THE INFLUENCE OF COMMERCIAL OYSTER CULTURE ACTIVITIES ON THE BENTHIC INFAUNA OF ARCATA BAY

by

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A Thesis
Presented to
The Faculty of Humboldt State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

December 1996

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ABSTRACT

The influence of oyster culture activities on the intertidal benthic invertebrate infauna of Arcata Bay, the northern arm of Humboldt Bay, California was assessed by ANOVA models, measuring community dominance and frequency, generating diversity and similarity/index volume curves, and by employing cluster analysis. Samples were taken in oyster bottom culture sites, sites where oyster shell has been deposited, and in natural communities functioning as control sites from the northern and southern portions of Arcata Bay during the summer of 1992 and the winter of 1993. The control site in the northern, or upper portion of Arcata Bay was a mudflat control, the southern, or lower control site was an eelgrass bed. Each control site was compared with an oyster bed and a site where oyster shell has been deposited, here shell deposition sites, from the same locality.

Results indicated that the deposition of crushed shell upon the bay substrate created a spatially heterogeneous environment, the community of which contains both infaunal and epifaunal species. Oyster beds also contained a different species composition in comparison with both control sites. Oyster beds appeared to exhibit changes in community structure between the seasons.

It was concluded that shell deposition sites probably represented a loss of habitat to species which normally feed in soft sediment environments. The introductions of non-native species as a result of instituting oyster culture in Arcata Bay were found to have molded the structure of the entire intertidal benthic community.

ACKNOWLEDGEMENTS

This project was partially funded by the California Department of Fish and Game through Mr. Ron Warner of the Eureka Office. My thanks to the State of California for the monetary support so vital to graduate research, and to Mr. Warner for providing logistical support and employment after my funding ran out.

My graduate advisor, Dr. Roger A. Barnhart of the California Cooperative Fisheries Research Unit, provided logistical, monetary, and personal support through some very difficult circumstances during my period of study. His patience and thoughtfulness are appreciated.

My committee members, Dr. Milton J. Boyd and Dr. Timothy J. Mulligan, provided direction and encouragement, and demonstrated a sincere personal interest in my graduate progression. Dr. Yoo Kim kindly contributed his statistical expertise.

Lorrie Bott graciously provided her expertise in identifying many specimens.

My fellow graduate students provided their intellectual, emotional, and physical support throughout. Linda Fukushima accompanied me on many frigid mornings on Humboldt Bay, as did Anne Gray and Margaret Glowacki.

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INTRODUCTION

Humboldt Bay is located 372 km north of San Francisco, CA. It is the fifth largest estuary along the U. S. Pacific Coast, excluding Alaska, and is second in size to San Francisco Bay in California. It is the only harbor of commercial importance between San Francisco Bay and Coos Bay, Oregon, 335 km to the north (Barnhart et al. 1992).

Covering approximately 62.4 km^2 at mean high tide (MHW) and 28 km^2 at mean lower low water (MLLW), Humboldt Bay is 22.5 km long and ranges in width from 0.9 km to 7.4 km (Shapiro and Associates 1980; Barnhart et al. 1992). It is divided into three distinct subunits; South Bay, Entrance Bay, and Arcata Bay (Figure 1). At low tide extensive intertidal mudflats are exposed, mainly in South Bay and Arcata Bay. These mudflats are separated by several deep, and numerous shallow channels. Approximately 20% of the intertidal mudflats in Humboldt Bay are composed of eelgrass beds (Barnhart et al. 1992). In Arcata Bay eelgrass beds cover 435 hectares, while in South Bay eelgrass beds cover 786 hectares (Harding and Butler 1979). Costa (1982) described Humboldt Bay as a tidally driven coastal lagoon with three shallow interconnected basins.

