Pacific Science (1987), vol. 41, nos. 1–4

Particle-Size Utilization in the Introduced Polychaete *Neanthes succinea* in San Francisco Bay[1]

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ABSTRACT: Particle-size utilization in the deposit-feeding polychaete *Neanthes succinea* was examined. Gut analysis revealed that worms in San Francisco Bay consumed a broad range of particle sizes (20–300 μm diameter). Gut sediment closely resembled size of surface sediment at the mouths of worm burrows indicating non-selective feeding. All size classes of worms consumed similar sized particles. The flexibility in feeding modes and diet of nereids is discussed.

Neanthes succinea (FREY AND LEUCKART) is a common, infaunal polychaete introduced to San Francisco Bay with the Virginia oyster from 1860–1910 (Carlton 1975). Broadly distributed in estuarine areas of both American coasts, Europe, and the Hawaiian Islands, its abundance and large size make it a useful organism for the study of polychaete feeding biology.

A number of studies on *N. succinea* from the eastern United States and Europe have focused on life history (Wilson 1892), reproduction (Lillie and Just 1913; Kinne 1954), larval morphology (Banse 1954), occurrence (Smith 1963), ingestion rate (Cammen 1980), and growth (Neuhoff 1979). Since its introduction, very little research has been done on California populations, but some studies on salinity tolerance (Hanson 1972; Kuhl and Oglesby 1979) and spawning behavior (Carpelan and Linsley 1961) have been done in the Salton Sea.

The information on the diet of *N. succinea* from the California coast is lacking, and from the eastern United States it is somewhat confused. Teal (1962) and Cammen (1980) call *N. succinea* a non-selective surface deposit feeder, but give no supporting data on particle sizes consumed. In contrast, Holland (personal communication) has found juvenile amphipods, *Corophium lacustre* and spionid polychaetes in the guts of worms from Chesapeake Bay.

The present study focuses on the diet of *N. succinea* in San Francisco Bay. Preliminary investigations on worms collected from the bay showed that *N. succinea* consumes mainly sediment. Therefore it was the aim of this study to (1) determine the particle sizes of sediment ingested by *N. succinea*, (2) examine possible particle size selection by comparing ingested particles with particles available for ingestion at the sediment surface, and (3) measure particle size ingested relative to worm length.

MATERIALS AND METHODS

The study was carried out from March 1983 to February 1984 in an intertidal mudflat in San Leandro Creek, one of many tidal creeks flowing into San Francisco Bay (Figure 1). Salinities are variable depending on season and tidal cycle, but can range from 18‰ in the summer to freshwater in the winter. Water temperature fluctuates from 13–20°C during the year. The mudflat proper is composed of very poorly sorted sediments (-2.25Φ). The flora is composed of a broad expanse of diatoms on the sediment surface over the entire mudflat. Macro-algae include the cosmopolitan green algae *Ulva* and *Enteromorpha*.

The epifauna consists mainly of the mussels, *Ischadium demissum* and *Mytilus edulis*, and barnacles. The under-boulder fauna includes

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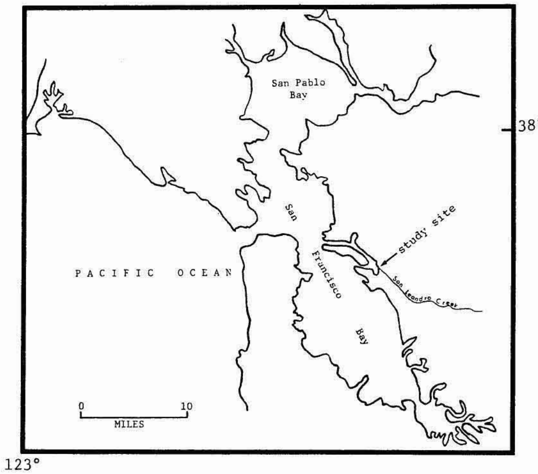

FIGURE 1. Map of San Francisco Bay showing study site near San Leandro Creek.

the crustaceans *Hemigrapsus oregonensis* (Decapoda), *Anisogammarus confervicolus* (Amphipoda), and *Tanais* sp. (Tanaidacea). Infaunally, *Neanthes succinea* and the bivalve *Mya arenaria* are the most common.

