vertical migrations as *N. mercedis.* During the season when *N. mercedis* is less abundant, *C. franciscorum* takes more gammarid amphipods and polychaetes while *P. macrodactylum* takes more copepods (Knight et al. 1980).

Crangon franciscorum is more marine and apparently less tolerant of water quality degradation when in freshwater than *Palaemon macrodactylus* (Siegfried 1980). Ovigerous females are never found in the delta, only in San Pablo and Suisun Bays. Increased osmotic stress in freshwater appears to prevent egg development at salinities below 15 ppt (Krygier and Horton 1975). Breeding occurs year round but with a peak from December through June (Israel 1936). During seasons of high river outflow *C. franciscorum* is absent from the western delta but abundant downstream (Siegfried 1980). Temperature and salinity interact in their physiological effects on *C. franciscorum*; low temperatures reduce its tolerance for low salinities (Khorram and Knight 1977). When salinities and temperatures rise in the western delta, *C. franciscorum* occurs in channels of the Sacramento River at much higher abundances than in the San Joaquin River. Salinity tolerances change with the acclimation of individuals, so downstream populations are less tolerant of freshwater than upstream populations (Shaner et al. 1987).

Like *Crangon franciscorum*, *Palaemon macrodactylus* is apparently limited in its upstream distribution by low salinity, but *P. macrodactylus* tolerates lower salinities and can be abundant in the more degraded waters of the San Joaquin River. Even at periods of high river outflow, when salinities are lowest, *P. macrodactylum* is found in the western delta. Reproduction appears to be initiated by increasing photoperiod in April or May and continues until August.

CHAPTER 6. FISH

6.1 HISTORICAL PROCESSES

The abundant species of fish in the delta (Table 5) are almost all introduced from the east coast or from Asia and Europe. The ecology of the native fishes prior to the arrival of European settlers is not well known. The decline of native fishes was presumably the result of habitat alteration combined with the introduction of foreign species, circumstances which continue to bring new changes to the delta. Two species which were formerly abundant in the delta are now extinct there; the thicktail chub (*Gila crassicauda*) was last seen in Cache Slough in 1958 (Moyle 1976), and only a few Sacramento perch (*Archoplites interruptus*) have been observed in the delta over the last 25 years, even though they once supported a commercial harvest. Thicktail chubs and Sacramento perch are the most frequent fish remains found in middens of the Patwin Indians which formerly inhabited the Sacramento-San Joaquin Estuary (Schulz and Simons 1973). Most other native species have undergone shrinkage of their ranges or population sizes (Moyle 1976), with the delta smelt (*Hypomesus transpacificus*) showing a recent and severe decline (L. Miller, California Department of Fish and Game; pers. comm.).

The greatest efforts to introduce fish into the delta were made immediately after the completion of the transcontinental railway. Oysters were the most commonly transported organism, but railway cars of oysters were often a means of bringing in various fish, either accidentally or intentionally. Many species of fish were introduced before 1900, but new arrivals have been reported in most decades since then (Table 5). The history of introductions has

Table 5. Abundance of the fish of the Sacramento-San Joaquin Delta and year of introduction or first capture for non-native species. R=resident, A=anadromous, N=nonresident visitor, M=euryhaline marine.

Common name	Scientific name	Abundance	Year
Pacific lamprey	*Entosphenus tridentatus*	Common (A)	
River lamprey	*Lampetra ayresi*	Uncommon (A)	
White sturgeon	*Acipenser transmontanus*	Common (A)	
Green sturgeon	*Acipenser medirostris*	Uncommon (A)	
I American shad	*Alosa sapidissima*	Common (A)	1871
I Threadfin shad	*Dorosoma petenense*	Abundant (R)	1953
I Brown trout (sea-run)	*Salmo trutta*	Rare (A)	
Steelhead	*Oncorhynchus mykiss*	Common (A)	
Pink salmon	*Oncorhynchus gorbuscha*	Occasional (A)	
Coho salmon	*Oncorhynchus kisutch*	Rare (A)	
Chinook (king) salmon	*Oncorhynchus tshawytscha*	Common (A)	

(Continued)

	Total	Intro'd	Native	Native %
# spp found in Delta	52	28	24	46%
resident	35	25	10	29%
anadromous	15	3	12	80%
Res or Anadromous	48	26	22	46%
Common / Res or Anad	32	18	14	44%
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

	Total	Intro	Native	Native %
Common or Abundant	34	19	15	44%

Liston et al (1986) also list prickly sculpin & riffle sculpin (Tui chub as extirpated)

possible arrivals: red shiner, spotted bass, rock bass

Table 5. (Concluded)