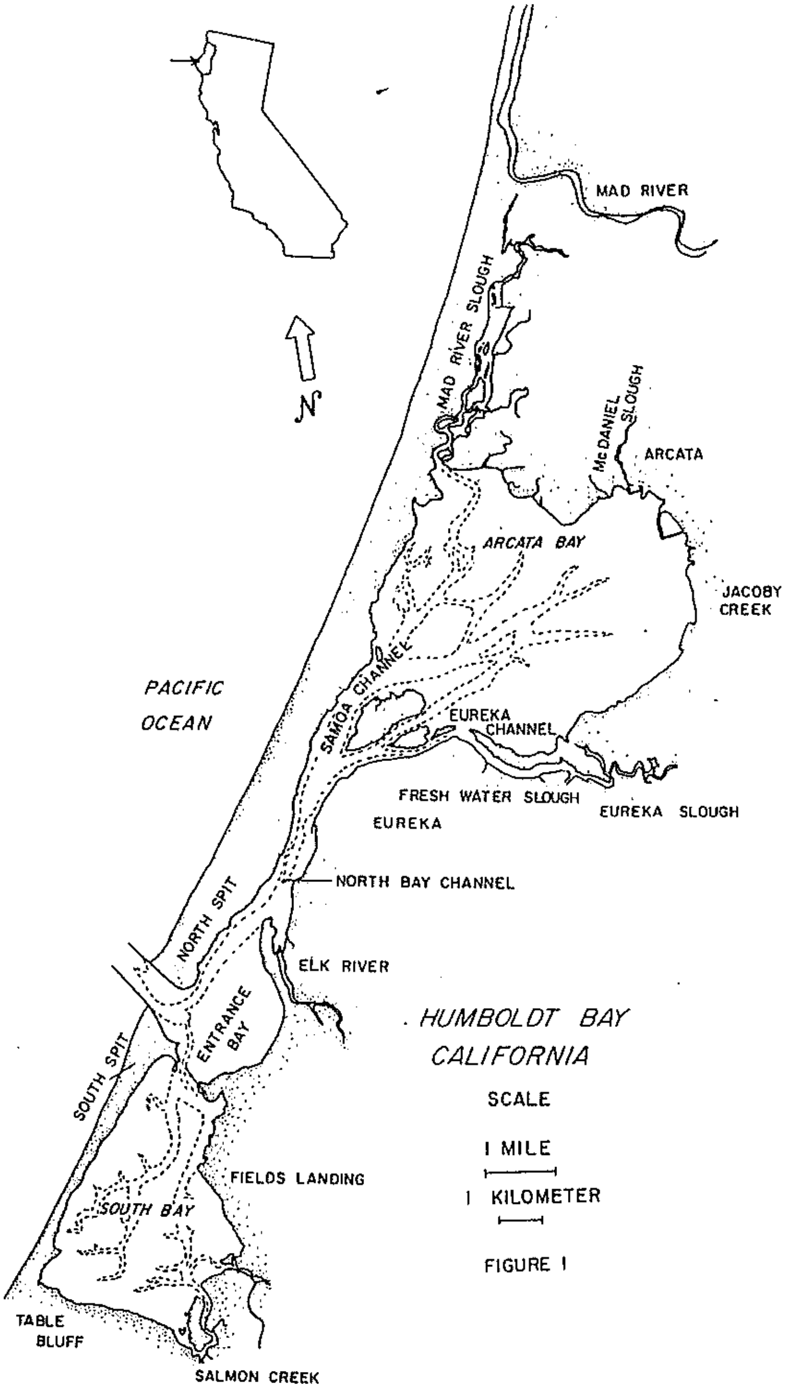


Figure 1. Humboldt Bay, California (from Costa 1982).

True estuarine conditions prevail near freshwater inputs on a seasonal basis (Barnhart et al. 1992).