Although no field observations of feeding behavior were made, *N. succinea* in the laboratory constructed U-shaped burrows, and actively probed around burrow openings. In the field, individuals of *N. succinea* were collected by hand, immediately fixed in 10% formalin and preserved in 70% ethanol. Samples of the sediment surface were collected by gently scraping the uppermost 1 cm of sediment around the burrow openings with a plastic vial. All animals and sediment samples were transported to the laboratory for analysis.

Individual worms were separated into three size classes, 2–5, 5–8, and 8–12 cm length, and defined as small, medium, and large size respectively. Prior to gut analysis, all worms were rinsed of adhering particles in distilled water. Guts were removed carefully, and contents placed in vials containing 15% H_2O_2 for 24 h to remove organic material. Surface sediment was rinsed and treated similarly. All samples of both gut and surface sediment were then rinsed again, and spread onto microscope slides. Using a phase contrast microscope with an ocular micrometer, the first 200 particles encountered on each slide were counted and measured at 100 X. Possible selective ingestion of different particle sizes was examined by comparing size-frequency distributions, and 95% confidence limits of mean particle size of the sediment at the mouth of worm burrows with that in worm guts. Electivity values were calculated using the formula of Ivlev (1961):

$$E = \frac{(r_i - p_i)}{(r_i + p_i)};$$

where E is the electivity value, r_i, the percentage of the ith particle size class in worm guts, and p_i, the percentage of the ith particle size class of the surface sediment. E varies from -1 to $+1$, where negative values indicate selection against a certain size class, positive values indicate selection for a certain size class, and zero indicates no selection.

RESULTS

Particles from the sediment surface in San Leandro Creek are moderately sorted, and range from 20–300 μm in width. Approximately 82% of these particles were less than 72 μm, and 51% ranged from 20–50 μm. *N. succinea* inhabiting San Leandro Creek ingest the identical particle size range of 20–300 μm, available to them at the surface, and 88% of the particles in the guts of these worms were less than 72 μm. Size-frequency distributions of surface and gut sediment are given in Figure 2. For particle sizes combined over a one-year period, no significant difference exists between surface and gut size-frequency distributions (Kolmogorov-Smirnov test; $p > 0.5$). The 95% confidence limits and ranges for mean particle size of surface and gut sediment are presented in Figure 3. Confidence limits overlap strongly in the months of June, August, October, and December, and are extremely close to overlapping in November, January, and February. Confidence limits calculated over the entire year (annual mean) overlap strongly, and these data suggest that there is no difference between particle size of surface sediment and sediment ingested by *N. succinea*.