	Common name	Scientific name	Abundance	Year
	Chum salmon	*Oncorhynchus keta*	Occasional (A)	
	Sockeye salmon	*Oncorhynchus nerka*	Occasional (A)	
	Longfin smelt	*Spirinchus thaleichthys*	Common (A-R)	
	Delta smelt	*Hypomesus transpacificus*	Common (R)	
	Thicktail chub	*Gila crassicauda*	Extinct	
	Hitch	*Lavinia exilicauda*	Common (R)	
	California roach	*Hesperoleucus symmetricus*	Rare (N)	
	Sacramento blackfish	*Orthodon microlepidotus*	Common (R)	
	Splittail	*Pogonichthys macrolepidotus*	Common (R)	
	Hardhead	*Mylopharodon conocephalus*	Uncommon (N)	
	Sacramento squawfish	*Ptychocheilus grandis*	Common (R)	
I	Fathead minnow	*Pimephales promelas*	Occasional (R)	1950's
I	Golden shiner	*Notemigonus crysoleucas*	Common (R)	>1891
I	Goldfish	*Carassius auratus*	Common (R)	>1900
I	Carp	*Cyprinus carpio*	Abundant (R)	1872
	Sacramento sucker	*Catostomus occidentalis*	Common (R)	
I	Black bullhead	*Ictalurus melas*	Common (R)	1874
I	Yellow bullhead	*Ictalurus natalis*	Rare (R)	1874
I	Brown bullhead	*Ictalurus nebulosus*	Common (R)	1874
I	White catfish	*Ictalurus catus*	Abundant (R)	1874
I	Channel catfish	*Ictalurus punctatus*	Common (R)	1940's
I	Blue catfish	*Ictalurus ~~furcatis~~* furcatus	Rare (R)	1979
I	Inland silversides	*Menidia beryllina*	Abundant (R)	1968 — ?
I	Mosquitofish	*Gambusia affinis*	Common (A-R)	1922
I	Striped bass	*Morone saxatilis*	Abundant (~~R~~)(A)	1879-82
	Sacramento perch	*Archoplites interruptus*	Extinct	
I	Bluegill	*Lepomis macrochirus*	Common (R)	1908
I	Redear sunfish	*Lepomis microlophus*	Uncommon (R)	>1949
I	Green sunfish	*Lepomis cyanellus*	Common (R)	1891
I	Warmouth	*Lepomis gulosus*	Uncommon (R)	>1921
I	White crappie	*Pomoxis annularis*	Common (R)	1951
I	Black crappie	*Pomoxis nigromaculatus*	Uncommon (R)	>1908
I	Largemouth bass	*Micropterus salmoides*	Common (R)	1874
I	Smallmouth bass	*Micropterus dolomieui*	Uncommon (R)	?
I	Bigscale logperch	*Percina macrolepida*	Common (R)	1953
I	Yellow perch	*Perca flavescens*	Extinct	1891-1950's
	Tule perch	*Hysterocarpus traski*	Common (R)	
I	Yellowfin goby	*Acanthogobius flavimanus*	Common (R)	1963
	Staghorn sculpin	*Leptocottus armatus*	Common (M)	
	Starry flounder	*Platichthys stellatus*	Common (M)	
I	Rainwater killifish	*Lucania parva*	Rare (R)	? 1958
	Prickly sculpin	*Cottus asper*	Common (R)	
	Threespine stickleback	*Gasterosteus aculeatus*	Uncommon (R)	
I	~~Chameleon~~ goby Shimofuri	*Tridentiger ~~trigoncephalus~~* bifasciatus	Common (R)	1985
I	Pumpkinseed	Lepomis gibbosus	Rare (R)	1939 in Delta
I	Wakasagi	Hypomesus nipponensis	Rare (R)	1994 in Delta

varied from phenomenal success to complete failure. One species, yellow perch (*Perca flavescens*), was introduced but became extinct 60 years later. Other species, such as pumpkinseed (*Lepomis gibbosus*), never survived, while some, such as channel catfish (*Ictalurus punctatus*), succeeded only after repeated introductions. The most recent successful introductions were of inland silverside (*Menidia beryllina*) (Moyle et al. 1974; Meinz and Mecum 1977) and bigscale logperch (*Percina macrolepidotus*) from the southeastern United States (Moyle et al. 1974), rainwater killifish (*Lucania parva*) from the east coast of North America (Hubbs and Miller 1965), and chameleon goby (*Tridentiger tigonocephalus*) and yellowfin-goby (*Acanthogobius flavimanus*) from Japan (Brittan et al. 1963). The documented explosive spread of yellowfin gobies from their first appearance in 1963 to their extreme abundance in 1967 (Brittan et al. 1970) is apparently typical for most successful introductions. Other species continue to arrive. For instance, blue catfish (*Ictalurus furcatus*) were first brought into California at Lake Jennings in San Diego county on October 23, 1969 (Richardson et al. 1970) and were reported in the Sacramento-San Joaquin Delta less than 10 years later (Taylor 1980). Young of the year were found in Clifton Court Forebay in 1986 (H. Chadwick, pers. comm.). White bass (*Morone chrysops*) have been brought into the drainage and may invade the estuary within the next few years.

