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SEASONAL VARIATIONS IN THE BENTHIC INVERTEBRATE FAUNA OF THE SAN JOAQUIN RIVER ESTUARY OF CALIFORNIA, WITH EMPHASIS ON THE AMPHIPOD, *COROPHIUM SPINICORNE* STIMPSON

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ABSTRACT.—Surveys of the benthic invertebrate fauna of the San Joaquin River in the vicinity of Antioch, California, indicated a relatively constant species composition in May and August, 1955. Dominant littoral species were the Asiatic clam *Corbicula fluminea* (Müller) and the ectoproct *Conopeum commensale* (Kirkp. and Metz.).

The dominant form living in the river bottom was the tube-dwelling amphipod *Corophium spinicorne* Stimpson, with numbers of this species increasing with an increase in the chloride content of the water. The incidence of *C. spinicorne* was found to be associated with brackish water and depths where the substrata were predominantly sand, gravel, or clay.

The material upon which this study is based was collected in the course of two surveys of the San Joaquin River, California. The first survey was made in May, 1955, the second in August of the same year, by the Department of Limnology of the Academy of Natural Sciences of Philadelphia. These periods were chosen to represent low flow and high flow conditions, for as Sumner *et al.* (1928) observed for the San Francisco Bay area, "the situation is . . . complicated by seasonal differences in the amount of water discharged by the tributary streams, the run-off being ordinarily five times as great during the first six months of the year as during the last six months."

Two areas, designated "Antioch" and "Bradford," were chosen for study (fig. 1). The Antioch area, adjacent to the bridge which crosses the river just upstream of the town of Antioch, is some 55 miles by channel from the mouth of San Francisco Bay. The average high tide salinity reported there by Filice (1954) was 0.3 ppt. This specific area was included in Filice's recent studies of faunal and substrate distribution within the San Francisco Bay estuary. The Bradford area, between Twitchell and Bradford Islands, is located some 11 miles farther upstream from Antioch, or about 19 miles downstream from Stockton, California.

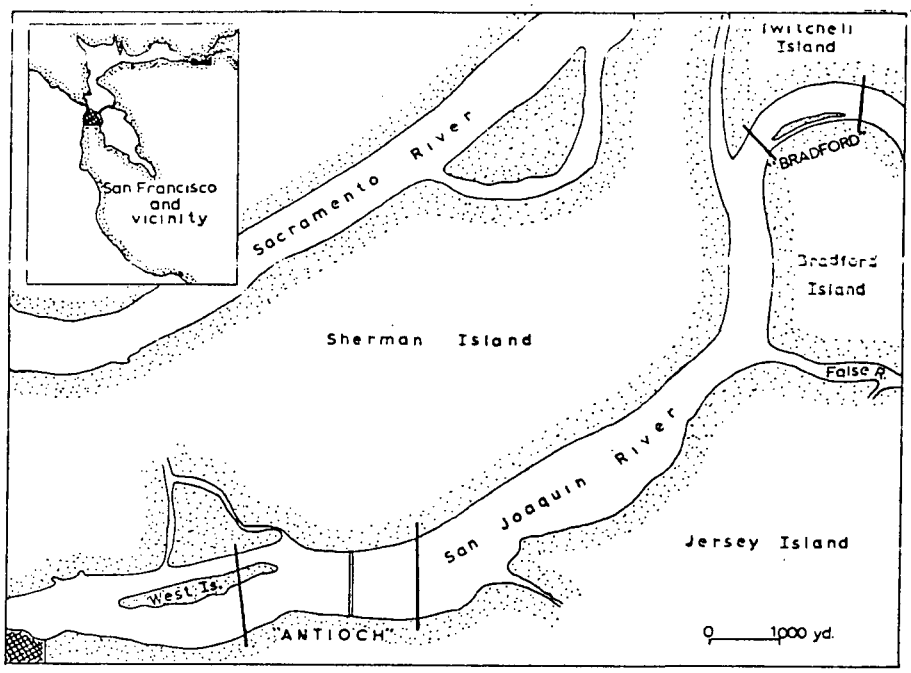

FIGURE 1.—*Chart of collecting areas in the San Joaquin River.*

Both areas were collected thoroughly for littoral benthic invertebrates. Subsequently, a series of samples was taken in the deeper water in each area by means of a weighted Peterson grab. To accomplish this a series of substations was established which traversed the width of the river and paralleled any islands that occurred within the two areas. The number of such substations was as follows:

