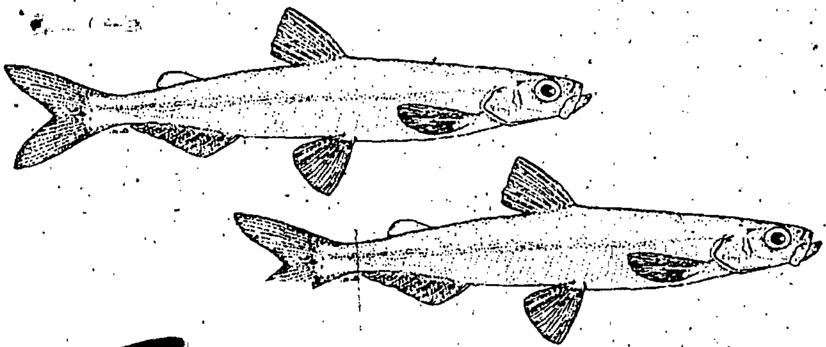
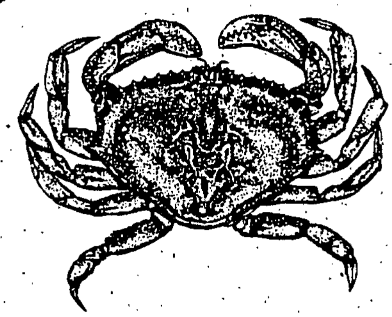




[redacted]

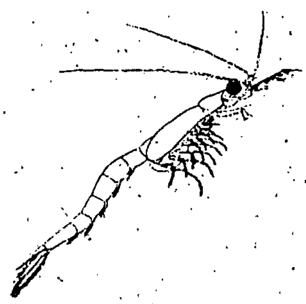
STATUS AND TRENDS REPORT

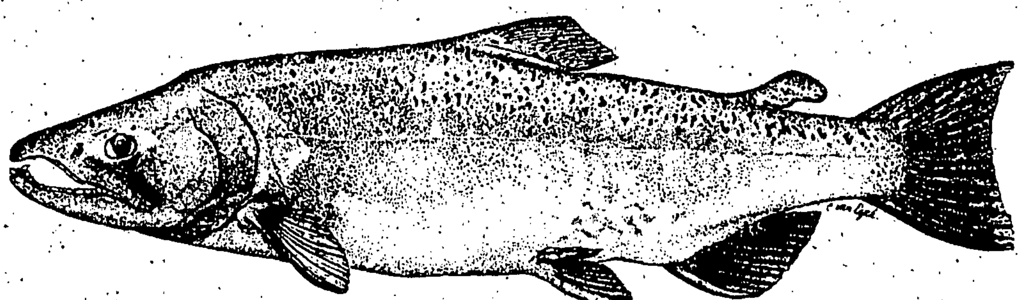
ON

AQUATIC RESOURCES

IN THE

SAN FRANCISCO ESTUARY





San Francisco Estuary Project

Mailing address:
P.O. Box 2050
Oakland, CA
94604-2050
(510) 464-7990
Fax: (510) 464-7979

Street Address:
Joseph P. Bort MetroCenter
101 8th Street
Oakland, CA
94607-4756

4.5.2 Crustaceans

Crustacean zooplankton have been the subject of much more study in Suisun Bay than any other area because of the importance of opposum shrimp (*N. mercedis*) as a principal food of young striped bass (Turner 1966a; Siegfried and Kopache 1980; Knutson and Orsi 1983; Orsi and Mecum 1986; Orsi et al. 1991). Studies describing copepod species and documenting their distribution have also contributed to general understanding of trophic dynamics in the Estuary (Orsi et al. 1983; Ferrari and Orsi 1984; Orsi and Mecum 1986). Laboratory studies arising from field observations have examined factors affecting the links between trophic levels (Meng and Orsi 1991).

Studies of plankton in the Delta and in the Lower Bay have been much more scarce. The only recent publication describing Delta zooplankton was that of Orsi and Mecum (1986) which ended with a recognition that invading species of copepods had drastically changed the zooplankton community from what they were describing. Evidence presented to the State Water Resources Control Board hearings (CDF&G 1987d) described long-term trends in Delta zooplankton through 1985. Very little has been published on riverine plankton, and what little has been done focussed more on phytoplankton (Greenberg 1964). Analyses of recent Delta zooplankton data are in preparation (Orsi et al. 1991). Zooplankton in Central, South, and San Pablo bays were described on the basis of the years 1978-1981 (Hutchinson 1981a, 1981b, 1982a, and 1982b; Ambler et al. 1985). Zooplankton distribution and population dynamics in coastal waters near San Francisco Bay have been studied as part of intensive studies of Dungeness crab biology (Hatfield 1983a; Reilly 1983).

4.5.2.1 Cladocera

Cladocera, or water fleas (Figure 10), are often the most abundant crustaceans in fresh water. Most species are widely distributed throughout large areas, including all of the species reported from the Sacramento-San Joaquin Estuary. Typically, cladoceran populations show strong seasonality in abundance and pronounced changes in reproductive habits in different seasons. During the warmer months of the years reproduction is by parthenogenesis and the females give birth to fully functional juveniles. Gestation times are around two days and generation times are usually less than one month. Thus, a population can rapidly increase under favorable conditions. Males and the larger eggs which they fertilize (called ephippia) are usually produced as temperatures

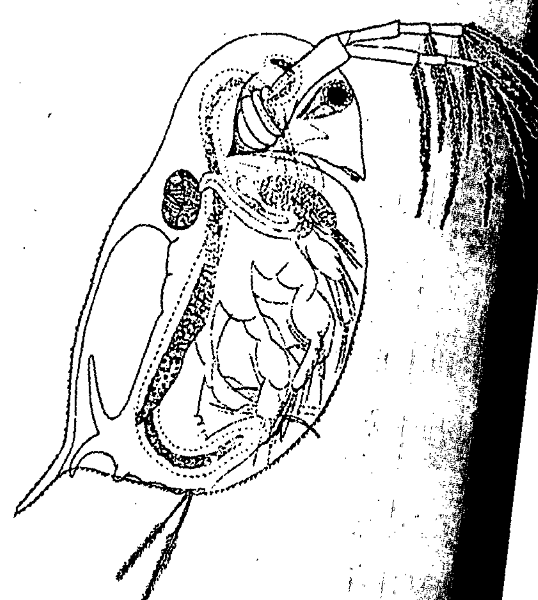


Figure 10 *Daphnia pulex*, usually
(modified from Pennack 1953)

and photoperiods decline. The fertilized ephippia sink to the bottom and are the primary method of overwintering for these animals. Ephippia are resistant to desiccation and, by passive attachment to waterfowl, are responsible for the wide distribution patterns of most Cladocera. Various morphological features of the ephippium appear to facilitate dispersal by fish or waterfowl (Dodson and Frey 1991). Once in a suitable habitat, the ephippium develops into a parthenogenetically reproducing female. Thus, successful colonization of a new habitat can be accomplished by transport of a single ephippium.