6.2 CONTROLS OF DISTRIBUTION

The distribution of fish species within the delta is based on productivity and the degree of impact that human activities have had on water flow. Electrofishing surveys in 1974 (Sazaki 1975) found that the greatest abundances of fish are in the slower and more productive waters of the San Joaquin River in the south delta. However, the less degraded but less productive waters of the Sacramento River in the north delta are the predominant areas in which native fishes were found. Because introduced species are more widely distributed, the northern delta supports the greatest diversity of fish species.

The fishes of the delta, like most other aquatic components of the delta community, are frequently controlled by the amount of delta outflow. Some ways in which moderately high flows benefit fish populations are as follows: (1) more flooded vegetation for species that lay eggs there, (2) more suitable habitat for nest construction in upstream streambeds that are normally dry, (3) easier access to upstream sites, (4) more shallow, flooded areas where small or young fish can avoid predators, (5) more easily followed environmental cues (scents and currents) for fish migrating to their natal streams, (6) dilution of pollutants, and (7) providing optimum conditions for food organisms. Fish whose populations have been documented as being tied to river outflows include chinook salmon, striped bass, splittail, American shad, and longfin smelt (Daniels and Moyle 1983; Stevens and Miller 1983). Water development projects and management strategies can have profound effects on these species (Stevens and Chadwick 1979). Some fish are insulated from the effects of variation in outflow by their use of a habitat type or by having a method of reproduction which is independent of flow effects. Several groups of species (i.e., anadromous species, resident species of riverine habitats, and resident species of lacustrine habitats) can be identified because of their shared responses to outflow or their use of similar habitats. Variation within species and in the nature of the delta across years prohibit any strict grouping of species, but some general patterns are apparent.

6.3 ANADROMOUS SPECIES

Adult anadromous species use the delta as a path to their upstream spawning sites, while juveniles use the path on their way to the sea. The delta is also a nursery area for outmigrating young. For some anadromous species the delta is a spawning site as well as part of the regular adult habitat. Common anadromous species of the delta include Pacific lamprey, river lamprey, American shad, white sturgeon, chinook salmon, steelhead, and striped bass. The latter five are economically the most important fish in the delta.

Lamprey. Pacific lamprey and river lamprey use the delta mainly as a path to and from their spawning sites, although some ammocoetes live in silty habitats in the delta (Moyle 1976; Wang 1986).

Sturgeon. Green and white sturgeon occur in the delta. Little is known of the biology of the comparatively rare green sturgeon (Moyle 1976). It is assumed to be similar to the white sturgeon (Wang

1986), although the adults are more marine. White sturgeon spawn between February and May, mostly in the Sacramento River (from Knights Landing to Colusa) and in its tributaries (Stevens and Miller 1970; Kohlhorst 1976; Moyle 1976; Wang 1986). Some juveniles feed in the delta, (Radtke 1966) but most are found west of Chipp's Island. While in the delta, sturgeon feed mostly on *Corophium* and *Neomysis* (Radtke 1966). The number of young sturgeon caught in the delta appears to be directly related to delta outflow, but this is partly a result of greater washout from upstream spawning sites (Stevens and Miller 1970). There is no apparent minimum flow requirement to initiate spawning activity, but survival of young sturgeon in the delta may be enhanced by high river outflows or low rates of diversion (Kohlhorst 1980).

The abundance of white sturgeon decreased from 1967 to 1974, but mean length of captured fish increased (Kohlhorst 1980). This pattern is best explained by continued growth of adults who have failed to reproduce. White sturgeon become of catchable size at 6-12 years, so adult fish in 1967-74 would have been produced in the late 1950's or early 1960's. Three reasons for impaired reproduction by this age class have been suggested (Kohlhorst 1980). After 1958 the volume of water exported from the delta greatly increased, resulting in the entrainment of young fish and the disruption of spawning migrations. Samples of sturgeon gonads in 1975 indicated concentrations of polychlorinated bipheyls (PCB's) of 24 ppm in the eggs. PCB concentrations of 3-7 ppm in other species have been shown to increase egg and larvae mortality. PCB's were widely used from 1930 to 1940 and concentrations in fish from the 1950's and 1960's may represent simple bioaccumulation. Finally, spawning stock size appears to undergo normal fluctuations that may be partly responsible for a small spawning stock. Since 1974, sturgeon populations in the delta have been increasing. However, although more young are produced, their growth rates are still lower than found for sturgeon in 1954 (Kohlhorst et al. 1980).