	May	August
Antioch	33	35
Bradford	14	16

At each of the substations three dredge-loads of bottom material were mixed together and this composite was then passed through matched fitted screens and searched for organisms. Thus, at Bradford in May, for example, a total of 42 grabs was made, constituting the 14 samples from this area. The dredging was done from the 28-foot Frazer River gill net launch, The Striper, belonging to the California Department of Fish and Game. Acknowledgment is here gratefully made of the state's cooperation, and of the assistance of their boatman, Mr. Vincent Catania.

Personnel assisting with the dredging phases of the survey work were Drs. Ruth Patrick, John Cairns, Jr., and C. W. Reimer, all of the Depart-

ment of Limnology. Chemical analyses of the water over the two survey areas were made by Miss Yvonne H. Swabey, of the Limnology Department's Division of Estuarine Science. I am also indebted to Miss Swabey for the statistical analysis of the data presented here.

Partial results of the chemical analyses of the water are presented in Table 1. The values presented were determined on bottom water collected with a Kemmerer water sampler.

TABLE 1.—*Characteristics of bottom water samples*

Water Characteristic	Antioch May High	Antioch May Low	Antioch August High	Antioch August Low	Bradford May High	Bradford May Low	Bradford August High	Bradford August Low
Chloride (ppm)	17	15	1330	980	14	12	300	130
Mean chloride (ppm)	16		1155		13		215	
Temperature (°C.)	16.0	18.0	20.8	20.0	17.3	17.1	21.0	21.2
pH	7.2	7.4	7.7	7.6	7.5	7.2	7.6	7.6

It is apparent from this that the chloride content of the water at both Antioch and Bradford increased considerably in August. These are all low values when one considers the situations encountered in more seaward portions of estuaries, but they do denote the change from fresh water to brackish water to which benthic organisms in such areas as these are subjected.

Species of invertebrates collected during the surveys are listed in Table 2.

TABLE 2.—*List of invertebrate species. X equals presence in area.*

Species	May Antioch	May Bradford	August Antioch	August Bradford
Cordylophora lacustris	X		X	X
Conopeum commensale	X	X	X	X
Neanthes succinea	X	X	X	X
Capitella capitata	X	O		O
Undet. Oligochaeta sp. 1	X	X		X
Undet. Oligochaeta sp. 2	X	O		O
Corbicula fluminea	X	X	X	X
Pisidium occidentalis		X	X	X
Balanus improvisus	X	O	X	O
Rithropanopeus harrisii	X	X	X	X
Corophium spinicorne	X	X	X	X
Synidotea sp.	X	X	X	X

There was a general similarity in the invertebrate fauna of both areas collected in May, and again in August. Dominant and consistently present were the Asiatic clam *Corbicula fluminea* (Müller) and the ectoproct *Conopeum commensale* (Kirkp. and Metz.). Equally consistent in their distributions, but in fewer numbers, were the crab *Rithropanopeus harrisii* (Gould) and the Nereid polychaete *Neanthes succinea* (Frey and Leuckart). The amphipod *Corophium spinicorne* Stimpson assumed a dominant position only in the dredged samples.