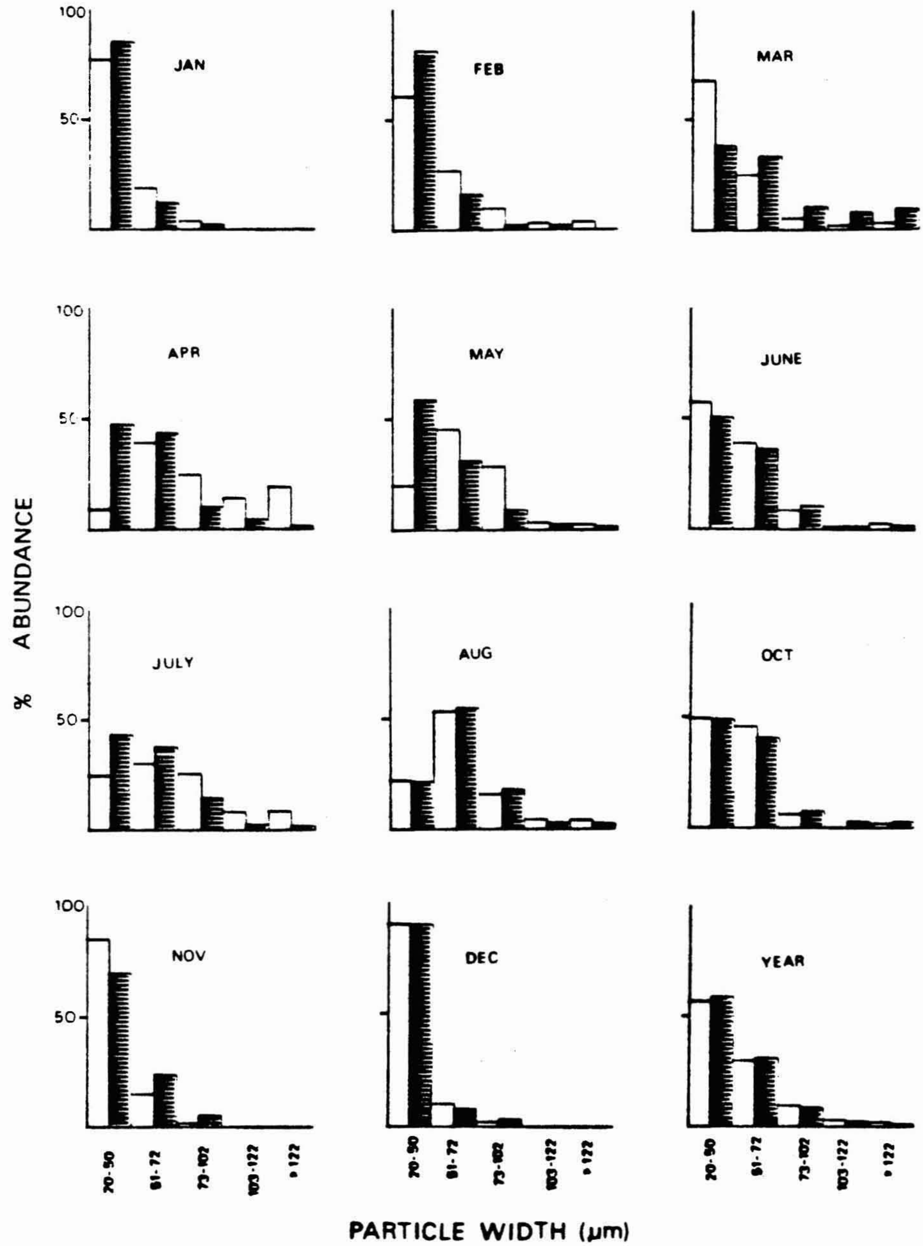

FIGURE 2. Size-frequency distributions for particle sizes of surface sediment (open bars) and worm gut sediment (striped bars).

Ivlev values for all worms examined are given in Table 1. Electivity values are negative for large particle size classes, indicating avoidance of these particles. However, only the $>122\,\mu m$ size class has a sufficient negative value approaching significance. Similarly, smaller particles ($<72\,\mu m$) have positive electivity values, but these are not large enough to suggest significant selection for these particles. Overall, in most particle size classes, elec-