Salmon. All five species of Pacific west coast salmon have been recorded from the Sacramento-San Joaquin Estuary; in order of abundance these are chinook, chum, pink, sockeye, and coho salmon (*Oncorhynchus tshawytscha, O. keta, O. gorbuscha, O. nerka,* and *O. kisutch*) (Hallock and Fry 1967). Only the chinook, or king, salmon occurs regularly. Four races of chinook salmon spawn in the Sacramento-San Joaquin river system: a fall run from July to December begins spawning in October, a late-fall run from October to April begins spawning in January, a winter run from December to July begins spawning in April, and a spring run from April to October begins spawning in August. Thus, runs can occur in all months and, although no spawning takes place in the delta, the large adults migrating through have been dramatic features of the aquatic environment. Because the adults rarely feed once they enter freshwater, their impact on the ecosystem is slight. Fry are abundant in the delta from February to April (U.S. Fish and Wildlife Service 1987). Out-migrating smolts appear in the delta mostly from April to June (Sasaki 1966c; Wang 1986). In their natal streams the juveniles are drift feeders, while in the delta their diets consist of *Neomysis*, amphipods, and shrimp (Wang 1986).

Formerly, the spring run of chinook salmon contained a large population that oversummered in cool, deep pools of upper Sacramento River tributaries, such as the McCloud or Pit Rivers, before spawning in the fall. Shasta Dam and other water developments have eliminated access to most of these habitats, and this run has declined sharply. The summertime releases from Shasta Dam are from the bottom of the dam, making the summertime flows of the Sacramento River greater, more constant, and cooler. This situation has apparently favored the fall run, which spawns in the main Sacramento River (Moyle 1976). Most of the $44 million derived from this fishery (Meyer Resources Inc. 1985) is based on this run. The winter and spring runs are now very low, and efforts are being made to place them on the State and Federal lists of threatened species.

how?

Variations in river flow affect salmon in several ways. High flows permit adults to spawn in small tributaries or to pass dams, but the young produced may be stranded after water levels decline. Nonetheless, this feature may permit rehabilitated streams to recover their salmon runs. High volumes of water prevent the reverse flows characterizing the lower San Joaquin River, thereby allowing San Joaquin fish to avoid swimming "upstream" to the export pumps (Sasaki 1966c). Finally, high runoff permits down-migrating juveniles to escape predation more effectively by hiding in emergent vegetation (Stevens and Miller 1983). Cross delta flows, increased water temperatures, and entrainment into water diversions are probably the features responsible for the loss of many fry and smolts from the delta (U.S. Fish and Wildlife Service 1987). Particularly for San Joaquin River smolts, survival is highly correlated with river flow (Stevens and Miller 1983; U.S. Fish and Wildlife Service 1987).

Steelhead, which are anadromous races of rainbow trout, are ecologically similar to salmon and have little impact on the delta community. Juveniles stay in their natal stream for 1, 2, or occasionally, 3 years prior to entering the ocean (Moyle 1976). As they pass through the estuary the juveniles feed on *Corophium*, various small crustaceans, and small fish (Sasaki 1966c). They are found in all habitats of the delta, but the length of time individuals stay in the delta and the delta's importance as a nursery area are unknown. Construction of Shasta Dam blocked access to about half of the suitable steelhead spawning sites in the Sacramento River drainage. Much of the salmon and steelhead production is now conducted at the Nimbus and Coleman fish hatcheries.

Shad. American shad were introduced in the 1870's and 1880's, at the height of silt deposition in the estuary from hydraulic mining (Hedgepeth 1979). Their semi-demersal eggs are kept in the water column when current velocities exceed 1 m/s. American shad eggs have wide perivitelline spaces, presumably to protect them as they bounce along the bottom; the chorion of the shad eggs is also particularly tough and thick (Wang 1986). One requirement for successful reproduction of striped bass, and probably American shad, is sufficient water velocities to keep the eggs and larvae suspended (Meinz and Heubach 1978). The explosive spread of American shad in the Sacramento-San Joaquin estuary was probably enhanced by having eggs that could not be smothered by silt. The semi-demersal eggs also serve to concentrate the young in the null zone where their zooplankton food is also concentrated--at least for striped bass (Stevens 1979). Both species spawn within the delta and avoid much of the habitat alteration and dewatering that have affected native anadromous species (Stevens and Miller 1983).

As with salmon, American shad spawn mostly in waters of the Sacramento River. American shad begin their spring spawning runs as early as September (Stevens 1972), but they do not become abundant until April and May. Shad spawn in May and June, and by July the adults are nearly absent from the delta (Stevens 1966). Males begin spawning at the age of 3 or 4 and females generally at the age of 4 or 5, although spawning individuals of either sex have been found at 2 years of age (Wixom 1981). Once an individual begins spawning, it spawns annually until death. California populations of American shad apparently differ from the native populations on the east coast in that they feed as they swim upstream (Stevens 1966). Stevens (1966) reported many stomachs filled with *Neomysis* (as many as 4,000 shrimp/stomach) with smaller quantities of copepods and cladocerans. Number and identity of food items in adult shad stomachs closely reflect the available zooplankton populations. Young shad begin their downstream migration as early as July, and by December they are almost completely gone (Stevens 1972). Food of young shad seems to be mostly copepods and cladocerans (Stevens 1966). River flows apparently affect shad populations primarily through their effects on habitat availability (Stevens and Miller 1983).