A consistent difference in kinds of species between the two areas was the absence of the barnacle *Balanus improvisus* Darwin in the Bradford area. This form occurred at Antioch on both surveys. The numbers and kinds of species remained remarkably constant between the two surveys. Seasonal differences in the overall fauna were slight, such as the absence of the colonial hydroid *Cordylophora lacustris* Allman at Antioch in May and its presence there in August.

It was in an examination of the dredge data that the most interesting information came to light, however. As mentioned earlier, the dominant benthic form from the deeper areas was *Corophium spinicorne*, a tube-dwelling amphipod (Family Corophiidae) (figure 2). Barnard (1952) reported a range for this species from Morro Bay, San Luis Obispo County (California), to Amchitka Island, Alaska, and it has been reported as a common resident in the sea and at the mouths of rivers (Carl, 1937).

FIGURE 2.—*Gravid specimens of* COROPHIUM SPINICORNE *Stimpson from Bradford collecting area, San Joaquin River, California. August, 1955.* ×10.

The incidence of *C. spinicorne* in the dredged samples is presented in Table 3.

There was an apparent increase in the incidence of *C. spinicorne* coincident with the increase in the chloride content from May to August at both

TABLE 3.—*Numbers of* COROPHIUM SPINICORNE *Stimpson in dredged samples.*

	Antioch		Bradford	
	May	August	May	August
No. of dredged samples	33	35	14	16
No. of *C. spinicorne*	471	1451	595	852
Mean no. *C. spinicorne*	14.3	41.3	42.5	53.3
Std. Error	2.4	9.7	9.0	11.9

Antioch and Bradford. The increase in amphipod populations was most drastic and dramatic at Antioch, where the mean number per dredge increased from 14.3 ± 2.4 in May to 41.5 ± 9.7 in August. This was concurrent with an increase in chloride content from a mean of 16 ppm to 1155 ppm. When tested for significance, the increase in *C. spinicorne* at Antioch and in the two areas taken as a whole proved to be significant at the 95% level. The apparent increase at Bradford was not of significant magnitude.

The distribution of *C. spinicorne* with respect to salinity has been noted by several investigators. This form, which is evidently marine in origin, has been reported from halobian extremes. While MacGinitie (1935) found it at 34 ppt salinity in Monterey Bay, Shoemaker (1949) reported its occurrence in the domestic water supply of the city of San Francisco.

Smith (1953) referred to *C. spinicorne* alternately as a "marine" and as a "brackish" water form, reporting it from the Salinas River (California) estuary at salinities as low as 2.2% sea water (or 0.8 ppt). In the San Francisco Bay area Filice (1958) found that this amphipod was most numerous near the upper limits of the estuary in the vicinity of Antioch. He classified the species as a "wide-ranging marine euryhaline form" occurring as it did at salinities up to 19 ppt. The results presented here certainly extend the range of *C. spinicorne* farther up the San Joaquin to an area where the water remains relatively fresh even in the summer. However, the data do indicate at either location (Antioch or Bradford) that the more saline conditions noted in August were more favorable for *C. spinicorne*.

But is chlorinity the only governing factor? It is evident that if it were one would expect a proportionately greater population at Antioch than at Bradford in August. Such was not the case. The mean number at Antioch was not greatly different from that at Bradford and tended to be lower rather than higher.

In his discussion of *Corophium volutator* Pallas, Hart (1930) concluded that this species, able to withstand great changes in salinity was limited in its abundance by the chemical and physical characters of the substratum. Since the depth of water and the type of substratum sampled at each of our dredge substations were recorded, information permitting an analysis of the *C. spinicorne* data in relation to these physical data was available.

The distribution of *C. spinicorne* with depth is presented in Table 4.

The figures given as "No. of *C. s.* Expected" are those which would be found if the amphipods were distributed randomly, and were based on the number of samples obtained in each depth interval.