First sighted by non-indigenous peoples in 1806 (Davidson 1891), Humboldt Bay was resighted and named in 1849 following the discovery of gold in California (Cutten 1920). Since the 1850's, the Humboldt Bay area has undergone substantial change. The principal ecological change to Humboldt Bay has been the enormous reduction in saltmarsh habitat due to filling for agricultural purposes (Shapiro and Associates 1980). The extensive saltmarsh habitat that comprised the eastern portion of the bay was dyked following completion of the Northwestern Pacific Railroad in 1901 and drained for agricultural use with the subsequent construction of Highway 101 in 1927 (Ray 1982). Along with these alterations to the size of the bay, a major commercial industry, oyster culture, began operations in 1955 within Arcata Bay (Barret 1963). Oyster culture was first attempted in Humboldt Bay with the introduction of the eastern oyster (*Crassostrea virginica*) into South Bay in 1895 (Bonnet 1935; Barret 1963). This attempt and subsequent others, including an effort to cultivate the native Olympic oyster (*Ostrea lurida*) (Bonnet 1935, 1936), were supported by the California Department of Fish and Game but failed for various reasons (Barret 1963). The Department of Fish and Game continued its efforts to encourage aquaculture until 1955 when the Coast Oyster Company (currently Coast Seafoods Incorporated), commenced the successful cultivation of the Pacific oyster (*Crassostrea gigas*) in Arcata Bay (Barret 1963). Coast Seafoods Incorporated has become a successful business, and currently harvests over 43% of the total tonnage of oysters produced in the State of California (R. Warner, California Department of Fish and Game, pers. comm.).

Presently, two types of oyster culture predominate in Arcata Bay. The first and most prevalent type is bottom culture, where oysters are grown on shell spread directly on the bay substrate. The second is oyster longline culture, where oyster shells containing spat are strung with line and suspended above the bay substrate. Oyster bottom culture covers approximately 163 ha of intertidal mudflat, whereas longline culture comprises approximately 6 ha (Ecoscan Resource Data, 1993) (Figure 2). The majority of oyster culture sites occur in intertidal mudflat areas favorable to eelgrass growth (Ecoscan Resource Data 1993). Waddell (1964) determined that the harvesting by mechanical dredge of bottom cultured oysters in Arcata Bay decreased the abundance of the native eelgrass, (*Zostera marina*), a finding supported by later bay studies (Thompson 1971; Harding and Butler 1979).

The abundance of macrofaunal assemblages in eelgrass beds is well documented and has been associated with biogenic structure (Orth et. al. 1984). Phillips (1984) summarizes numerous macrofaunal and nektonic species which utilize eelgrass beds of the Pacific Northwest, acknowledging that less is known pertaining specifically to benthic infauna. In Humboldt Bay, eelgrass communities