Cladocera swim by sudden contractions of their antennae and are efficient feeders on a wide variety of materials from throughout the water column, including phytoplankton, bacteria and colloidal suspensions. They are widely recognized as an important level for food chains in the upper portions of estuaries (Haertel and Osterberg 1967).

Cladocera seldom occur in abundance in areas where salinity is greater than 1 ‰ ([electrical conductivities] EC > 600 μS/cm), and are therefore more abundant in waters of the Delta than in Suisun Bay. All cladocerans have the bulk of their populations at conductivities under 1000 μS/cm and there is no apparent separation of the genera by conductivity within the small range within which they all live (Figure 11). Of the three most commonly collected species of Cladocera, *Bosmina longirostris* is the most abundant species throughout the Delta, *Daphnia pulex* (with *D. schodleri* and *D. galeata*) is less abundant and more of its population is found within a narrower range of salinities, *Diaphonosoma leuchtenbergianum* is least abundant but a larger proportion of its population is found at higher conductivities (Figure 11). *Bosmina* is the most widely distributed genus, occurring in measurable densities in Suisun Bay in all but two of the years since sampling began in 1972 and in 6 of the 10 years of sampling in Carquinez Strait (unpublished data CDF&G). Abundance of *Bosmina* may be partly controlled by the abundance of the predaceous shrimp *N. mercedis* (Orsi and Mecum 1986). *Daphnia* also has been found in Suisun Bay in all but two years of the sampling, but it occurs at extremely low densities (less than 10 per cubic meter in half of the years. *Daphnia* was found at Carquinez Strait in only 4 of the 10 years of sampling there, almost solely during periods of high Delta outflow. Densities of all three species are highly correlated with temperature and, excluding *Diaphanosoma*, with chlorophyll *a* concentration (Orsi and Mecum 1986). These associations with temperature conform to the greater abundance of all species in the San Joaquin River, because it is generally warmer than the Sacramento River and supports higher densities of phytoplankton (Orsi and Mecum 1986). *Diaphanosoma* has the most restricted distribution of the three abundant native cladocerans; it has never been collected in samples taken at Carquinez Strait, and when collected in Suisun Bay its mean density has never exceeded 45 per cubic meter.

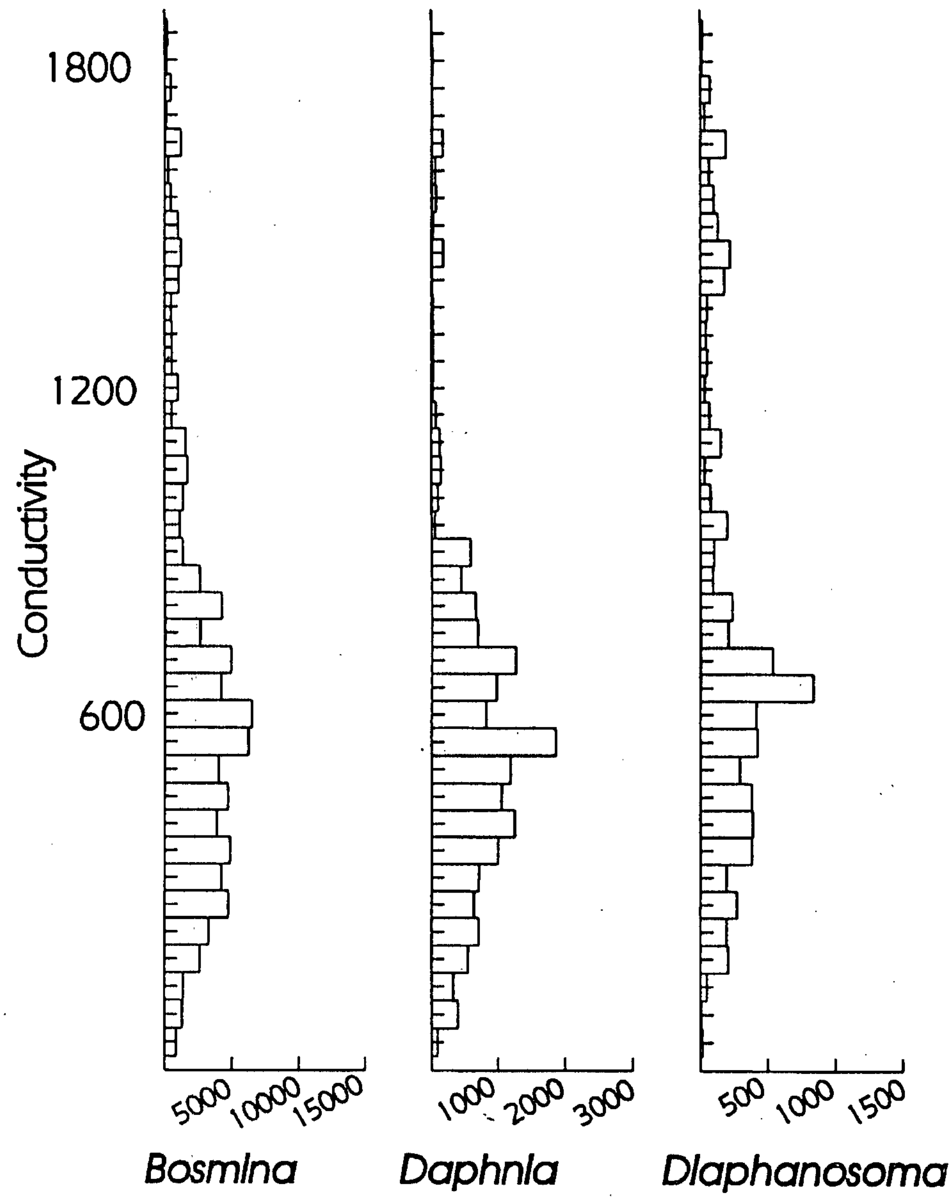


Figure 11 Mean catch (no. per cubic meter) of three species of Cladocera at different ranges of conductivities (μS/cm). (data from CDF&G).

Average densities of cladocerans have shown a long-term decline in abundance similar to that of the rotifers. The decline in cladocera is apparent in most genera except *Bosmina* and varies within different parts of the estuary. The decline in Cladocera appears to have been more sudden, occurring in the late 1970s as the rotifers in the Delta reached the end of their period of decline. Population densities have remained at rather constant low levels, but the lowest values for the three most abundant species all occurred in 1982-1983. A small recovery in abundance in all three taxa occurred through 1984-1986, but in recent years they have returned to extremely low levels.