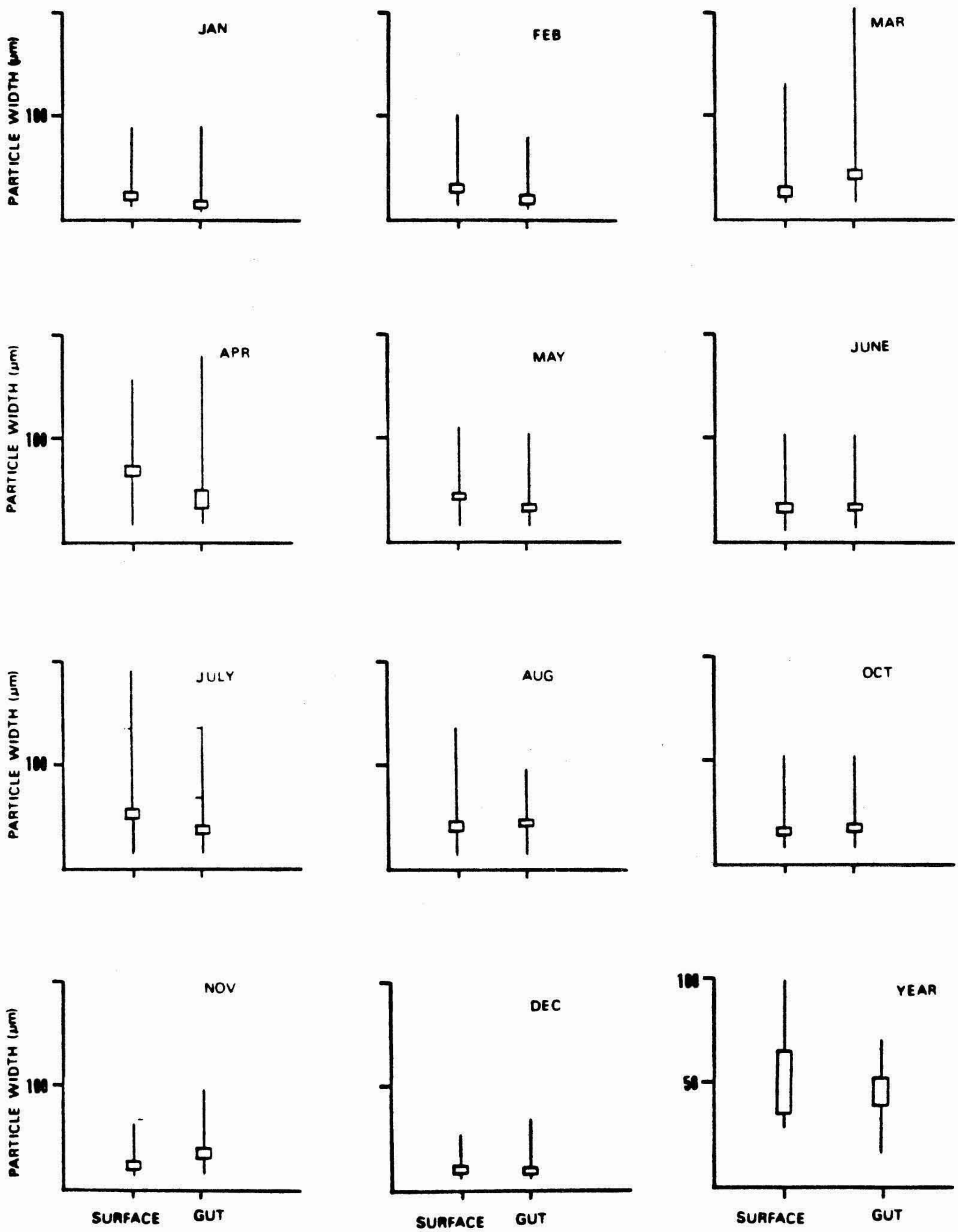

FIGURE 3. Range and 95% confidence limits for means of surface sediment and worm gut sediment.

TABLE 1

ELECTIVITY VALUES CALCULATED FROM PARTICLE-SIZE DISTRIBUTIONS OF SURFACE AND GUT SEDIMENT SAMPLES FROM *Neanthes succinea* (n = 30) FEEDING ON SEDIMENTS IN SAN LEANDRO CREEK

Size Class (μm)	20–50	51–72	73–102	103–122	>122
Electivity	0.017	0.009	−0.066	−0.020	−0.255

TABLE 2

MONTHLY SAMPLING OF GUT PARTICLE SIZE OF *Neanthes succinea* FROM SAN LEANDRO CREEK. Particle size values are in μm

MONTH	n (WORMS)	n (PARTICLES)	WORM LENGTH (cm)	$\bar{X}$ (PARTICLE SIZE)	s^2	s	HIGH	LOW
March 1983	2	200	4.7	63.55	1543.2	39.28	326.4	20.4
			5.0					
April	5	200	6.0	58.96	794.8	28.19	265.2	20.4
		200	6.0	54.26	684.6	26.16	255.0	20.4
		200	7.0	50.49	613.5	24.77	153.0	20.4
		200	7.5	60.99	1120.8	33.48	214.2	20.4
		200	9.5	50.23	571.9	23.91	132.6	20.4
May	2	200	7.0	49.15	598.2	24.45	153.0	20.4
		200	8.5	46.46	516.2	22.72	132.6	20.4
June	2	200	3.0	49.77	456.4	21.37	132.6	20.4
		200	7.0	51.10	397.3	19.13	153.0	20.4
July	3	200	5.0	67.32	819.7	28.63	173.4	20.4
		200	7.5	44.06	471.3	21.71	122.4	20.4
		200	13.0	57.88	920.0	30.33	204.0	20.4
August	2	200	7.0	63.34	506.7	22.51	142.8	20.4
		200	9.0	61.30	551.0	23.47	153.0	20.4
October	3	200	8.0	47.84	376.8	19.41	153.0	20.4
		50	10.5	52.84	949.9	30.82	204.0	20.4
		200	10.5	53.86	529.2	23.00	153.0	20.4
November	2	200	9.0	46.46	470.2	21.46	142.8	20.4
		200	9.0	37.79	183.7	13.55	91.8	20.4
December	3	207	2.5	28.67	89.7	9.42	71.4	20.4
		100	5.0	30.29	112.3	10.60	71.4	20.4
		101	10.0	33.12	252.6	15.80	102.0	20.4
January 1984	3	180	6.0	35.93	264.4	16.26	112.2	20.4
		200	8.0	29.78	118.5	10.88	71.4	20.4
		200	13.5	34.98	275.5	16.60	132.6	20.4
February	3	200	3.5	34.07	256.6	16.02	122.4	20.4
		200	6.0	31.52	204.0	14.28	122.4	20.4
		200	18.5	39.42	239.1	15.40	102.0	20.4