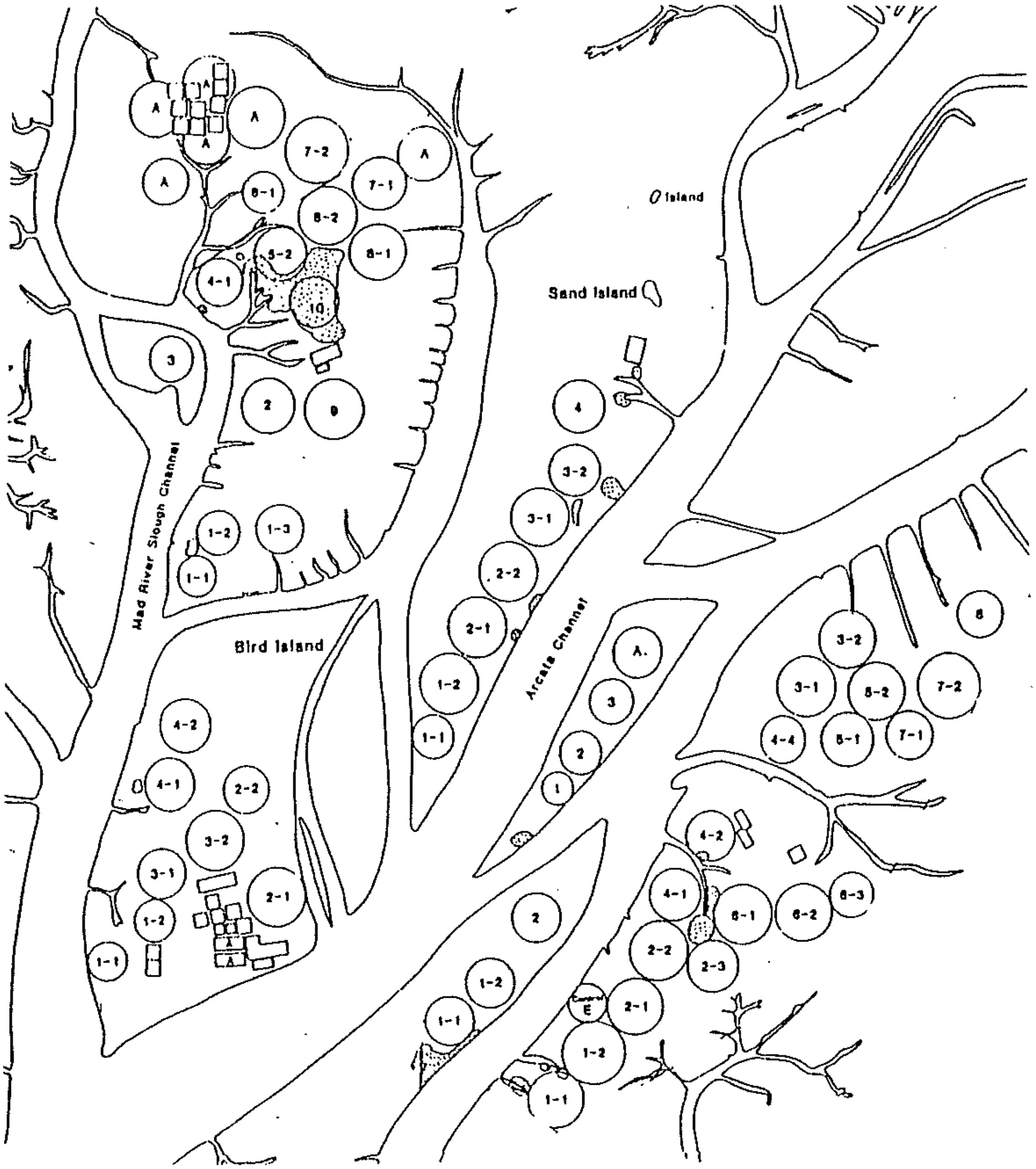


Figure 2. Oyster culture and shell deposition sites in Arcata Bay, California (from Ecoscan Resource Data 1992). Circles represent oyster bottom culture sites. Rectangles and squares represent oyster longline culture sites. Stippled areas represent shell deposition sites.

serve as an important food source for many migratory birds, particularly the black brant (*Branta bernicula nigricans*) (Barnhart et al. 1992). Numerous species of shorebirds feed on the invertebrate assemblage, with the Dunlin (*Calidris alpina*) favoring eelgrass seeds (Holmberg 1975). Fish species of commercial value which utilize eelgrass beds, especially during their juvenile stages, include the English sole (*Parophys vetulus*) and rockfish (*Sebastes*), which feed on the rich fauna associated with eelgrass beds. (Toole 1978; Mike Prall pers. comm.). In addition, Pacific herring (*Clupea harengus pallasi*), which comprise the largest commercial fishery in the bay, utilize eelgrass beds as a spawning and nursery ground (Miller and Schmidtke 1956; Rabin and Barnhart 1986; Barnhart 1988). Numerous non-commercial fish species are also found in eelgrass beds in Humboldt Bay (Toole 1978; Barnhart et. al. 1992; T. Mulligan pers. comm.).

Oyster processing for market produces large quantities of empty shells. Coast Seafoods Incorporated applies for a permit from the Army Corps of Engineers to deposit oyster shell near the Mad River Slough in the northwest portion of Arcata Bay (Figure 3). Shell has been deposited in this area since the late 1950's without a noticeable, incremental increase in mounding according to Coast Seafood personnel (Coast Seafoods Inc, pers. comm.). This permitted shell deposition site comprised one of the sampling sites in the Upper Bay Sites. Deposition of shell has also occurred in other parts of Arcata Bay; one location deposited within the past ten years was on an eelgrass patch near Indian Island(R.

