Chapter 3

BENTHIC INVERTEBRATE SURVEY AT WHITE SLOUGH, VALLEJO, CALIFORNIA

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This project is a survey of the benthic (mud-dwelling) invertebrates of White Slough along the Napa River, just north of San Pablo Bay (see map, p. vi). Public and governmental interest has increased in tidal flats and salt marshes such as White Slough because of the recognition that they are very important to resident and migratory animals.

Why would anyone be interested in the spineless creatures of the mudflat? Fish and birds are usually considered to have greater commercial and aesthetic importance. One strong reason to study a site's benthic invertebrates is that, unlike birds or fish, they cannot escape deleterious environmental changes. The benthic invertebrates of the White Slough site directly reflect the physical influences of the White Slough ecosystem. Benthic invertebrates reflect environmental influences in two ways, through species diversity and specimen abundance (total abundance). Harsh environmental conditions generally reduce species diversity. Biomass may also go down with environmental changes. However, if a species does exceedingly well in rigorous environmental conditions, biomass could remain constant.

Another reason to study the benthic invertebrates of White Slough is that they are an important link in the Napa River Marsh food chain. Thousands of species thrive in the Napa River Marsh biosystem (Baltz, 1981). The most noticeable consumers of mudflat benthic fauna are the shorebirds that rest and feed there on their season migration. Seventy percent of the canvasback ducks in the Pacific Flyway stop in the Napa River Marsh (Baltz, 1981). Shorebirds annually can consume a very significant proportion of estuarine benthic productivity (Nichols, 1977). The health of the benthic faunal community directly affects the health of all the other organisms dependent on them.

Situated between the Napa River and the city of Vallejo, White Slough receives both tidal flow from the Napa River and fluvial flow from Chabot and Austin Creeks (Corps, 1985). State Highway 37 divides White Slough into a larger northern area (125 hectares) and a smaller southern area (56 hectares) (Baltz, 1981) (Figure 1). White Slough was originally a seasonal wetland (Baltz, 1981). Around the turn of the century the area was diked by levees. During the winter of 1976-1977 the levees protecting White Slough broke and allowed the tidal waters of the Napa River to enter the previously-diked slough land (Corps, 1985).

White Slough is an interesting and worthwhile site for a benthic survey for several reasons. Because we know the date on which the dike broke, we know precisely how long the benthic community has been developing. The relative youth of the benthic community might influence species diversity. White Slough is also an area of high sedimentation; therefore the benthos living there must be specially adapted to its

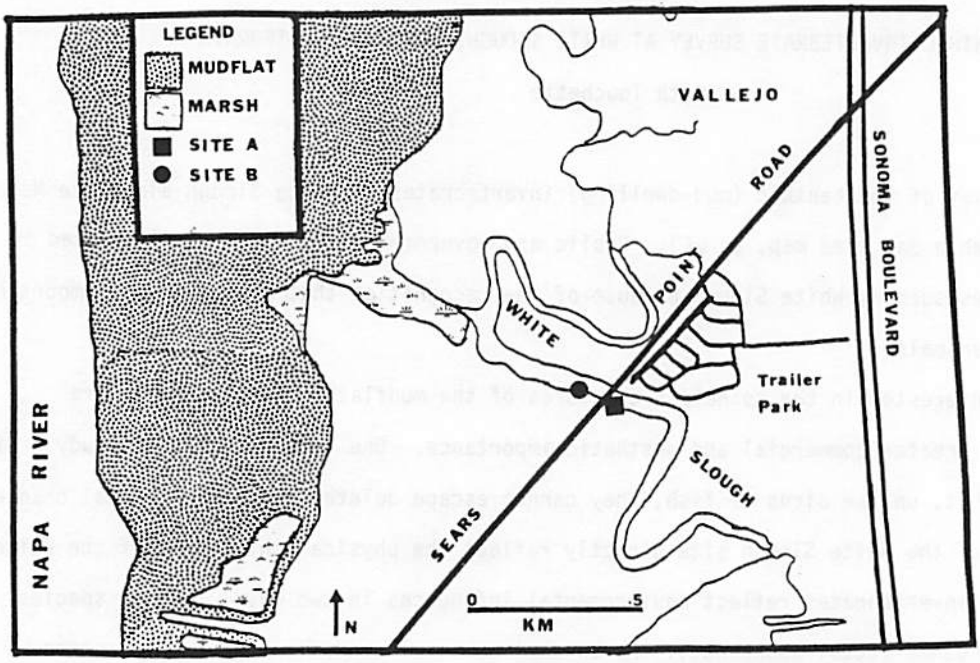

Figure 1. Map of the White Slough Study Site and Vicinity.
Source: USGS Base Map, N3807.5-W12215/7.5, 1981.

