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Interagency Ecological Program for the Sacramento-San Joaquin Estuary

Newsletter

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Sierra Nevada Runoff into San Francisco Bay — Why Has It Come Earlier Recently?

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By the time most of the Sierra Nevada snowpack has melted each summer, freshwater outflows from the Sacramento-San Joaquin Delta to San Francisco Bay are typically small, even after the wettest winters. These small delta outflows during the warm months (in comparison with the large flows of winter and spring) are overwhelmed by salty coastal waters, and the bay becomes more and more salty as summer progresses. Because longer low-flow seasons allow the bay to become saltier, timing of the Sierra Nevada snowmelt and runoff, which are the source of the delta flows, has a profound influence on the salinity of the bay and, thus, can affect its ecosystems (Peterson *et al* 1995).

Consequently, a recent tendency toward earlier snowmelt and runoff — described in this article — is a matter of concern. Is it a symptom of global warming? Is it a response to local or regional urban heat-island effects? Or is it just a normal part of the variability of California's hydrology? These possibilities raise concerns also about how much earlier the low-flow seasons in San Francisco Bay might begin in the future if the observed trends continue and how well the bay ecosystems will be able to cope with the flow-timing changes.

The "earlier runoff" trend was first noted by Maurice Roos, DWR, in 1987 (Roos 1987). Although it has much year-to-year variability, the runoff-timing trend can be detected by eye (Figure 1a) and is significantly different from random-chance occurrences according to a range of statistical tests (Dettinger and Cayan 1995). Since early in the century, the average April-June fraction of annual runoff has diminished from almost 50% to less than 40%. The trend toward smaller late-spring and early-summer fractions of each year's streamflow from the Sierra Nevada is shown in Figure 1a. This trend has been compensated for by a subtler set of opposite trends toward more winter and early-spring streamflow during the same period. The influence of these monthly trends on the overall timing of streamflow in the American River near Sacramento is shown in Figure 1b, in which the average recent flow regime is compared with the average flow regime from 30 years ago, when flows usually peaked almost a month later. Inspection of a large collection of streamflow records indicates that similar changes occurred throughout much of the western United States. A clue to their origin is that in the Sierra Nevada these changes are most accentuated in middle altitudes and are muted in streamflow records representing very high (more than 2,500 m) or very low (less than 1,000 m) altitudes.

The mechanism involved in these trends is mostly a hastening of the peak snowmelt period in recent decades in response to an observed trend toward warmer Januaries, Februaries, and Marches in the Sierra Nevada (Figure 2). Actually, this temperature influence is somewhat surprising, because historically the dominant control on seasonal runoff-timing fluctuations has been precipitation timing rather than temperature (Cayan *et al* 1993). Since the late 1940s, however, temperatures throughout the year in the Sierra Nevada have increased, with the January-March season experiencing the greatest warming, a total of about 2°F) in 50 years (Dettinger and Cayan 1995). During the same period, precipitation timing has shown little if any overall

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Radical Changes in the Estuary's Zooplankton Caused by Introductions from Ballast Water

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Copepods and mysid shrimp are crustacean plankton important as food for larval and small fish. Large changes have occurred in their abundance and species composition in Suisun Bay and the Delta since 1978 and especially since 1992. The cause is introduction of non-indigenous species from ballast water of ocean-going ships. Such introductions, first detected in 1978, became frequent in 1992-1993, when 3 copepods and 2 mysid shrimp were introduced (Table 1). The spate of introductions in 1992-1993 appears related to a sharp increase in shipping at the Port of Oakland. None of the other major ports in the bays or on the rivers showed such an increase in these years.

The native copepod fauna (excluding the small, benthic harpacticoids) of Suisun Bay and the delta consisted mainly of several species of *Diaptomus* and *Cyclops* in fresh water and 3 *Acartia* species in saline water seaward of the entrapment zone. *Eurytemora affinis*, the important entrapment zone copepod, was possibly introduced along with striped bass in 1879. *Oithona davisae*, a cyclopoid copepod native to Japan, was already present in San Pablo Bay in 1963 when zooplankton sampling was first done. For some reason it did not appear in DFG Suisun Bay samples until 1979.

In 1978, the first exotic calanoid copepod to appear, *Sinocalanus doerrii* from China, apparently slipped into an unoccupied niche between the ranges of *Eurytemora* in the entrapment zone and *Diaptomus* in the San Joaquin River between the mouth of Old River and Stockton. Although *Diaptomus* species were found throughout the delta, their abundance was highest in this section of the San Joaquin River. *Sinocalanus* eventually spread to Stockton, and *Diaptomus* abundance fell to low levels. Although the range of *Sinocalanus* overlapped the upstream extent of *Eurytemora*, it had, at most, a minor impact on *Eurytemora* abundance. Since 1987, however, *Eurytemora* has been replaced in the entrapment zone by two other Chinese calanoids and in 1994 *Sinocalanus* disappeared throughout its range. *Diaptomus* abundance, however, has not shown a resurgence.