Examination of the patterns of abundance of cladocerans through time for areas dominated by Sacramento River water, San Joaquin River water, and Suisun Bay shows the importance of outflow on cladoceran abundance and distribution. The sustained very high outflows of 1983 produced peak abundances of most cladoceran genera in Suisun Bay (Figure 12), although even these peaks are much smaller than the usual densities encountered upstream (Figures 13 and 14). The moderately high outflows of 1986 produced peaks in abundance for all genera within the Delta but had little effect on Suisun Bay populations. *Bosmina* is the most common genus of cladoceran and shows the smallest proportional change in abundance through time; the less abundant *Daphnia* and *Diaphanosoma* show much greater declines in abundance following 1977.

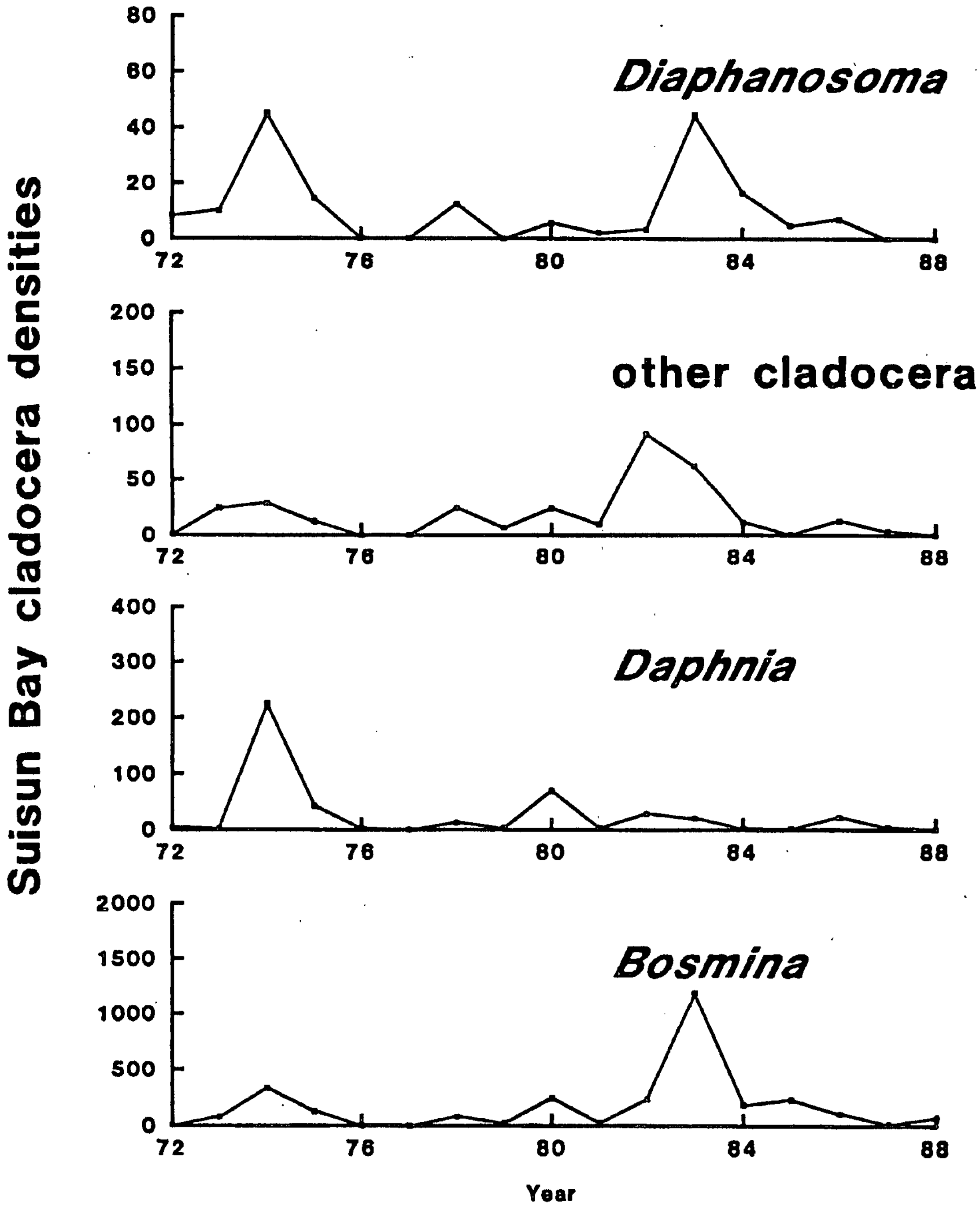


Figure 12 Mean densities of the three most abundant species of cladocerans in Suisun Bay (no./ per cubic meter). Data provided by CDF&G.