American shad populations expanded very rapidly following their introduction in 1871. A commercial shad fishery existed by 1879. From 1900 until 1945, the commercial catch was frequently 1 million pounds and rose in 1917 to 5.6 million pounds. After 1945, shad populations declined, and in 1957 commercial fishing in the delta was banned (Skinner 1962). Formerly, American shad spawned throughout the estuary (Nidever 1916; Hatton 1940), but now only the upper reaches of the north delta are used (Stevens 1966; Painter et al. 1977). The decline in shad populations seems to be most closely tied to water diversions. Upstream reservoirs reduce the amount of spring outflows and so may fail to attract adults upstream and fail to transport young fish to appropriate nursing areas downstream. Diversions within the delta entrain many shad and may reduce zooplankton abundance by decreasing residence times of water in the delta. The decline of shad populations coincides with the construction of Shasta Dam. Operation of Shasta Dam has changed the delta from an estuarine to a freshwater system, so the simultaneous declines in anadromous species, like shad, and increases of freshwater species, like channel catfish, are not surprising.

Striped Bass. The breeding biology of striped bass is very similar to that of American shad and their successful introduction into California may, perhaps, be attributed to their silt tolerant eggs. This may have been particularly important since chinook salmon (the native, anadromous, predatory fish) were probably decimated by hydraulic mining at the same time striped bass were introduced. As with American shad, most reproduction of striped bass takes place in the waters of the Sacramento River. In most years the high concentrations of total dissolved solids in the lower San Joaquin River block the upstream migration of most striped bass (Farley 1966; Radtke 1966). Timing of spawning in striped bass appears to be set by temperatures near 15 °C; in cooler, wetter years many bass migrate as far upstream as Red Bluff, while in warmer, drier years most spawning occurs before the fish have moved past Sacramento (Farley 1966). Similarly, striped bass that spawn in the San Joaquin River do so as much as 1 month earlier than those in the Sacramento River, and this has been attributed to the higher temperature of that water (Chadwick 1958; Wang 1986).

Male striped bass begin their spawning runs in late March or early April and are followed by the females, which arrive in late April and early May (Radtke 1966). Differences in temperature between years and in direction of migration, as already noted, can affect the timing of these runs. Spawning is usually completed by May (Farley 1966) but has been reported as early as April and as late as June (Scofield 1931; Calhoun et al. 1950; Erkkila et al. 1950; Chadwick 1958; Moyle 1976; Wang 1986). Adult striped bass are almost strictly piscivorous (Thomas 1967), taking a wide variety of prey but particularly young striped bass and threadfin shad. However, they do not feed heavily during their spawning migration and so have little effect on fish populations within the delta (Stevens 1966). Some adult striped bass remain within the delta all year, often in the expanse of open water in Frank's Tract (Radtke 1966).

Young striped bass commonly stay within the delta for up to 3 years. When fish are smallest, copepods constitute their most common prey (Heubach et al. 1962; Eldridge et al. 1981), but by the time the bass are 3 months old, *Neomysis* is the dominant dietary item (Stevens 1966). Seasonal abundances of young threadfin shad and of *Neomysis* appear to control the diet of young striped bass, with larger individuals getting progressively better able to catch shad even at low densities (Figure 41; Stevens 1966). In their first year striped bass eat invertebrates almost exclusively. By their second fall (when shad are abundant and *Neomysis* are scarce) their diet is half fish, but it returns to almost 90% *Neomysis* when that prey is abundant. This pattern continues through the next two falls but with a general increase in the use of fish at all seasons. Within the delta *Corophium* are sometimes a significant portion of the diet (Stevens 1966).

For many years there was a close relationship between spring outflows and reproductive success of striped bass (Turner and Chadwick 1972) and