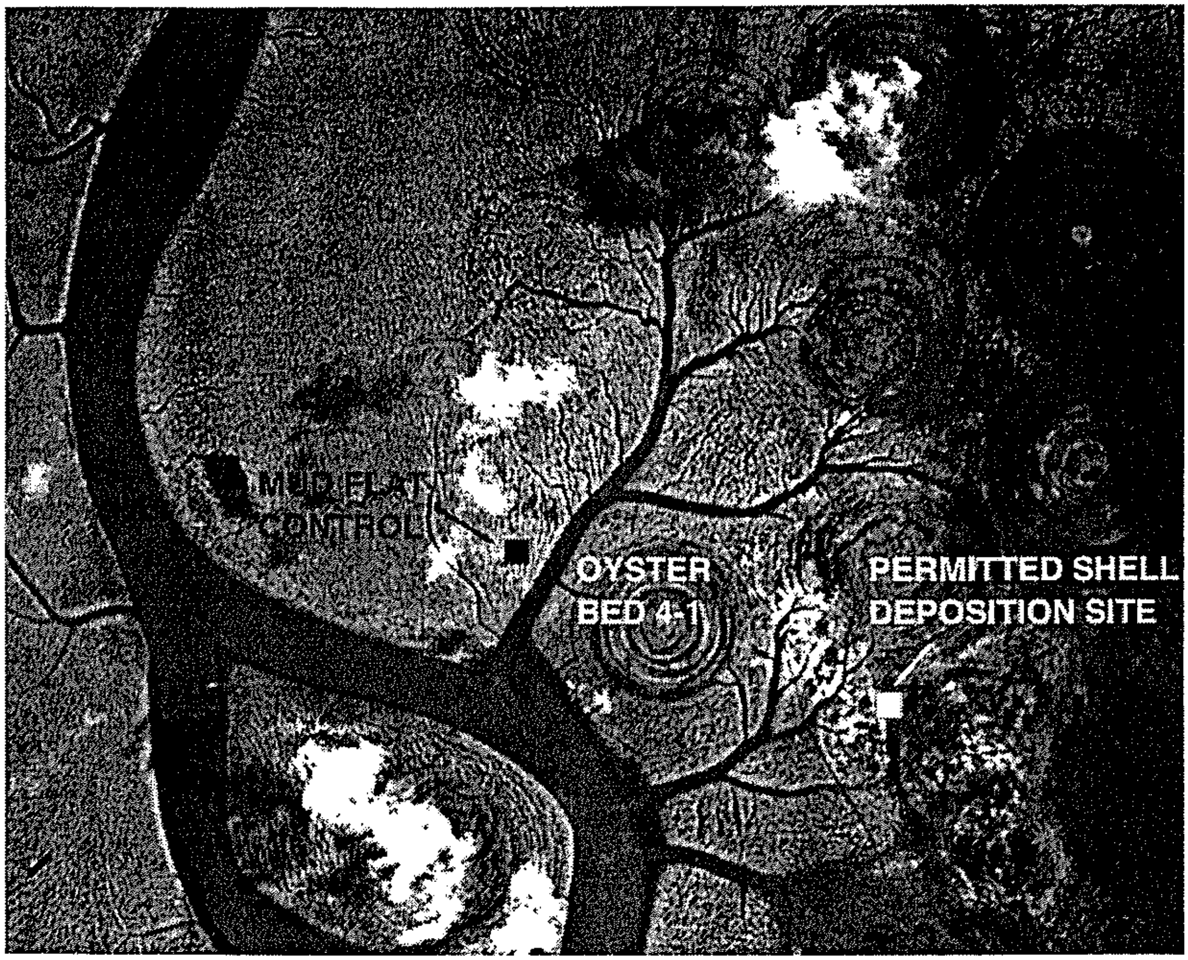


Figure 3. Sampling Sites in Upper Bay Sites, Arcata Bay, California, June 5, 1992. Circular areas are oyster beds. Shell deposition appears multicolored; from white to very dark. White irregular shapes are clouds. Eelgrass appears as dark areas along channel banks, and in far righthand portion of photograph.