effects. White Slough also is an area of potential development. The richness and complexity of the benthic community would be affected by some developments, but these effects cannot be known until the benthic community itself is investigated.

Past Studies

No specific surveys have been made of White Slough. The U.S. Army Corps of Engineers (1975) investigated the benthos of Mare Island Strait, which is three miles southwest of White Slough. Sediment from Mare Island Strait sites were usually inhabited by fewer taxa than sediment from other areas throughout the bay. The study found that sediment from undredged stations had a greater variety of life than from disturbed stations.

Nichols (1973) presents an excellent overview of San Francisco Bay benthic surveys, emphasizing the methodologies and limitations of each. The first major study of the benthic fauna of the bay was the Albatross study of 1912-1913 (Nichols, 1973), which was initiated by the decline of productivity in the fisheries caused by overfishing, pollution and siltation.

Salinity is a very important determinant of benthic species diversity, and the diversity of species decreases as one ascends the San Francisco Bay system. Filice (1958) found that more species occur at seaward Point San Pablo than at riverward Antioch. Sediment size, depth and temperature are also important influences on species diversity (Filice, 1958). Filice also found a decline in diversity of benthic species near waste outfalls, which led to the application of species diversity as a tool for assessing environmental impacts (Filice, 1959).

McCall (1977) studied sediment in which all living animals had been eliminated (defaunated) at two sites along Long Island Sound. He found that more opportunistic species inhabited the defaunated sediment first. It took several months for the equilibrium species to establish themselves in McCall's study. Nichols (1979) found that intermittent instability of sediments on the intertidal and shallow subtidal mudflats in South and San Pablo bays probably contributes to the low species diversity found there, because only few species can survive the stressful conditions.

Methodology

Two sites at White Slough were surveyed. Transect A is located on the southeast side of the Highway 37 sluice (Figure 1). This side receives only sporadic tidal action. High water is continuously maintained because the sluice gate was placed too high to allow all but the highest tides to flow through the tunnel.

Transect A was surveyed on November 22, 1985, and on February 9, 1986. November 9 was a cloudy day, with an air temperature of 60°F. The day was sunny on February 9, with an air temperature of 70°F. In November, samples were taken at Transect A around 1:30 P.M., three hours before a low tide of -1 foot. In February, samples were taken at Transect A around 3:00 P.M. Salinity at the site measured 16 grams (g) total dissolved salts (TDS) per liter in Transect A in November, and 8 g TDS per liter in February.

Transect B is on the northwest side of Highway 37, in the northern part of White Slough, on the side of the checkdam that receives tidal action. It was surveyed only on November 22, at 3:30 P.M. Salinity measured 8 g TDS per liter.

Each transect was made from the shore to a point 3.6 m into the water. Samples were taken at 1.2 m, 2.4 m, and 3.6 m intervals along the transect. Samples were taken at random stations to the left or right of the transect. The February Transect A was 3.6 m further west along the shore than the November Transect A. The author wanted to compare seasonal differences at Transect A, but did not want to get a sample from previously disturbed sediment. Samples at Transect A were taken with a can of 1648 cm^3 volume. A slightly larger can, with a volume of 4452 cm^3, was used at Transect B. The cans had vents drilled in them to ensure the escape of air. After taking a sample, the author made sure the mud in the can was level and quickly overturned the can into a bowl, before its contents leaked out of the vents. Sea water samples were taken at Transect A and Transect B in both November and February. The sea water samples were taken at the surface, in the middle of the transect surveyed.

The sediment was sieved through a 30-mesh screen. One milliliter of rose bengal was added to the samples after sieving. Rose bengal marks the protein in living animals. The specimens were preserved in 10 percent formalin solution.