TABLE 4.—*Distribution of* COROPHIUM SPINICORNE, *with depth.*

Depth Interval (in feet)	May				August			
	Antioch		Bradford		Antioch		Bradford	
	No. of C. s.		*No. of C. s.*		*No. of C. s.*		*No. of C. s.*	
	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
0–10	271	322 (+)	340	279 (–)	415	210 (–)	320	265 (–)
11–20	99	119 (+)	42	2 (–)	580	464 (–)	107	142 (+)
21–40	100	30 (–)	127	202 (+)	290	632 (+)	107	63 (–)
over 40	0	0	85	112 (+)	416	145 (–)	321	382 (+)

It is evident from the table that numbers of *C. spinicorne* observed deviated from the expected frequencies at both locations and on both surveys. The deviations were sufficiently large for statistical tests to show that the amphipods were *not* randomly distributed among the depth intervals, but were concentrated at different levels. These levels varied between the stations and between the surveys. In May excess numbers occurred in the two levels above 20 feet in Antioch, but at depths greater than 20 feet at Bradford. In August the excess numbers at Antioch occurred between 21 and 40 feet, while those at Bradford occurred in alternate intervals as shown. Considering then the Antioch area in the two seasons, it will be noted that the excess populations of amphipods occurred at depths 20 feet deeper in August than they did in May. In the Bradford area the greater numbers were found in the deepest water in May, while in August the 11 to 20 feet level was increased by the depletion of the interval below it. These rather definite selections of certain depths may indicate a predilection for a given depth *per se*, or for some feature associated with that depth. Such a feature or characteristic may be substratum.

The distribution of substrate type with water depth is shown in Table 5. The percentage of the samples taken in each depth interval which was predominantly sand, gravel, peat, mud or clay is indicated. The relative abundance of *C. spinicorne* in the various depth intervals is shown by the signs of the deviations from expected frequencies (table 4).

It has been noted that there was a striking difference in the numbers of *C. spinicorne* in the first two depth intervals in the two areas in May. The data in Table 5 show that the large numbers of *C. s.* at Antioch were associated with a substratum that was predominantly sand. The dearth in these levels at Bradford occurred on substrata which were mostly peat and sand. The latter paradox may be explained by the fact that only one sample was obtained at the 11–20 foot level at this station and may not have been representative. The fact that the excess numbers of *C. spinicorne* at Bradford were associated with sand and gravel substrata at deeper levels indi-

TABLE 5.—*Distribution of substrate type with water depth. Deviations in numbers of* COROPHIUM SPINICORNE *are those from Table 4.*

Month	Area	Depth, feet	No. of Samples	Per Cent of Samples: Sand	Gravel	Peat	Mud	Clay	Deviation in Nos. of *C. s.*
May	Antioch	0–10	19	68	0	11	16	5	+
		11–20	6	67	0	17	0	17	+
		21–40	8	50	38	0	0	12	–
		over 40	0	—	—	—	—	—	
May	Bradford	0–10	8	25	0	63	0	12	–
		11–20	1	100	0	0	0	0	–
		21–40	3	67	0	33	0	0	+
		over 40	2	50	50	0	0	0	+
August	Antioch	0–10	10	30	10	50	10	0	–
		11–20	14	29	0	7	64	0	–
		21–40	7	71	15	14	0	0	+
		over 40	4	100	0	0	0	0	–
August	Bradford	0–10	6	33	0	17	50	0	–
		11–20	2	0	0	50	50	0	+
		21–40	2	100	0	0	0	0	–
		over 40	6	67	17	16	0	0	+

cates that this negative association with sand was not necessarily typical. Again in August, the excess populations were generally associated with sand and gravel substrata, although mud and peat at the 11–20 foot interval accounted for some of them at Bradford.

Of particular note is the seasonal change in the substrata at each location and the associated changes in depth distribution of the amphipods. It is clear that the sandy substratum found at depths to 20 feet at Antioch in the spring was partially replaced by peat and mud in August, and at that time most of the amphipods were associated with greater depths where the substratum was predominantly sand. Such changes were not so clear-cut at Bradford, but the tendency toward the sand or gravel habitat was evinced.