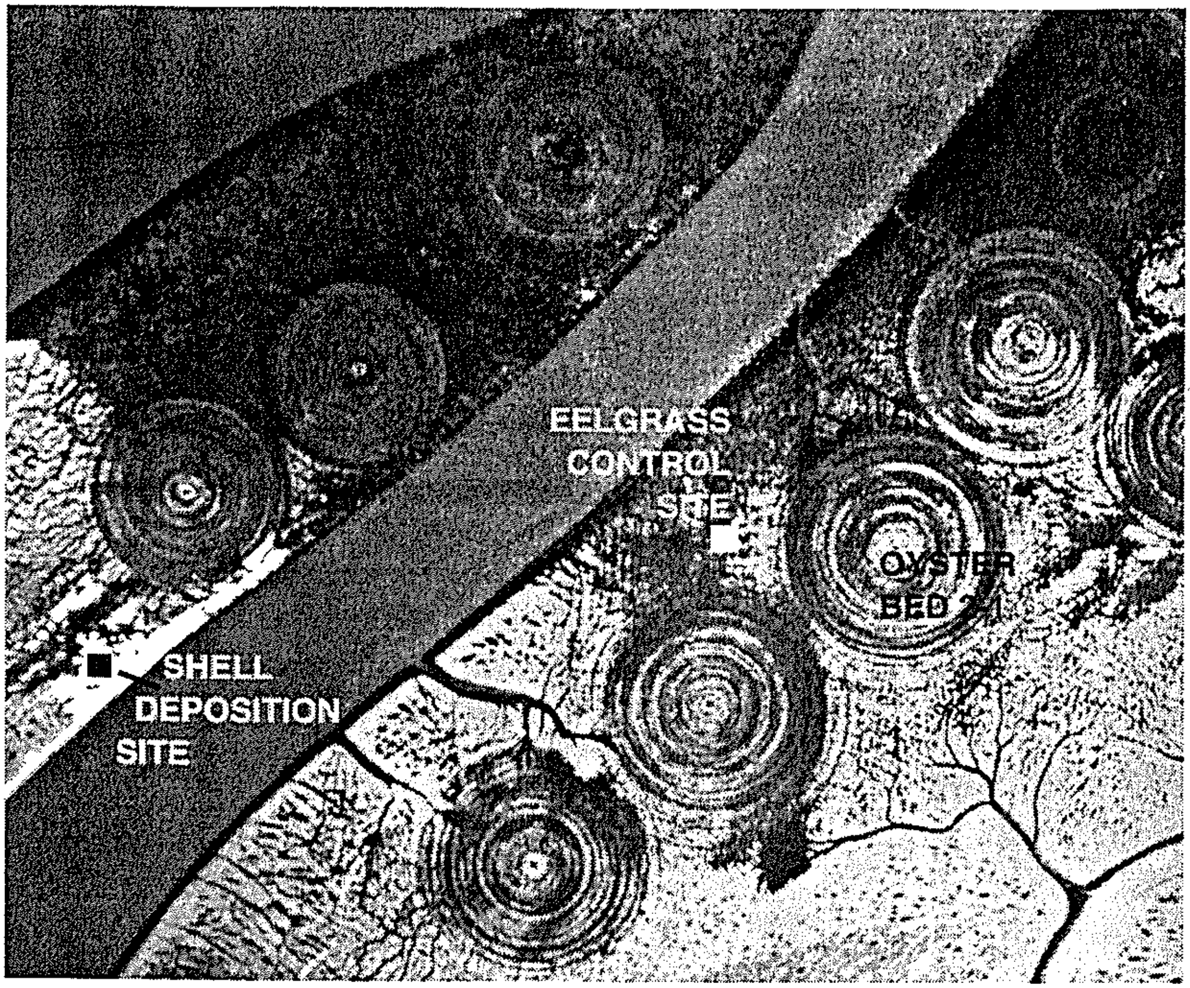


Figure 4. Sampling Sites in Lower Bay Sites, Arcata Bay, California, June 5, 1992. Circular areas are oyster beds. Shell deposition appears white. Mudflat areas appear light. Eelgrass areas appear dark.