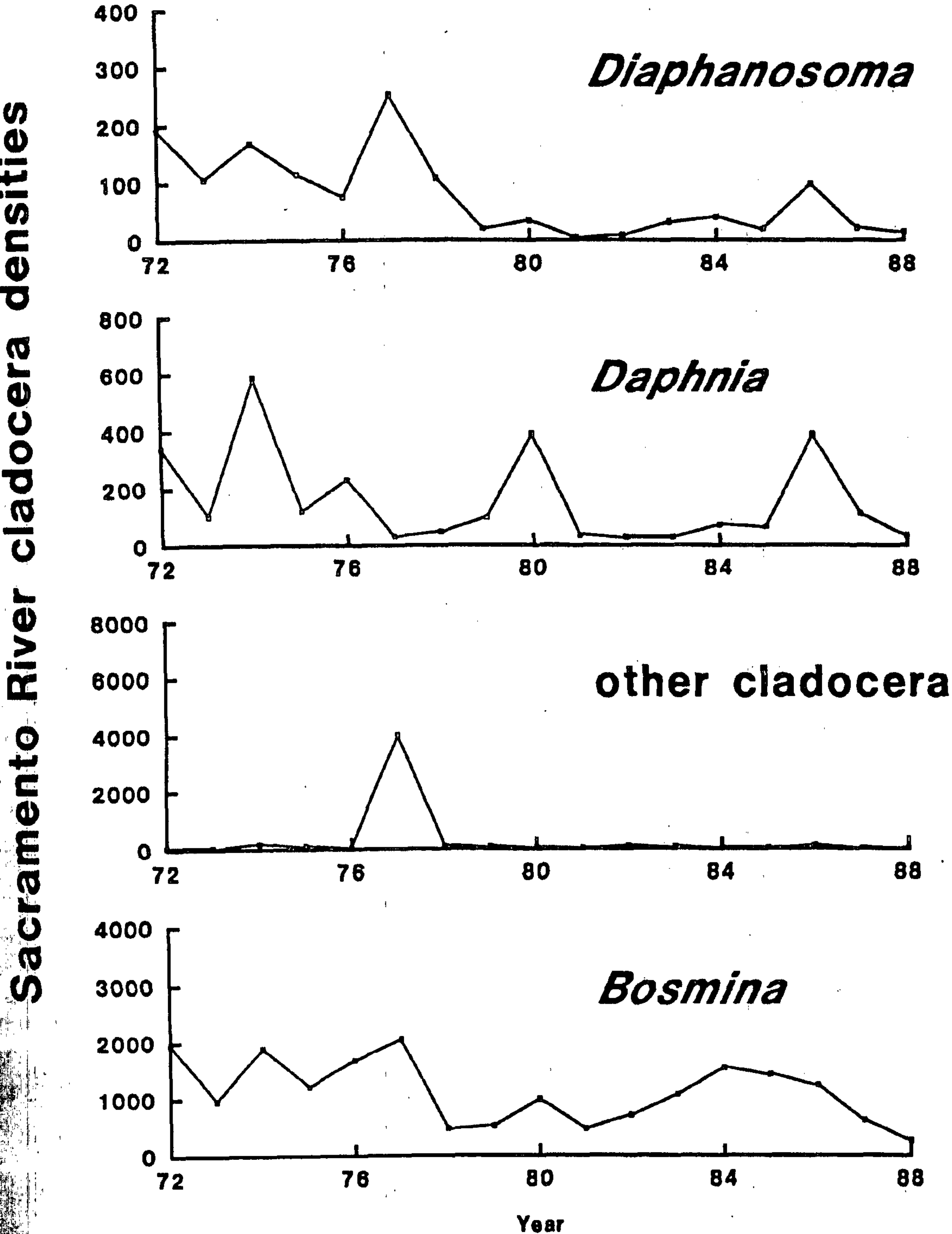


Figure 13 Mean densities of the three most abundant species of cladocerans in the Sacramento River (no./ per cubic meter). Data provided by CDF&G.

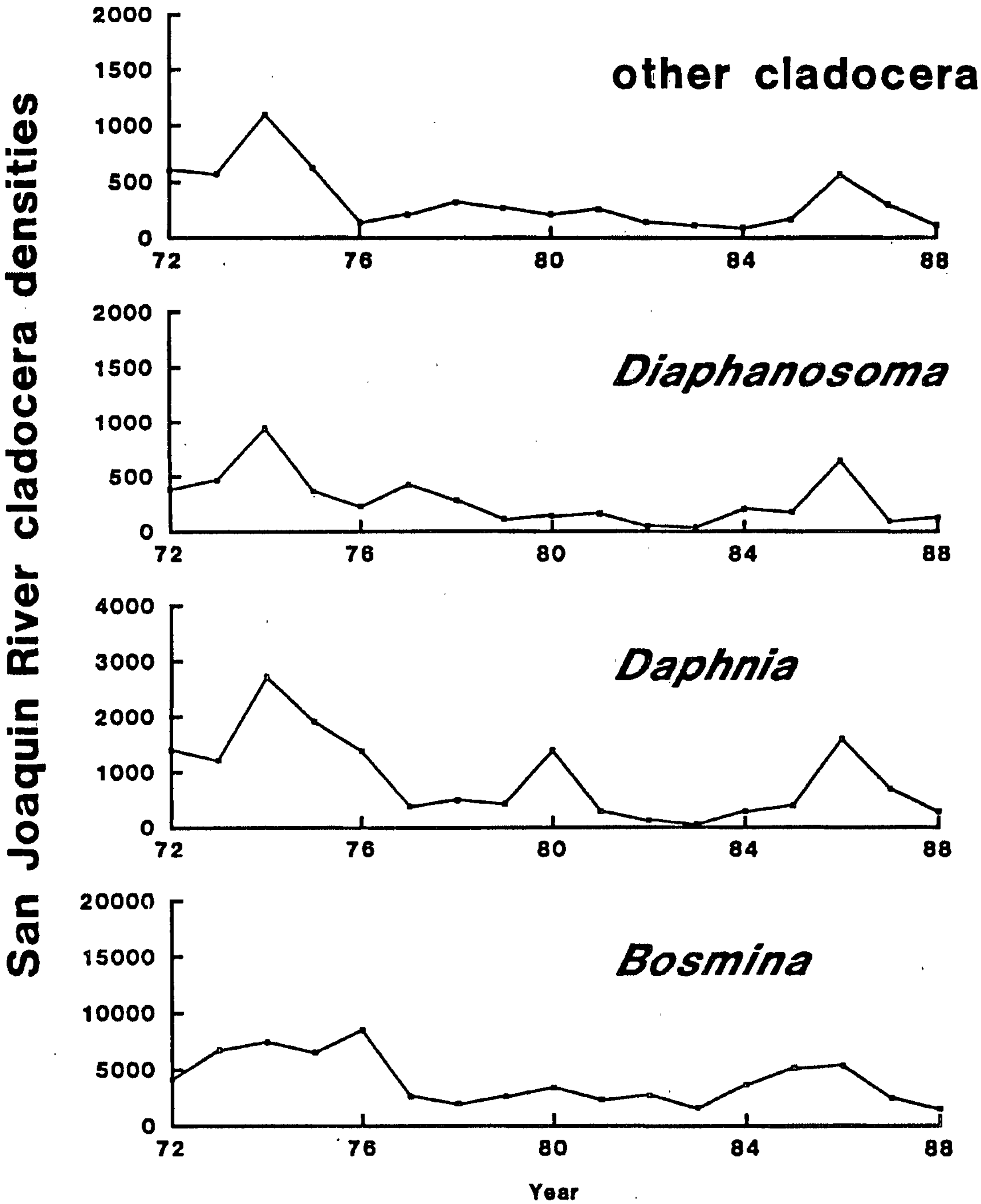


Figure 14 Mean densities of the three most abundant species of cladocerans in the San Joaquin River (no./ per cubic meter). Data provided by CDF&G.

4.5.2.2 **Copepoda**

Copepods are small crustaceans (Figure 15) that feed and live in the water column like Cladocera but which are evolutionarily derived from oceanic animals so that their greatest diversity and abundance is in salt water. Harpacticoid copepods are predominantly benthic copepods and are not sampled very efficiently in studies of zooplankton. Calanoid copepods replace Cladocera in most of the Bay below Chipp's Island; Cyclopoid copepods are generally found in more freshwater habitats with Cladocera. Calanoid copepods swim in a slow, smooth gliding pattern by movements of their mouthparts occasionally punctuated by sudden jerks propelled either by the same mouthparts or by their legs and antennae. Cyclopoid copepods move by a series of leaps propelled by flattened appendages on the abdomen and their first antennae, followed by a period of passively sinking (Williamson 1991). Cyclopoids respond to disturbance by escape responses that may involve hops at velocities up to 4 times that used in normal locomotion. Copepods are the primary food for many small fish in the Estuary, including larval striped bass.