This body of data would indicate that mud and peat were less favorable habitats for *C. spinicorne* than were sand, gravel and clay. Similar results were found by Filice (1958) in the more seaward portions of the estuary. He felt that *C. spinicorne* avoided mud and favored sandy substrata.

In order to determine if one bottom type supported greater numbers of *Corophium* than another, the samples from each location were classified on the basis of the major component and the incidence of the amphipod tallied for each type. These data are presented in Table 6, together with the numbers of *C. spinicorne* expected on the basis of the number of samples of each type of substratum. Numbers which deviated significantly from expected frequencies are indicated by the (+) and (–) signs.

It can be seen that *C. spinicorne* at all times either attained or exceeded expected numbers in sand; in clay when it was available. This was usually true for gravel also. The data definitely indicated an aversion to peaty substrate throughout the area and to mud when mud became a major component of the substrate. The fact that in May mud did not occur in the

Bradford samples and constituted only 9% of the samples at Antioch but had increased to 25–30% by August at both areas was probably influential in the distribution of the amphipods. We have seen that when mud became a dominant feature of the bottom to a depth of 20 feet at Antioch in August the major incidence of *Corophium* shifted to greater depths where sand predominated.

TABLE 6.—*Distribution of* COROPHIUM SPINICORNE, *with substratum.*

	May				August			
	Antioch		Bradford		Antioch		Bradford	
	No. of *C. s.*		No. of *C. s.*		No. of *C. s.*		No. of *C. s.*	
Substratum	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
Sand	300	325	255	243	663	955 (+)	426	604 (+)
Gravel	43	10 (–)	42	33	83	244 (+)	54	42
Peat	43	10 (–)	255	216 (–)	290	76 (–)	160	78 (–)
Mud	43	36	0	0	415	176 (–)	213	128 (–)
Clay	43	90 (+)	42	103 (+)	0	0	0	0

Overall, this study has indicated the greater incidences of *Corophium spinicorne* in the San Joaquin River were associated with brackish water and depths where the substrata were predominantly sand, gravel, or clay.

References Cited

BARNARD, J. L. 1952. Some amphipods from central California. The Wasmann Journal of Biology 10(1): 9–36.

CARL, G. C. 1937. Flora and fauna of brackish water. Ecology 18(3): 446–453.

CRAWFORD, G. I. 1937. A review of the amphipod genus *Corophium* with notes on the British species. Jour. Mar. Biol. Assoc., U. K. 21(2): 589–630.

FILICE, F. P. 1954. A study of some factors affecting the bottom fauna of a portion of the San Francisco Bay estuary. The Wasmann Journal of Biology 12(3): 257–292.

———. 1958. Invertebrates from the estuarine portion of San Francisco Bay and some factors influencing their distribution. The Wasmann Journal of Biology 16(2): 159–211.

HART, T. J. 1930. Preliminary notes on the bionomics of the amphipod *Corophium volutator* Pallas. Jour. Mar. Biol. Assoc., U. K. 16(3): 761–790.

MACGINITIE, G. E. 1935. Ecological aspects of a California marine estuary. American Midl. Naturalist 16(5): 629–765.

SHOEMAKER, C. R. 1949. The amphipod genus *Corophium* on the west coast of America. Jour. Washington Acad. Sci. 39(2): 66–82.

SMITH, R. I. 1953. The distribution of the polychaete *Neanthes lighti* in the Salinas River estuary, California, in relation to salinity, 1948–1952. Biol. Bull. 105(2): 335–347.

SUMNER, F. B., G. D. LOUDERBACK, W. L. SCHMITT, AND E. C. JACKSON. 1914. A report on the physical conditions in San Francisco Bay, based upon the operations of the United States Fisheries Steamer "Albatross" during the years 1912 and 1913. Univ. California Publ. in Zool. 14: 1–198.