Identifications were made through a binocular microscope using Light's Manual (Light, 1975), Project MER Handbook (Shettler, 1971), and a key to the benthic invertebrates of Mare Island Channel (Chapman, 1980). The author was helped in identifications and/or verifications of the most common species by Kipp Baron, David Lindberg, Rich Everett and Dusty Chivas. The author's inexperience is a probable source of underestimating numbers and misidentifying species. In particular, Odostomia snail counts are probably overestimated, because the author was unable to distinguish living from dead specimens inside the tiny shells.

RESULTS

Altogether in the three transects, 907 specimens were identified. Fourteen different taxa from the phyla Nematoda, Annelida, Arthropoda and Mollusca were recognized.

The greatest variety of taxa (12) and largest number of specimens (411) were identified in Transect A in November (Table 1). The most abundant taxon was oligochaeta, which composed 57 percent of the specimens identified. Odostomia, the second most abundant taxon, composed 15 percent of specimens identified (Table 2). Distribution varied between stations within Transect A in November. For example, 150 oligochaetes were identified at station A1, whereas 90 were identified at A2, and 20 were identified at station A3 (Table 1).

The second greatest number of taxa (7) and specimens (371) were found in Transect B in November (Table 1). Odostomia composed 90 percent of specimens identified, whereas oligochaetes composed 8.4 percent (Table 2). Distribution of species was not uniform at the stations within Transect B. Three Nereidae were identified in sample B3, but none were identified in samples B1 and B2 (Table 1).

Seven taxa and 125 specimens were identified from Transect A in February (Table 1). Odostomia composed 70 percent of specimens identified, while nereids composed 16 percent (Table 2). Transect A in February also showed non-uniform distribution at the stations.

Differences also existed between the taxa occurring in Transect A in November and February. No oligochaetes were identified in Transect A in February. The author identified eight Capitella in November, but none were recognized in February. In February, four Amplesia milleri were found at Transect A, although none were found at either Transect A or B in November. A slight increase in number of nereidae specimens was observed between November and February from Transect A. The general decrease in numbers of specimens in February caused the taxa that retained stable populations to comprise a higher percent distribution than they did in November (Table 2), even though their actual numbers did not increase significantly (Table 1).

The Six Most Abundant Organisms Collected

Several kinds of organisms, including four kinds of worms, a snail, and a shrimplike animal, were encountered repeatedly in the three transects. These organisms are important indicators of their environment because their large numbers indicate effective adaptation to the environment of White Slough, rather than chance dispersal. The six most abundant organisms collected were the genera Capitella and Odostomia, and representatives of the taxa Gammaridea, Oligochaeta, Nematoda and Nereidae. To the

TAXA	November 22, 1985 Transect A Number of Specimens per Sample				February 9, 1986 Transect A Number of Specimens per Sample				November 22, 1985 Transect B Number of Specimens per Sample			
Sample	A1	A2	A3	Total	A4	A5	A6	Total	B1	B2	B3	Total
Nematoda unidentified species	4	4	6	14	0	3	0	3	0	0	3	3
Oligochaeta unidentified species	150	90	20	260	0	0	0	0	4	10	17	31
Family Nereidae	10	4	4	18	7	3	10	20	0	0	3	3
Family Spionidae	0	1	0	1	0	0	0	0	0	0	0	0
Capitella	4	3	1	8	0	0	0	0	0	0	0	0
Balanum improvisus	0	0	6	6	2	0	0	2	0	0	0	0
Copepoda unidentified species	1	17	6	24	0	0	0	0	0	0	0	0
Gammaridea unidentified species	3	3	9	15	0	4	0	4	0	0	0	0
Amplesia milleri	0	0	0	0	3	1	0	4	0	0	0	0
Hyperidea unidentified species	0	0	2	2	0	0	0	0	0	0	0	0
Odostomia	30	6	24	60	63	14	10	87	63	28	240	331
Gemma gemma	0	3	0	3	1	4	0	5	3	0	0	3
Total Specimens for Each Sample	202	131	78	411	76	26	20	125	70	38	263	371
TOTALS	Total Specimens for Transect A, November 22,			411	Total Specimens for Transect A, February 9			125	Total Specimens for Transect B, November 22			371

Table 1. Table showing number of specimens per sample, and total number of specimens for Transect A in November and February, and Transect B in November