The replacement of *Eurytemora* was in part due to the introduction of an exotic clam, *Potamocorbula amurensis*, in 1986. This clam feeds on the nauplii of copepods, and *Eurytemora* nauplii appear to be particularly vulnerable. Competition with a Chinese calanoid, *Pseudodiaptomus forbesi*, introduced in 1987, may also have played a role. The replacement of *Eurytemora* has been a seasonal one; *Eurytemora* is present during winter and spring when clam grazing rates are low and when *P. forbesi* abundance is also low. In the San Joaquin River at Stockton, upstream from the range of the clam, *Eurytemora* is present until late spring when *P. forbesi* becomes very abundant. All native copepods are now most abundant in winter and spring, while summer and fall are dominated by the exotics, many of which are subtropical or even tropical species.

Pseudodiaptomus forbesi is now sharing the entrapment zone with still another Chinese exotic, *Acartiella sinensis*, introduced in 1993. This species is not abundant in fresh water and does not reach the eastern delta.

A major change in the habitat of all of these calanoid copepods has been the reduction in phytoplankton, their primary food resource, especially since the introduction of *Potamocorbula*. Phytoplankton had already been declining throughout the bay and delta since the mid-1970s, but *Potamocorbula* grazed phytoplankton to ve low concentrations in Suisun Bay an the western delta. A reduction in foo availability would not affect cop pods until a limiting or threshold lev is reached. At this level egg produc tion would decline sharply. labora tory experiments have shown tha such threshold levels are generall $<3\,\mu g/L^{-1}$ chlorophyll *a*. Such concentrations have been typical of the estuary in recent years.

In 1979, a Chinese cyclopoid copepod, *Limnoithona sinensis*, entered the estuary and became abundant. In 1993, still another *Limnoithona* species, *L. tetraspina*, appeared and by early 1994 had replaced *L. sinensis*. The abundance of *L. tetraspina* has exceeded 40,000 m^{-3}, making it the most abundant copepod we have ever seen in the estuary. Thanks to *Limnoithona*, cyclopoid copepods became more abundant than calanoids in 1992 and continued their dominance in 1993 and 1994 (Figure 1).

Table 1
NATIVE AND INTRODUCED COPEPODS AND MYSID SHRIMPS AND YEAR OF INTRODUCTION

NATIVE COPEPODS	INTRODUCED COPEPODS	YEAR INTRODUCED
Diaptomus spp.	*Eurytemora affinis*	1879?
Cyclops spp.	*Oithona davisae*	Before 1963
Acartia spp.	*Sinocalanus doerrii*	1978
Minor species	*Limnoithona sinensis*	1979
	Pseudodiaptomus marinus	1986
	Pseudodiaptomus forbesi	1987
	Acartiella sinensis	1992
	Tortanus sp.	1993
	Limnoithona tetraspina	1993

NATIVE MYSIDS	INTRODUCED MYSIDS
Neomysis mercedis	Acanthomysis aspera
Four minor species found mostly in San Pablo and San Francisco bays	Acanthomysis sp.

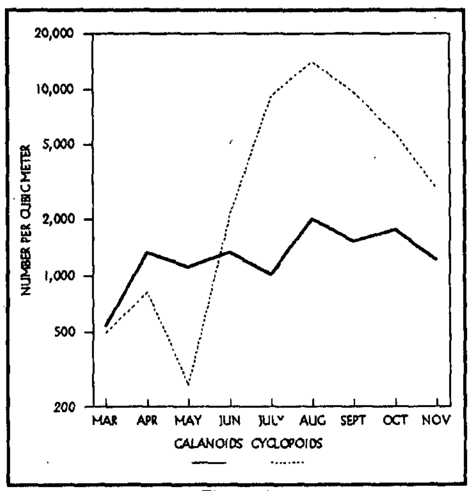

Figure 1
CALANOID AND CYCLOPOID COPEPOD ABUNDANCE IN 1994

This sudden explosion of cyclopoid copepods suggests that something has happened to the trophic status of the estuary. Cyclopoids have a different feeding mode than calanoids. They grasp particles rather than filter them from the water as calanoids do. As a consequence, they are more predacious than most calanoids. Although calanoids are also capable of predacious feeding, they are not active predators. An exception is a large calanoid, *Tortanus* sp., introduced in 1993. It is a known predator on other copepods and may have been responsible for the disappearance of *Pseudodiaptomus* in western Suisun Bay in 1994.