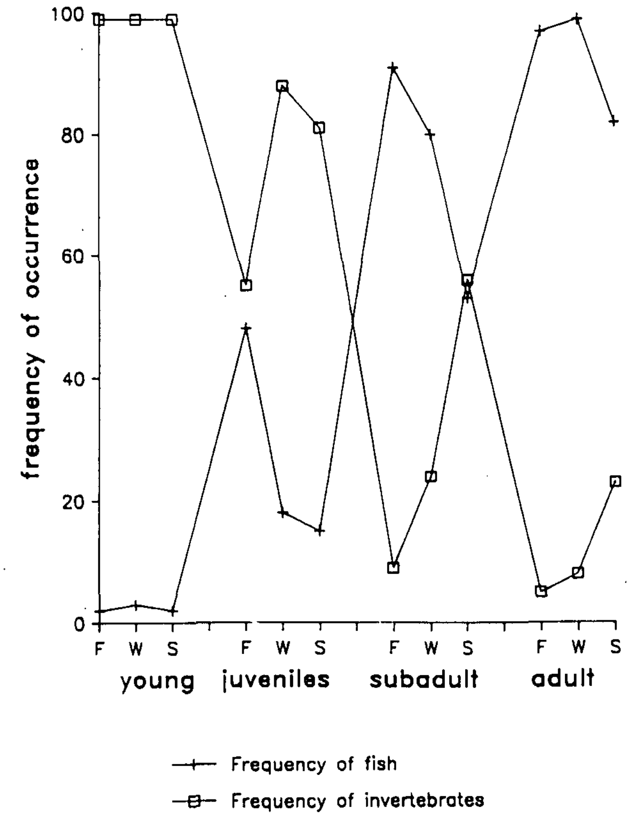

Figure 41. Contributions of vertebrate and invertebrate prey to the diets of four size classes of striped bass across seasons of differing abundances of *Neomysis mercedis*, the most common invertebrate prey. *Neomysis mercedis* is least abundant during the fall season (F) and most abundant during the spring season (S). Modified from Stevens (1966).

between spring outflows and the survival of young (Stevens 1977a). Since the drought of 1976-77, these relationships have broken down, with the abundance of young striped bass always lower than expected. Many reasons have been proposed for the lowered production but those now seriously considered (Stevens et al. 1985) are as follows:

(1) Adult populations have declined to levels insufficient to produce enough eggs to permit population growth. The principal objection to this theory rests on the observation that average fecundities of individual fish are 0.5 million eggs and can be as high as 2 million (Moyle 1976). Inherent in this objection is the assumption that young striped bass are controlled by density-dependent processes, so that fewer young imply greater survival rates. Entrainment in water diversions and toxic effects of chemicals on the environment are two density-independent factors that may kill many young striped bass in the delta. An additional objection to the role of limiting adult population size is the observation that the initial introduction consisted of a much smaller population than currently available. This overlooks the substantial changes in the delta since 1871.

(2) Plankton food supplies were particularly depressed following the drought and this may limit growth of young striped bass. Phytoplankton blooms in the central delta have coincided with shutdowns of the Tracy pumping plants, implicating lower residence times in the decline of productivity. Alternatively, much of the variability in striped bass abundance can be associated with variance in biological oxygen demand within the delta, and it has been suggested that better sewage treatment has reduced delta productivity. The average densities of zooplankton in the delta have not changed greatly, but calculations of densities where the striped bass begin feeding show a very marked decline. In any case, it seems evident from laboratory determinations of the food requirements of young striped bass (Daniel 1976; Eldridge et al. 1981) and recorded densities of zooplankton in the field (Daniel 1976) that the only young striped bass apt to survive are those that find themselves in unusually dense patches of prey. The size and density of such patches seem to have declined since the 1976-77 drought.

(3) Many young striped bass are lost through entrainment into water diversions. The pumping plants at Tracy, coolant intakes at power plants, and agricultural uses are the principal sites of such entrainment. On average the three main diversions take up to 300 m^3/s, 90 m^3/s, and 110 m^3/s, respectively (Chadwick et al. 1977). The concentration of young bass and bass eggs, at least in the agricultural diversions, are equal to the concentrations in the sloughs (Allen 1975). Striped bass losses were estimated to be 869 million in 1978 and 910 million in 1979.

(4) Toxic chemicals have been found in the delta at concentrations sufficient to kill striped bass (Finlayson and Lew 1983), but the occurrence of such high concentrations is probably rare.

These factors may all interact, and their effects may be exacerbated by effects of temperature and dissolved oxygen fluctuations that may limit the distribution of striped bass within the delta (Coutant 1985).

6.4 RESIDENT SPECIES

Species that do not migrate from the delta must be able to survive there year-round. The delta's conditions were formerly much more variable and harsh than the present, highly managed situation. Most native resident species are characterized by breeding biologies which minimize the impact of annual variations in delta outflows, but many are apparently sensitive to the drastic habitat changes that characterize most of the delta. Most current resident fishes in the delta are not native; most of the endemic fauna have declined in abundance or range. Native resident fishes occur primarily in the more saline habitats of the western delta or in the less productive waters of the Sacramento River, which are avoided by most of the introduced fish species.