TAXA	TRANSECT A NOV. 22				TRANSECT A FEB. 9				TRANSECT B NOV. 22			
STATION	A1	A2	A3	Aan	A4	A5	A6	Aaf	B1	B2	B3	Ban
1. Nematoda	2.0	3.1	7.8	3.4	0	10	0	3.0	0	0	1.2	.8
2. Oligochaeta	74	69	30	57	0	0	0	0	5.6	26	6.5	8.4
3. Nereidae	4.9	3.1	5.1	4.4	9.2	10	50	16	0	0	1.2	.8
4. <u>Capitella</u>	2	2.3	1.3	1.9	0	0	0	0	0	0	0	0
5. Gammaridea unidentified species	1.5	2.3	11.5	3.6	0	14	0	3.2	0	0	0	0
6. <u>Odostomia</u>	15	4.6	31	15	83	49	50	70	90	74	91	90
7. other	.6	15	17	8.7	8	17	0	8.4	.4	0	0	2.2

Table 2. Distribution of six most abundant taxa for samples and transects, in percent.

Notes:

Aan- Average percent distribution for all of transect A in November

Aaf- Average percent distribution for all of transect A in February

Ban- Average percent distribution for all of transect B in November

average reader, these names do not mean very much. The following descriptions have been included to make the conclusions of this study more tangible and meaningful.

<u>Capitella</u>

This polychaete superficially resembles an earthworm, but its head and tail regions are barely discernible. Polychaete worms have many body segments, while oligochaetes, like earthworms, have fewer. <u>Capitella</u>'s body tapers at both ends. Generally, <u>Capitella</u> shows a preference for more saline waters than San Pablo Bay.

<u>Odostomia</u>

<u>Odostomia</u> are tiny parasitic snails (Light, 1975). The tiny lip on the mouth of their shell is their diagnostic feature.

<u>Gammaridea</u>

This organism superficially resembles a shrimp, but it is only distantly related. The Gammaridea are by far the most abundant amphipod in both fresh and marine waters. Gammaridea are scavengers, and many live in mud (Light, 1975). Two taxa of Gammaridea were collected in this survey, Amplesia milleri, and another larger one of an unidentifiable species. The larger amphipod is the one in the percent composition table. A diagnostic feature of Amplesia milleri is red eyes.

Oligochaeta

The class oligochaeta contains the familiar earthworm and about ten families of minute aquatic worms. Marine oligochaetes live within, and feed upon, benthic detritus. In general, marine oligochaetes are particularly abundant in areas of organic enrichment, because they, unlike many other organisms, can withstand low oxygen conditions (Light, 1975).

Nematoda

Nematodes are a large phylum of worms that are found in practically all habitats. Nematodes are easily recognized by their elongated, round, unsegmented bodies. This worm is in a completely different phylum than the oligochaetes and polychaetes.

Nereidae

The Nereidae family of polychaetes is easily recognized by its four eyes and four fleshy head projections called cirri. It is armed with a pair of jaws for catching prey (Shettler, 1971). Like all polychaetes, it is predominantly marine, but can be found at very low estuarine salinities.

Discussion

Comparison between the benthic environments of White Slough and Mare Island Strait allows one to discern environmental similarities and differences between the two sites. The Army Corps of Engineers (1975) surveyed the benthos of Mare Island Strait at two sites: MIS-A (Mare Island Strait), which was located in the dredged middle portion of the Strait, about three miles from the White Slough site; and MIS-B, which was located in an undredged portion of the Strait. The Corps (1975) identified 33 taxa in Mare Island Strait, whereas 14 taxa were identified at White Slough. The author's inexperience as a taxonomist and handler of delicate samples probably contributed to this discrepancy.

Differences in benthic diversity and percent composition existed between the Mare Island Strait and White Slough surveys. Copepods were common at MIS-A, but they were found only in two samples in White Slough Transect A in November. Streblospio benedicti (family Spionidae) composed two percent of collected specimens at MIS-B, although only one specimen of the family Spionidae was identified in all of the White Slough sites (Table 1). Instead, the most abundant polychaetes were of the family Nereidae.

A seasonal decrease in oligochaetes also occurred in the Corps stations. Oligochaetes decreased from 95 percent of species to 21 percent of species between September and March at MIS-B.