tivity values are close to zero, indicating that *N. succinea* is not selecting specific particle sizes.

A tabulation of the one-year gut particle-size survey of *N. succinea* is given in Table 2. The three worm size classes have similar mean particle sizes (45.5–50.0 μm) and all three 95% confidence limits overlap (Figure 4) suggesting that particle size ingested is independent of worm length.

DISCUSSION

Though nereids are generally omnivorous, only a few species are known to be deposit feeders (Fauchald and Jumars 1979). Hence, very few papers have focused directly on nereid particle feeding or their effects on the benthos.

In San Francisco Bay, *Neanthes succinea* is a strict surface deposit feeder (Fong 1985). The results of the present study indicate that

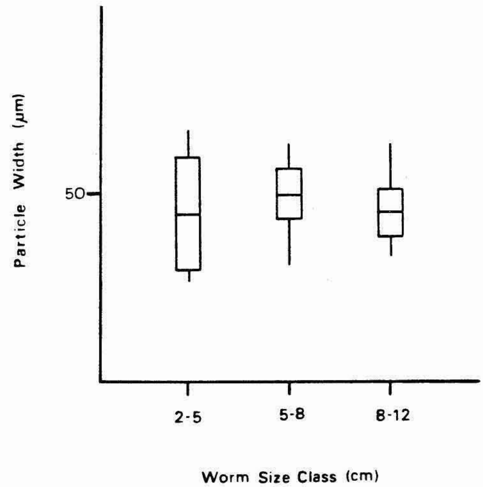

FIGURE 4. Range and 95% confidence limits for mean particle width of gut sediment relative to worm length.

this polychaete consumes a wide range of particle sizes. Moreover, the sediment sizes in worm guts closely resemble sizes of surface sediment available for ingestion (Figure 2). Ivlev values indicate no selection for any size class below 122 μm. These data alone are not sufficient enough to conclude non-selective feeding since worms may be living under optimal sediment conditions (Hammond, 1982). Worms did not feed readily in the laboratory, therefore experiments to test particle size preference were impossible. However, worms in the field consume not only sediment of extremely broad range, but also a considerable amount of allochthanous material. If worms were feeding selectively, these materials (mainly small bits of terrestrial plants) would not be present in worm guts. Moreover, there appears to be no relationship between worm body length and sizes of particles ingested. These results and observations lead to the conclusion that *N. succinea* is a non-selective surface deposit feeder in agreement with the earlier reports of Teal (1962) and Cammen (1980).

Many cases for non-selective deposit feeding have been reported in capitellids, opheliids, orbiniids, and cirratulids (Fauchald and Jumars 1979). But, the small amount of research on particle-size utilization by *N. succinea* precludes any comparison with the present study. Furthermore, nereids in general show extreme flexibility in feeding modes. For example, *Nereis virens* is herbivorous at Woods Hole, but omnivorous at other locations (Theede et al. 1973). *Nereis diversicolor* is omnivorous, but also capable of filter feeding using a mucous cone (Fauchald and Jumars 1979). Therefore, generalized feeding modes for certain species may not be very valuable. Additional studies from different locations should be attempted to consolidate what little information exists for *N. succinea* and other nereids.

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