Feeding. Unlike the introduced species, each native species has a distinctive diet or foraging mode. Splittail (*Pogonichthys macrolepidotus*) are exceptionally euryhaline compared to other cyprinids. They are distributed widely through the delta, but are particularly abundant in the western delta and Suisun Bay. Splittail are the only resident species that have been shown to be controlled by patterns of delta outflow; they spawn on flooded vegetation and presumably years of high water provide more suitable habitat (Daniels and Moyle 1983). Their barbels, large upper caudal fin lobe, and downward oriented eyes indicate that splittail are bottom browsers (Moyle 1976). Gut-content analyses show that they consume invertebrates, particularly *Neomysis* in Suisun Marsh (Herbold 1987) and amphipods or clams within the delta (Caywood 1974). Blackfish (*Orthodon microlepotus*) and hitch (*Lavinia exilicauda*) are most abundant in the lower San Joaquin River near Mossdale where concentrations of dissolved solids are frequently high, and most non-native species are rarely found (Turner 1966c). Both blackfish and hitch feed in midwater, blackfish primarily on phytoplankton or organic detritus and hitch on zooplankton (Moyle 1976). The piscivorous Sacramento squawfish (*Ptychocheilus grandis*) and the bottom-browsing Sacramento sucker (*Catostomus occidentalis*) are found more frequently in upper parts of the rivers than in the delta. Tule perch (*Hysterocarpus traski*) and prickly sculpin (*Cottus asper*) feed on bottom invertebrates, but tule perch are bottom pickers that concentrate on *Corophium* while prickly sculpins are lie-in-wait predators that feed on large invertebrates and small fish. Introduced resident fishes include: yellowfin goby, common carp (*Cyprinus carpio*), and various catfish and sunfish. The diets of these fish in the delta have not been thoroughly described but all are bottom browsers on a wide array of prey, including mysid shrimp, insect larvae, and copepods. Larger catfish are piscivorous.

Breeding. Most of the native resident species appear to breed mostly in tributaries of the delta (Moyle 1976; Wang 1986). Tule perch breed within the delta, but by giving birth to live young they minimize any impact of variations in river outflow. Similarly, prickly sculpins avoid the effects of environmental fluctuations by laying their eggs on the underside of submerged rocks or trees where the males guard the eggs (Wang 1986).

Nest building is a reproductive strategy used by some of the most successfully introduced resident species. Bullheads and catfish (family Ictaluridae) and sunfish, crappies, and largemouth bass (family Centrarchidae) all raise their young in nests. In addition, most of these species are isolated from the effects of outflow variation by living in the still waters of dead-end sloughs in the eastern portion of the delta (Turner 1966c). Two exceptions to this pattern of habitat selection are the white catfish and channel catfish. The white catfish is apparently more tolerant of dissolved solids than any other catfish, since it occurs throughout the delta and down to Suisun Bay in salinities of 8 ppt (Turner 1966c). Perhaps as a consequence of this tolerance it is the most abundant catfish in the delta, accounting for 95% of catfish caught. It also is the most popular warmwater sportfish in California (Turner 1966c). Channel catfish are more stenohaline than white catfish and are found most commonly in the larger channels of the Sacramento River. Repeated efforts were made to introduce this species from 1874 to 1940 when a self-reproducing population was finally established (Moyle 1976). The success of this introduction coincides with the construction of Shasta Dam and the greatly reduced incursion of saline waters into the delta. Yellowfin gobies lay their eggs in a burrow. In Japan this species is catadromous, moving down into more saline mudflats to spawn (Wang 1986). Yellowfin gobies are abundant in the delta, and their ecology needs more research.

Four introduced cyprinids reside in the delta, exhibiting three reproductive strategies that minimize the risks of breeding in a variable environment. Carp and goldfish do little breeding within the delta; instead they appear to migrate up the rivers to more freshwater conditions (Turner 1966c). Breeding in the delta seems to be concentrated in quieter water such as in Frank's Tract or in dead-end sloughs (Wang 1986). Both species are bottom-feeding generalists and are found most commonly in the San Joaquin River where dissolved solids concentrations are high (Turner 1966c). Fathead minnows (*Pimephales promelas*) and golden shiners (*Notemigonius crysolucas*) have probably been distributed throughout the delta as bait releases by fishermen (Wang 1986). Fathead minnows are common only in localized patches, generally in small creeks (Wang 1986). They build nests, guarded by the males, in shallow water (Moyle 1976; Wang 1986). Golden shiners are more widely distributed, usually occurring in still water in association with centrarchids. They exhibit no parental care or migration but frequently safeguard their eggs by laying them within the nests of centrarchids (Wang 1986).

Shad. Threadfin shad breed by broadcasting their eggs and milt. Their high fecundity and rapid growth compensate for the presumed high mortality of eggs. The breeding season in the delta is prolonged (Wang 1986); this may permit the population to reproduce successfully in the face of any variation in flow. Threadfin shad eat copepods and cladocerans (Moyle 1976) and are eaten extensively by striped bass, largemouth bass, and other centrarchids (Kimsey and Fisk 1964). The threadfin shad is one of the most numerous fish species in the delta.

Smelt. Delta smelt and longfin smelt are native planktivores which are similar in their breeding biology but differ greatly in their response to outflow conditions. Between 1967 and 1978 longfin smelt in the delta varied in abundance by a factor of 450, while delta smelt in the same period varied only by a factor of 5.3 (Stevens and Miller 1983). In recent years, however, the delta smelt population has plummeted (Figure 42). Both species migrate into the delta in winter and lay their adhesive eggs between December and May, but delta smelt tend to spawn later than longfin smelt (Radtke 1966).