Food availability (phytoplankton) for calanoids has been reduced, but cyclopoid food resources may have increased. What the cyclopoids consume is unknown. The introduced cyclopoids are small — 0.6 mm long at maturity — and would not be able to feed on adult calanoids, which are generally twice their size. Even the nauplii of the calanoids should be too large. Rotifers are a possible prey item, but rotifer abundance has been declining since the late 1970s. Ciliated protozoa may be a food source, but we know nothing of the abundance of ciliates aside from protozoan counts made in 1966-1967 by the original DFG Delta Study.

Mysid shrimp have also been affected by changes in the trophic status and by introductions. The only abundant native mysid in Suisun Bay and the delta, *Neomysis mercedis*, underwent a long-term downtrend starting in the late 1970s. This decline became pronounced after 1986 and has been attributed to the reduction in the food resource for young mysids, phytoplankton. In 1992, two Asian mysids appeared in eastern San Pablo Bay and western Suisun Bay. The abundance of one, *Acanthomysis aspera* from Japan, remained low and it did not move into the entrapment zone. The other, an undescribed species of *Acanthomysis*, moved upstream during 1993, and in 1994 occupied the same range as *Neomysis* and achieved a higher abundance than *Neomysis*. The invading mysids are somewhat smaller than *Neomysis* but probably have similar feeding habits. Competition with introduced amphipods may also affect *Neomysis*.

Because of the exotic species, the abundance of native copepods and mysids is unlikely to rebound even if the estuary becomes more eutrophic. Unless ballast water dumping is controlled, more non-indigenous and possibly harmful species may arrive. These can be fish and benthos, such as the European ruffe and the infamous zebra mussel, as well as zooplankton. In January 1994, the "ballast water initiative" became law in California. This law merely asks ship masters to follow the International Maritime Organization's Guidelines for the Discharge of Ballast Water. These guidelines suggest that ballast water be exchanged in the open sea at depths >2000 meters before a ship enters a port. The assumptions are that freshwater and estuarine organisms will be pumped out of the tanks or killed by the sea water if they remain in them, and oceanic organisms pumped into the tanks will not be able to live in coastal or estuarine waters. The California law does not require ballast exchange but does require under penalty that a ballast water control form be filled out to show what the vessel master has done with his ballast. The law also provides a penalty for falsifying information on the form. However, the Coast Guard has failed to provide support for DFG, and this law has not been enforced. Ballast water dumping is still totally unregulated.

Program Revision

The Agency Directors are scheduled to meet on October 17 to review the recommended changes in the Interagency Program's monitoring and special studies elements. In this short 3-month period, staff and other interested parties must pull together into a program all the information being gathered for the revisions. Following are some of the steps and meetings underway to help accomplish this formidable task.

- Over the past few weeks, there has been a flurry of meetings of the project work teams with part of their charge being to develop recommendations for specific monitoring and special studies elements.
- On July 6 and 13, staff responsible for implementing the Central Valley Project Improvement Act is discussing its Comprehensive Assessment and Monitoring Program. Parts of this program may complement the Interagency Program.
- On July 6 and 7, Leo Winternitz and Pat Coulston met with Judd Monroe, Jim Buell, Chuck Hanson, and Bill Alevizon of the stakeholders to go through a formal process leading to recommended changes. Their results will be summarized in a draft report from the stakeholders to the Interagency Program.
- On July 26 and 27, the Interagency Program's Science Advisory Committee will hold a 2-day workshop with staff and others to review the program and develop recommended changes.
- On August 1, the Modeling Forum is sponsoring a 1-day workshop to discuss the data needs of physical, chemical and biological modelers.
- On August 7, Interagency Program staff will hold an all-day meeting to review information gathered to date and further define the process leading to the recommended program.
- In mid-August, Interagency Program staff is scheduled to have a draft report from this spring's real-time monitoring evaluation. The report will probably contain recommendations about how real-time monitoring should be included in the overall program.
- DFG will soon be releasing a draft document describing a comprehensive Central Valley salmonid monitoring program.
- A management advisory group composed of representatives of water interests, environmental interests, and agencies has met several times to provide management input to the Agency Coordinators.

It will be a challenge to take all of these often disparate pieces and shape them into a comprehensive data collection and interpretation effort that can provide the kind and volume of information needed by decision makers. In addition, any program developed through this process must be coordinated with existing efforts such as those underway at the San Francisco Estuary Institute to arrive at a program that provides a systemwide information network.