There are many environmental similarities between Mare Island Strait and White Slough. Salinity varied throughout the year at White Slough and in Mare Island Strait, primarily due to variations in fresh water inflow. Rates of sediment accumulation in Mare Island Strait are 100 times the rate of accumulation throughout the Bay (Dhont, pers. comm., 1986). White Slough probably is affected by the high rates of sedimentation in Mare Island Straits, but no data are available.

One major source of the differences between the Mare Island Strait and White Slough surveys may be depth. The Corps took its samples at a 30 to 150 foot water depth, whereas the author took her samples from a one to three foot depth.

Both White Slough and Mare Island Strait can be considered unstable environments. Adult populations of equilibrium species are not permitted time to become established, because of the continual variety and strength of environmental stresses, especially the high rates of sedimentation and salinity fluctuations. Instability in environmental factors throughout the year may have created instability in oligochaete populations.

Benthic species diversity has been shown to correlate not with absolute salinity on a particular day, but to its overall range throughout the year (Nichols, 1979). Relatively few species can withstand large salinity variations. One adaptive strategy the benthos have is living only part of the year, when salinity is favorable. Perhaps the oligochaetes in Transect A were killed by the substantial decrease in salinity between November and February (Table 3).

	TRANSECT A		TRANSECT B	
DATE	November 22 1985	February 9	November 22	February 9
TEMPERATURE	52° F	50°F	52°F	50°F
TDS g/l (o/oo)	16	8	8	7

Table 3. Temperature and Total Dissolved Salts (TDS) at the White Slough transects, in November and February.

Notes:
TDS for a typical winter at the Golden Gate 30.6 o/oo (Conomos, 1979, p. 64)
TDS for a typical winter at Carquinez Strait 10 o/oo (Conomos, 1979, p. 64)

Salinity fluctuations represent only one of many environmental stresses in White Slough. Sediment instability may represent the strongest of the abiotic influences on the benthos of the Bay (Nichols, 1979). The benthos of the northern White Slough also have to adapt to the stress of intertidal dessication and temperature variations. The strong environmental stresses of White Slough favor a greater proportion of opportunistic species. Opportunistic species are characterized by small size, rapid development, many reproductions per year and a high death rate (Nichols, 1979). In areas with less environmental variability, such as the central Bay, a greater number of species can adapt to the environment. Fewer species can adapt to White Slough, and those few opportunistic species were encountered repeatedly in identifications. Often opportunistic species are outcompeted in more stable environments. McCall (1977) characterized Amplesia milleri, which was found in both the Mare Island Strait and White Slough surveys, and Capitella, which was identified only in the White Slough survey, as opportunistic. Both Capitella and Amplesia milleri showed large seasonal variations in White Slough. Oligochaetes varied between seasons in both White Slough and Corps (1975) surveys, which is also characteristic of opportunism.

The differences in taxa between Transect A and Transect B seem largely attributable to dissimilarities in environmental factors. In November, Transect A had twice as many dissolved salts as Transect B (Table 3). Because Transect A was located in a small closed saltpond, extensive sun could cause a large amount of evaporation and increase salinity, or large rainstorms could quickly reduce it. The rains in late February of 1986 probably caused a great reduction of salinity in the salt pond, which this study could not record. Tidal action keeps the salinity of the North Slough relatively stable. Perhaps salinity dissimilarities explain why a greater number of saline-favoring Capitella were found at Transect A than Transect B.

Unlike the benthos in the South Slough, the benthos in the North Slough must withstand low tide dessication and temperature variations twice a day. Birds also can feed on the benthos during low tide. The predominant taxon in Transact A was oligochaeta, whereas the predominant taxon in Transect B was Odostomia (Table 3). The shells of Odostomia give protection from dessication and temperature differences, which may explain why there are more Odostomia at Transect B than Transect A, and why there are fewer soft worms. Movement to lower levels of the sediment is another intertidal adapation organisms in Transect B may practice.

Although the author did not measure oxygen concentrations, the relatively stagnant nature of water at Transect A leads one to infer that Transect A has a more oxygen-poor environment than Transect B. Because marine oligochaetes are well adapted to oxygen-poor environments, they might be allowed to outcompete other organisms in Transect A. Because oxygen does not appear to be as limited in Transect B, other organisms can compete more efficiently. This may account for the lower percent composition of oligochaetes in Transect B (Table 2).