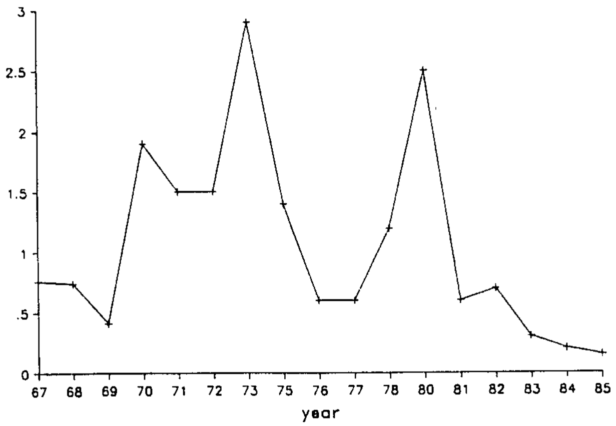

Figure 42. Mean catch of delta smelt per trawl across 17 years. Data are from trawls performed by California Fish and Game in the course of regular sampling of striped bass abundance.

Longfin smelt abundance is closely correlated with outflow for all months from February to September, while delta smelt abundance is not significantly correlated with outflow of any month (Stevens and Miller 1983). Diets of the adults of these two species show little overlap; longfin smelt eat predominantly *Neomysis*, whereas delta smelt eat mostly copepods and cladocerans (Moyle 1976). Delta smelt distribution seems to be tied to the presence of the entrapment zone; there is a significant correlation between the catch of delta smelt in midwater trawls and intermediate conductivities of water in the area where the trawls were made (Herbold 1987).

Centrarchids. A variety of sunfish, crappie, and black bass reside in the delta year round, principally in dead-end sloughs. Bluegill, the most abundant sunfish in the delta, and the less abundant green sunfish are widely distributed. Warmouth are more restricted to dead-end sloughs and the western delta (Turner 1966b; Sazaki 1975). Although 1963-64 surveys reported no redear sunfish, Sazaki found them in the northeastern delta in 1974, while surveys in 1984-85 found them to be more abundant and more widely distributed within the waters of the Sacramento River (California Department of Fish and Game 1987).

Both black crappie and white crappie occur in the delta but black crappie are much more abundant, particularly in the western delta (Turner 1966b; Sazaki 1975). Largemouth bass are the dominant black bass of the delta with smallmouth bass restricted almost entirely to the easternmost delta waters. As with the other centrarchids, the black basses are most often found in the still, rich waters of dead-end sloughs.

CHAPTER 7. REPTILES AND AMPHIBIANS

All amphibians found in the delta (Table 6) occur predominantly in the marsh or riparian habitats, except for California slender salamanders (*Batrachoceps attenuatus*) and arboreal salamanders (*Aneides lugubris*) which occur in upland habitats. Bullfrogs (*Rana catesbeiana*), an introduced species, are now abundant and widely distributed.

Massive hunting efforts to supply San Francisco restaurants with frog legs in the late 1800's decimated populations of native red-legged frogs (*Rana aurora*), which were formerly abundant in the Central Valley. Only the female red-legged frogs were of sufficient size to interest the froggers, and this may have prompted the introduction of bullfrogs because both sexes are of sufficient size (Jennings and Hayes 1985). The effects on reproduction were much more severe, therefore, on red-legged frogs than on bullfrogs. This disparity in selection pressure may have contributed to the subsequent domination of the valley by bullfrogs (Hayes and Jennings 1986). Predation by introduced fishes probably also played a large role in reducing populations of the red-legged frogs (Moyle 1973).

Table 6. Amphibians of the Sacramento-San Joaquin delta and their distributions within habitat types. Modified from U.S. Army Corps of Engineers (1979) and Rollins (1977). Habitat abbreviations: Aq=Aquatic, Ag=Agricultural, M=Marsh, R=Riparian, Up=Upland, and Ur=Urban.

Common name	Species	Habitat	Abundance
Bullfrog	*Rana catesbeiana*	R,M,Up	Common
Red-legged frog	*Rana aurora*	R,M,Up,Ag	Rare
Foothill-yellow-legged frog	*Rana boylei*	R,M,Up	Uncommon
Pacific tree frog	*Hyla regilla*	R,M,Up,Ag	Common
Western spadefoot toad	*Scaphiopus hammondi*	R,M,Up,Ag,Ur	Common
Western toad	*Bufo boreas*	R,M,Up,Ag,Ur	Common
Tiger salamander	*Ambystoma tigrinum*	R,M,Up	Uncommon
Yellow-eyed salamander	*Ensatina escholtzi xanthoptica*	R,M,Up	Occasional
California slender salamander	*Batrachoceps attenuatus*	Up	Occasional
Pacific giant salamander	*Dicamptodon ensatus*	R,M	Occasional
Arboreal salamander	*Aneides lugubris*	Up	Uncommon
California newt	*Taricha torosa*	R,M,Aq	Common
Rough-skinned newt	*Taricha granulosa*	R,M,Aq	Occasional