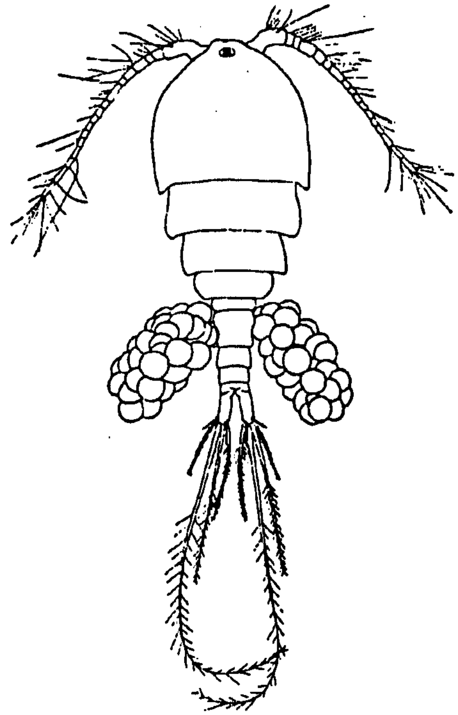


Figure 15 Typical cyclopoid copepod, 1-2 mm., with egg sacs. (Modified from Pennak 1953)

All copepods in the Estuary are sexual and cannot reproduce parthenogenetically, unlike the rotifers and water fleas. However, females store sperm so a single mating can allow a female to produce a series of fertilized eggs (in the Calanoidea) or of eggsacs (in the Cyclopoidea). Development and incubation are generally rapid with sexual maturity attained within one or two weeks in most species and with hatching of eggs taking from 12 hours to 5 days. After hatching young copepods go through a series of molts as nauplii similar to some other crustacea and a further series of copepodid stages which resemble the adult. Declining temperatures and shortening photoperiods may prompt the production of thicker shelled, over-wintering eggs or larval stages may form cysts and fall to the bottom. Similarly, cyclopoids may also encyst at high water temperatures during the summer. Although most copepods are widely distributed, the lack of a specialized dispersal stage, like the cladoceran's ephippium, has apparently led to most freshwater and estuarine species being somewhat less widely distributed than most species of Cladocera. However, recent introductions of several species of copepods argues that larger cargo ships, with vast quantities of ballast water, have permitted widespread dispersal of coastal copepods. The abundance of exotic copepods in the estuary coincides with the change in trans-Pacific shipping to larger, canister carrying ships in the late 1970s.

In the Sacramento-San Joaquin estuary the abundant native copepods are sharply separated primarily by salinity (Figure 16) and season (Ambler et al. 1985). Figure 16 illustrates the distribution of catch from all collections averaged over the conductivities of the water where they were taken; abundance of a species at a particular station will depend on location, season, and amount of flow into the Bay. Note the much larger range of conductivities represented for copepods (in Figure 16) than for Cladocera (in Figure 11). The genus *Acartia* contains two species (*A. californicus* and *A. calussi*) which undergo complementary seasonal successions of abundance in South Bay (Ambler et al. 1985). Another species of the lower Bay (*Oithona davisae*) is not included in the figure but peaks in abundance in the autumn (Ferrari and Orsi 1984). In the late 1970s and 1980s populations of invading species, unintentionally introduced from China, *Sinocalanus doerri, Limnoithona sinensis*, and *Pseudodiaptomus forbesi* rapidly increased in abundance. Native copepods, particularly *Eurytemora affinis*, suffered large declines in abundance while these species have increased in abundance (Orsi et al. 1983; Orsi and Mecum 1986). In the Delta the dominant copepod genus was formerly *Cyclops* but is now *Pseudodiaptomus*.