Warner, California Department of Fish and Game; Coast Seafoods Inc. pers. comm.) (Figure 4). Shell at this site was deposited in a large mound, later spread out, and the site is currently used as an oyster seed bag holding area. This shell deposition site comprised one of the sampling sites in the Lower Bay Sites. Shell deposition sites comprise nearly 13.4 ha of intertidal habitat in Arcata Bay (Ecoscan Resource Data, 1993). Crushed oyster shell was suggested as a control of eelgrass growth in oyster cultivation sites in the Canadian Maritime Provinces, because dense eelgrass growth apparently obstructed oyster harvest and had a negative impact on oyster growth (Taylor 1954). It is a common practice to deposit crushed oyster shell in oyster bottom culture sites to create a firmer substrate upon which oysters can grow (Craig Codd, Coast Seafoods Incorporated).

Studies describing the assemblages of oyster bed communities have for the most part been limited to native oyster reefs and the natural associated shell deposition (Wells 1961; Hughes and Thomas 1971 a,b; Maurer and Watling 1973; Bahr 1974; Dame 1979; Larsen 1985; Larned 1991). While the majority of these studies focused on the entire macrobenthic community, Larned (1991) studied the associated benthic infauna.

Density and diversity of macrofaunal assemblages associated with native oyster reefs and their shell remains are greater than density and diversity levels of macrofaunal assemblages in non-oyster bed environments (Barnes et al. 1973; Dauer et al. 1982; Larsen 1985). Although these studies have established a high diversity of native oyster reef macrofauna in relation to surrounding benthic environments, published studies describing the relationships between shellfish culture and infauna are virtually non-existent (Castel et al. 1988). Everett et al. (1992, in press) found that stake culture of commercial oysters in Coos Bay, Ore. decreased recruitment of clams, while rack culture had no effect on clam abundance. Both types of culture resulted in increased densities of peracarid crustaceans. Castel et al. (1988) compared the macro- and meioinfaunal components of commercial rack and bottom culture of the Pacific oyster (*Crassostrea gigas*) with seagrass (*Zostera noltii*), and "baresands" in Arachon Bay, France. They found macrofaunal abundance to be greatest in vegetated sediments, followed by baresands and oyster cultivation areas, and meiofaunal abundance greatest in vegetated sediment, oyster culture areas, and baresands, respectively.

The purpose of my investigation was to determine what influence, in terms of community structure, oyster bottom culture and crushed shell deposition have on the intertidal benthic environment in Humboldt Bay, California.

STUDY AREA

Benthic samples were collected from several sites in the lower and upper parts of Arcata Bay (Figure 2). The Lower Bay Sites consisted of the following sites near the Bracut Channel (Fig. 2 ; Fig. 4):

1) The shell deposition site near Indian Island.
2) Oyster Bed #2-1, as identified by Coast Seafoods Inc., in East Bay.
3) An eelgrass control site in East Bay.

The Upper Bay Sites consisted of the following sites near the Mad River Slough Channel (Fig. 2; Fig. 3):

1) The permitted shell deposition site.
2) Oyster Bed #4-1, as identified by Coast Seafoods Inc.
3) A mudflat control.

The collection of samples from these two areas provided information on the two intertidal habitats in Arcata Bay currently under oyster cultivation; lower mudflats and eelgrass meadows. The Lower Bay sites' height ranged from approximately -0.5m for the eelgrass control, to approximately 0.5m for the shell deposition site near Indian Island. The Upper Bay sites ranged from 0.5m for oyster bed #4-1 and the permitted shell deposition site, up to 1.0m for the mudflat control site.

METHODS AND MATERIALS

Determination of sampling sites within each area for each sampling period was done in a random fashion, with actual sampling then restricted to that chosen site. The sampling technique employed was based upon the concentric nature of the oyster bottom culture sites. A small diameter pcv tube marked with six equidistant (approximately sixty degrees apart) vertical lines was placed into the sediment at the center of each site. Therefore six samples were taken per site. Random distances were measured out from each vertical line to pinpoint each sample location (Figure 5). The area of each site sampled was based upon the smallest site in each area, with the exception of the shell deposition site near Indian Island. This site was relatively irregular in form, preventing establishment of a concentric area. The sampling technique was modified by measuring out randomly chosen distances from a selected center point, until a randomly chosen distance fell within site boundaries. This sampling protocol avoided the chance clustering of samples.