Microenvironmental differences might be the source of variation between stations located only 3.3 m apart within the same transect. Jones (1961) noted that none of the species in his study exhibited an even pattern of distribution. Most of the species he studied were randomly dispersed throughout his study areas. Sometimes they were distributed in high population clumps. Most of the taxa studied in

White Slough seem to be distributed in clumps, but more samples need to be taken to verify this distribution. Both Jones (1961) and this study show that small multiple samples seem to be the best way to get good quantitative data. A single large sample might miss several unique clusters of taxa. It would be like trying to determine the ethnic variety of San Francisco by surveying one huge block of Chinatown.

The sources of uneven distribution are difficult to discern. Small differences in salinity, sediments and depth can produce large variations in taxa. Also, clumping may be advantageous to some species. Adaptive resources, like tube networks, then can be shared. Larval distribution, which can be based on physical factors such as currents and wind direction, probably also is an important determinant of species distribution (Jones, 1961).

Conclusions

The instability of the San Pablo Bay environment contributes to the state of benthic population instability in both Mare Island Strait and White Slough, causing a greater proportion of opportunistic taxa to be found in these environments, than in more stable Bay and oceanic environments. Differences in environmental stresses produce differences in taxa between Mare Island Strait and White Slough, and between the northern and southern White Slough areas. Different taxa vary in their ability to adapt seasonal variations in salinity and sediment stability. Generally, those species characterized as opportunistic show the most seasonal variation in populations. Microenvironmental variations and species interactions cause large variations in taxonomic diversity and populations within small areas. The interaction of many complex environmental and biological factors produce the benthic community of White Slough, which is in no way uniform.

The first benthic surveys were initiated by the decline in productivity in the San Francisco Bay fisheries 75 years ago (Nichols, 1979). Early biologists hoped that the relative immobility of the benthos would allow them to evaluate quantitatively the anthropogenic effects of pollution and siltation. The effects on more mobile, more valuable organisms could then be extrapolated from the benthic variations in populations and diversity caused by environmental disruptions. What most benthic surveys have shown, including this one of White Slough, is that any detrimental anthropogenic effects on the benthos will be very difficult to separate from natural variations in salinity, sedimentation, weather patterns, food supply and species interaction (Nichols, 1979). It will be difficult to determine how development will affect the White Slough benthos.

Quantitative understanding on how the interaction of environmental factors affects benthic diversity seems to be moving at a snail's pace, especially in the environmentally unstable South and San Pablo bays. The large amount of understanding that can be gained from studying the benthos makes continued research worthwhile, however. If baseline benthic values can be determined, then man in the future will be able to predict the effects of reduced freshwater inflows, waste outfalls, dredging and filling on the Bay's biota (Nichols, 1979). Relatively undisturbed sites, such as White Slough, provide useful places to establish these baselines. The role of the benthos in the White Slough food chain should also be studied. It is hoped that the study of the benthos will aid in man's understanding of his specific role in the decline of the Dungeness crab, striped bass, and other fisheries in the Bay, as well as give him a clearer understanding of the complex Bay environments.

APPENDIX

Transect A - November

I marked the starting point along the south slough shore with a yellow stake. One pace was approximately 30 centimeters. From the yellow stake, I put in three more stakes heading N13E into the water. Each sample was taken a random number of paces left (S27W) or right (N83E) from the base transect.

Transect B - November

Transect B is located on the northwest side of the slough. The bearing was found to be N15E from the metal pole on the northwest side of Highway 37 to the F on the foundation health plan sign. I then walked 50 yards S83W to the small stone wall on the slough. From that corner, I then walked 72 paces S27E, and put in another stake. From this base stake, I walked S67E into the water. Samples were taken a random number of paces (N3E) or right (S20W) of the central line.

Transect A - February

From the yellow stake marking Transect A in November, I walked 11 paces towards the Highway 37 (N40E), in order to ensure an undisturbed transect that would still be similar to Transect A in November. I walked N10E into the water. Each sample was taken a random number of paces left (S30W) or right (N79E) of the main transect.

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