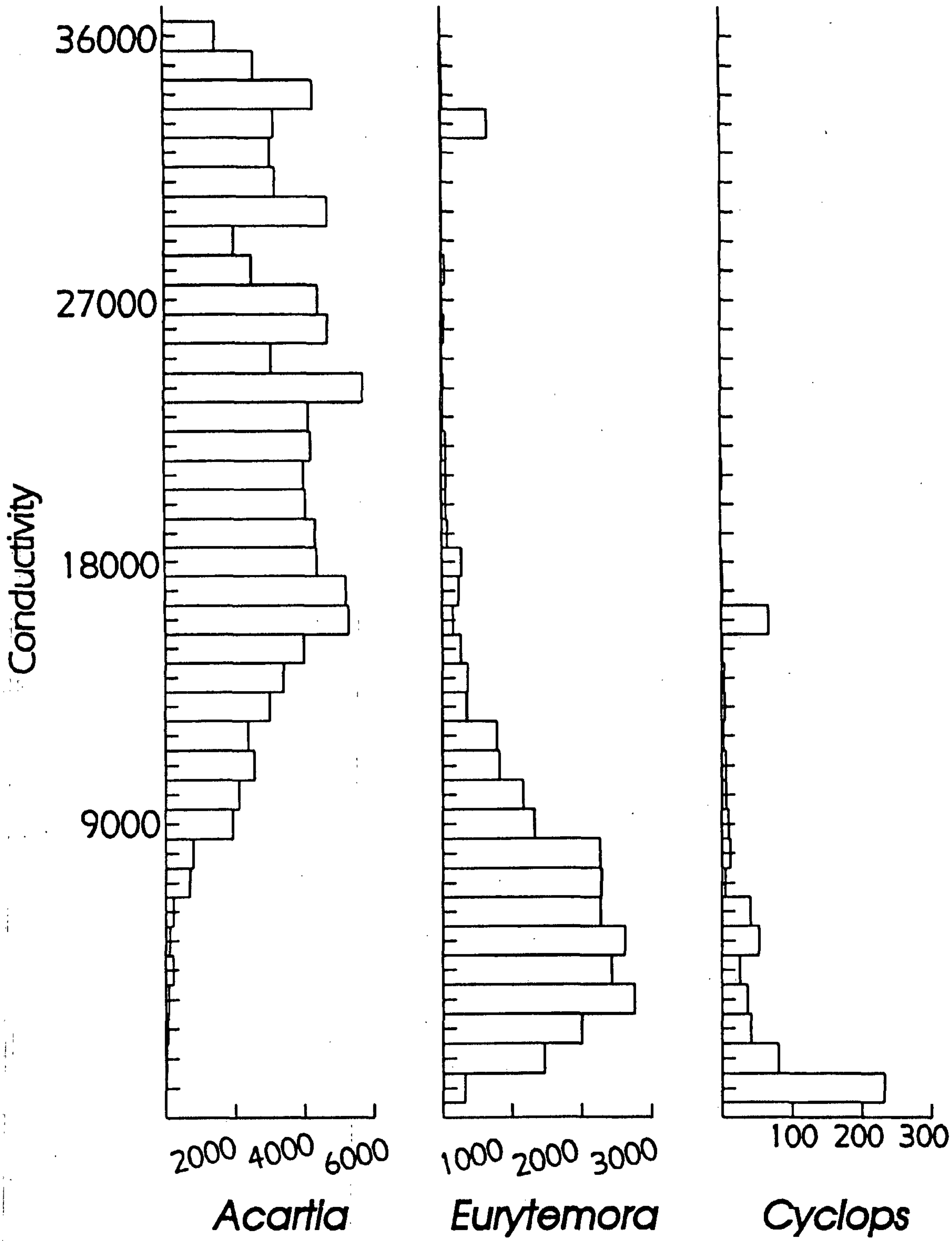


Figure 16 Mean catch (#· m^{-3}) of three species of Copepoda at different ranges of conductivities (μS/cm). Data provided by CDF&G.

Most species of copepods have undergone severe, long-term declines in abundance (CDF&G 1987b). Only the marine species *Acartia* shows no evidence of a trend through time. This species is least abundant in the sampling area during years of high outflow and is usually most abundant when salinity in Suisun Bay is greatest (CDF&G 1987b). Invasion of the western Delta and Suisun Bay by *Sinocalanus doerri* in 1978 and by *Pseudodiaptomus forbesi* in 1987 was followed by declines in the abundance of *Eurytemora affinis* and the almost complete elimination of *Diaptomus spp.* (CDF&G 1987b; Meng and Orsi 1991). Most copepods, including *Acartia*, have been at record low abundances in Suisun Bay since the arrival and explosive spread of the clam *Potamocorbula amurensis*.

Analysis of the dominant native copepod species in waters of the Sacramento River, the San Joaquin River, and Suisun Bay shows that the decline is sharpest in the rivers (Figures 17, 18, and 19). *Eurytemora*, overall the most abundant copepod in both rivers, declined in abundance in 1978 and has remained generally below average densities of 500 l^{-1} whereas in 4 of the 6 earlier years its average density exceeded 1000 l^{-1}. *Cyclops vernalis* and *Diaptomus spp.* show sharp declines through the 1970s in both rivers, although the *Diaptomus* decline stretches out to 1981 while *C. vernalis* was extremely rare by 1977. Both species showed a short-lived return to high density following the high outflows of February 1986. These mean densities are not adjusted for salinities, and simple changes in water quality due to low inflows may be adequate explanation for the declines.

The introduced copepods, *Limnoithona sinensis* and *Sinocalanus doerri*, are predominantly found in fresh water. Due to increases in the abundances of these species the average densities of copepods in each river are still high in most years (Figure 20). The simple replacement of native species by exotics is not a complete picture because *Sinocalanus doerri* inhabits stations further upstream than those occupied by the formerly abundant *Eurytemora affinis* (Orsi et al. 1983), so measures of average abundance are inflated by the greater range of the introduced species. Nonetheless, densities of native copepods are markedly lower in areas where introduced copepods are now abundant. Striped bass larvae prey more easily on native copepods than on introduced species, at least some of which have more effective escape responses (Meng and Orsi 1991). The introduced *Sinocalanus doerri* may be an additional predator on native copepods, as *S. tenellus*, a related species, has been shown to be an effective predator on nauplii (Hada and Uye 1991).

Within Suisun Bay only *E. affinis* shows a consistent pattern of decline through time, and the decline is not as severe as at upstream sites. The most abundant copepod in Suisun Bay, *Acartia*, showed increased abundance in dry years until recently. As in the rivers, *C. vernalis* fell to very low numbers in 1977 but was increasing to its former levels until 1987. All species in Suisun Bay were at extremely low abundances in 1988, when *Potamocorbula amurensis* was at high densities and chlorophyll *a* concentrations failed to attain their usual seasonal peaks. Introduced species of copepods are generally not a large part of the populations in Suisun Bay, but generally increase in abundance there in response to periods of high outflow (Orsi et al. 1983).

Suisun Bay (Figure 19) usually supports copepod densities about twice those found in the Delta (Figure 17 & 18). Average densities in Suisun Bay range from 2000-10,000 l^{-1} while the average densities at river sites are usually between 1,000 and 4,000 l^{-1}. Although downstream transport of copepods is thought to be important in controlling the abundances of freshwater forms in downstream areas (Orsi et al. 1983; CDF&G 1987d) there is not an inverse relationship of copepod abundance in the different regions in wet years. The high flows of 1983 led to low abundances in all regions whereas the high flows of spring 1986 did not lead to any apparent shift of the populations downstream.

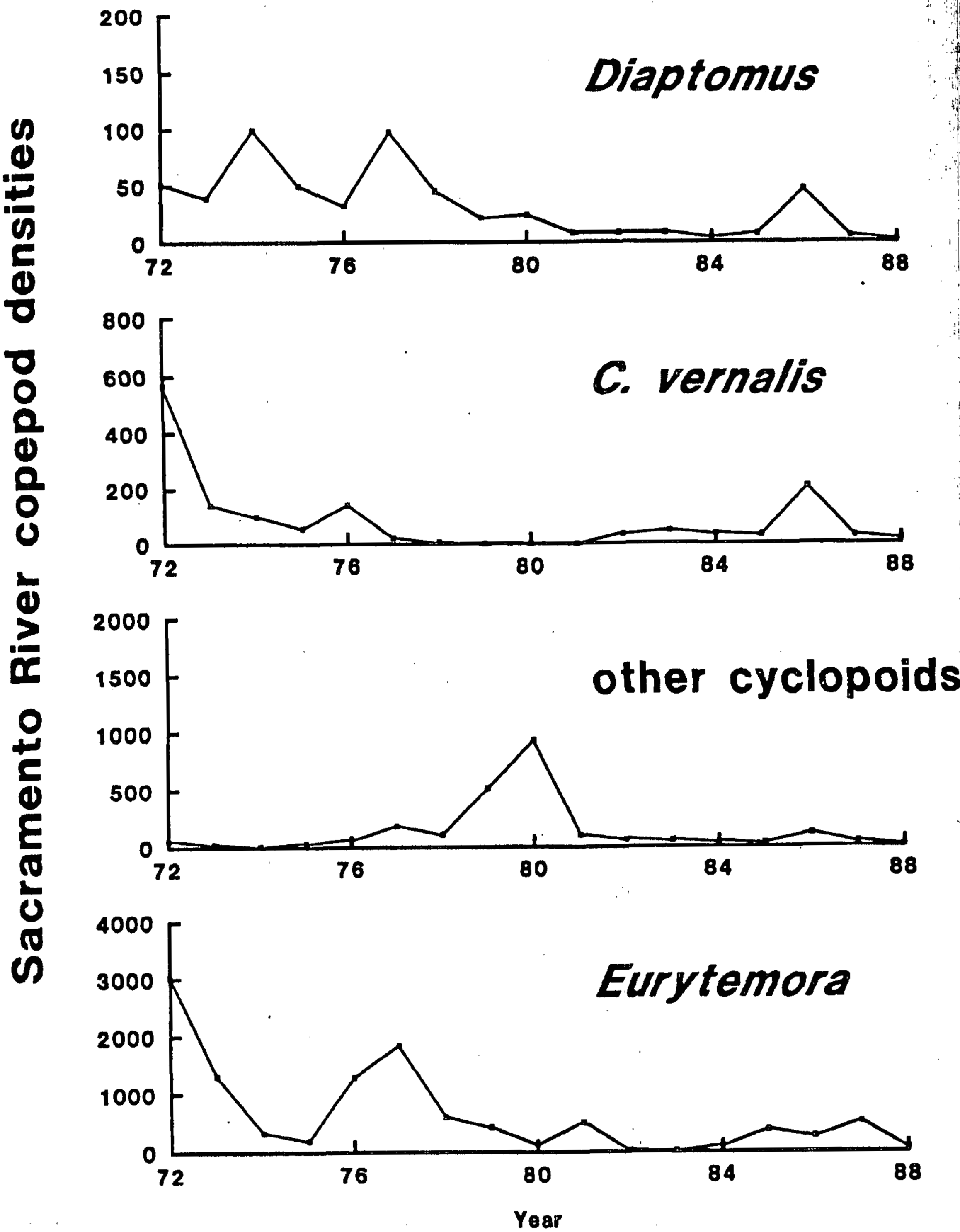


Figure 17 Mean densities of the four most abundant species of copepods in the Sacramento River (no./ per cubic meter). Data provided by CDF&G.

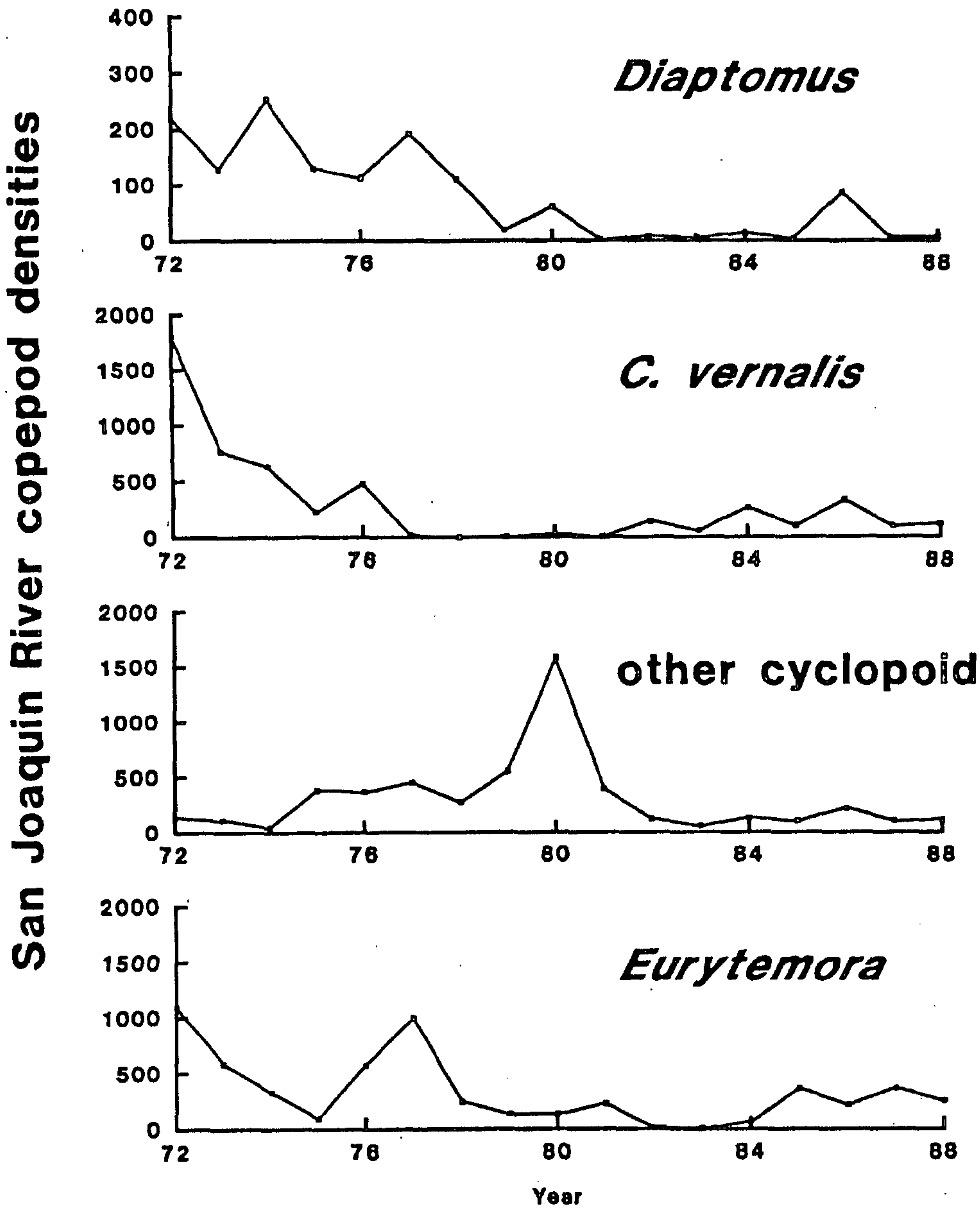


Figure 18 Mean densities of the four most abundant species of copepods in the San Joaquin River (no./ per cubic meter). Data provided by CDF&G.

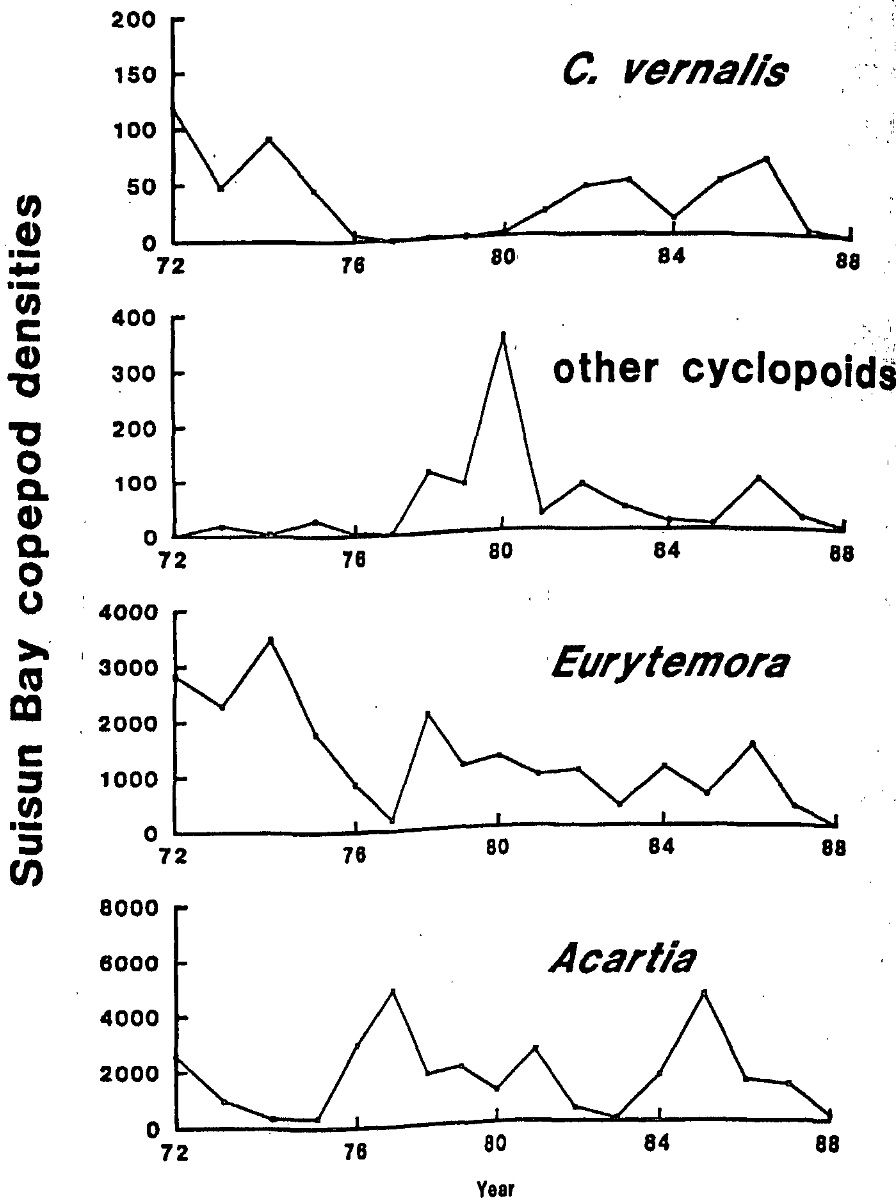
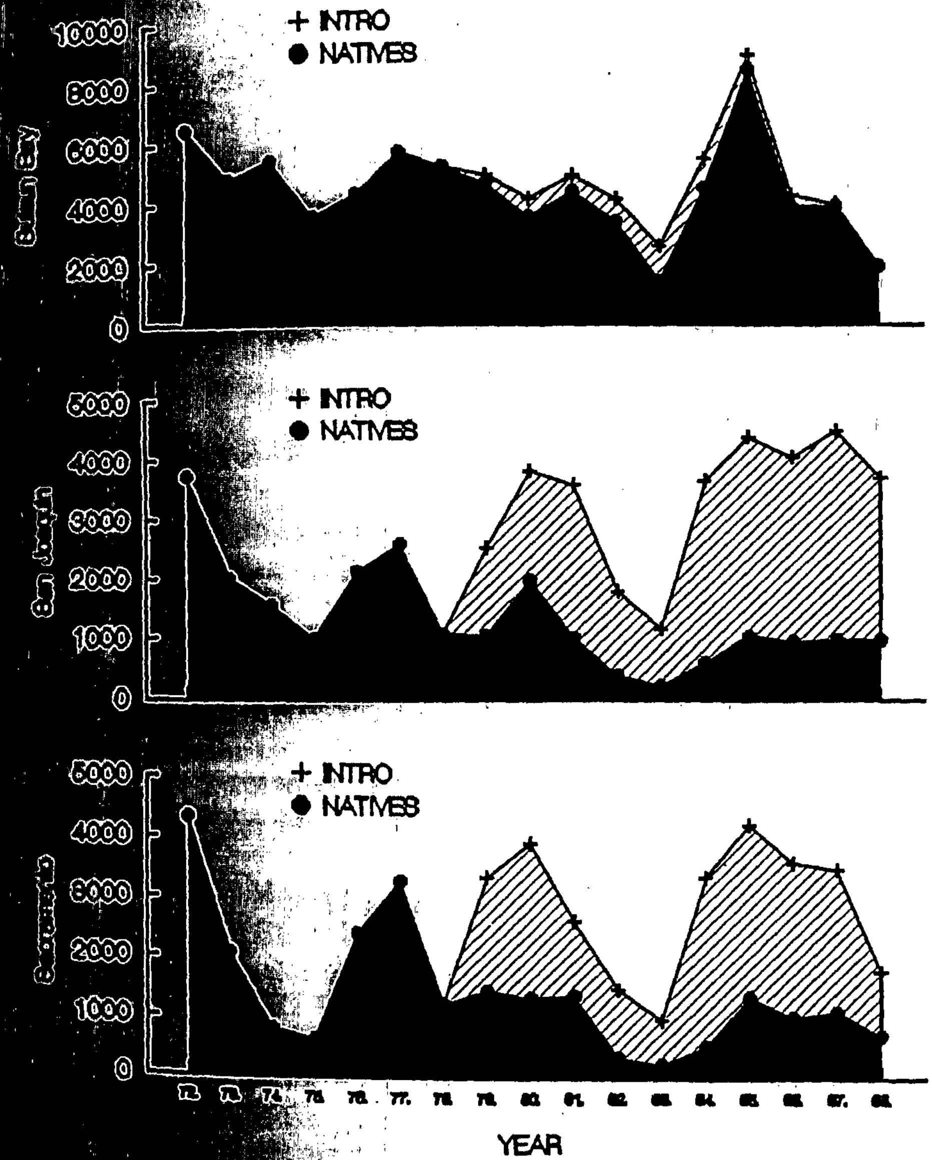


Figure 19 Mean densities of the four most abundant species of copepods in Suisun Bay (no./ per cubic meter). Data provided by CDF&G.



...parison of densities (mean number per cubic meter) of native and
...pods in three areas: Sacramento River, San Joaquin River, and Suisun Bay
... by CDF&G)