Benthic samples were taken with a coring device made from pcv tubing, 10.2cm in diameter and 81.1cm^2 in area. The core was inserted to a depth of 10cm. After extraction, samples were sieved through a 1.0mm mesh screen, fixed in 10%

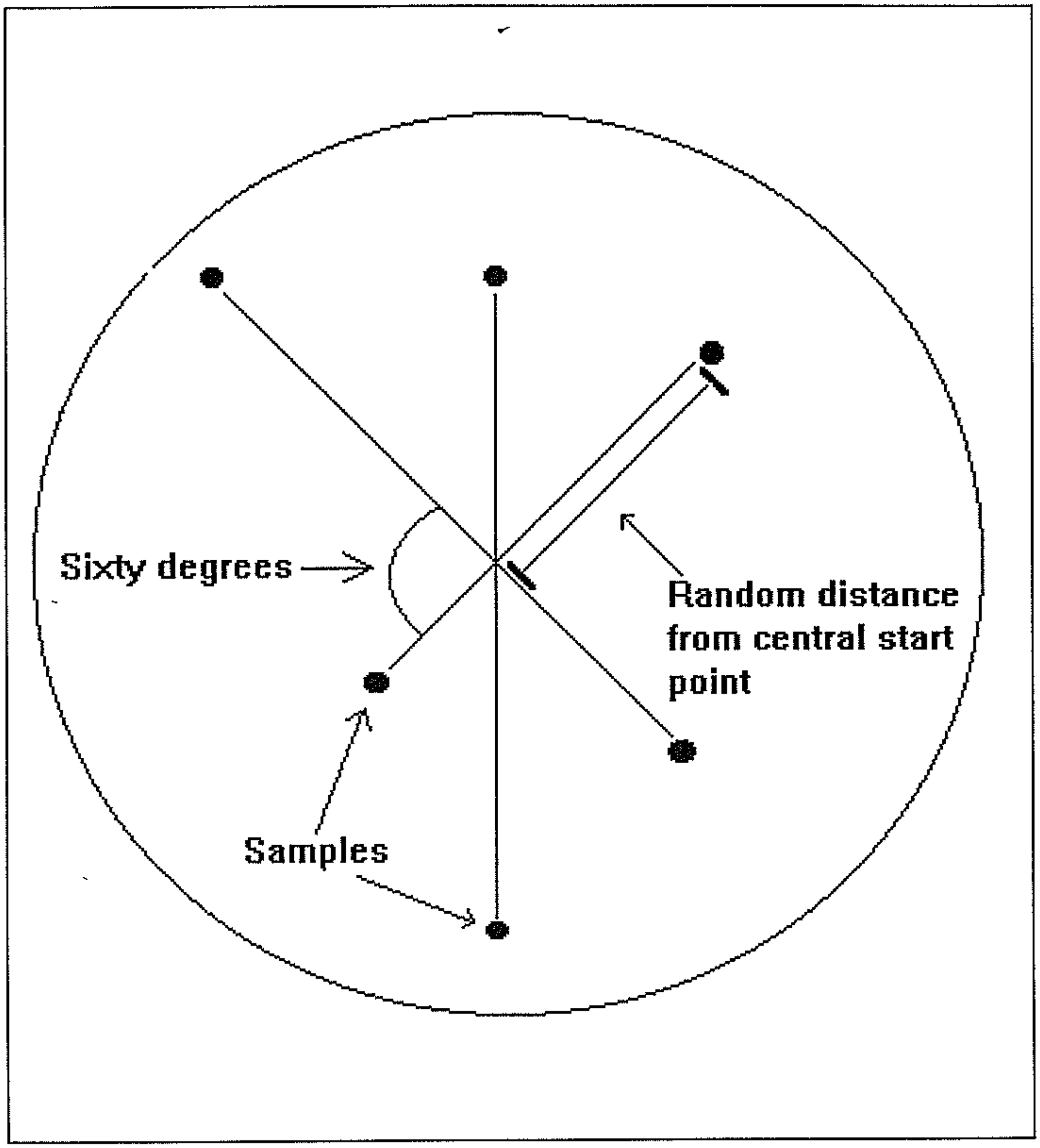


Figure 5. Schematic diagram of sampling technique used to collect benthic samples in Humboldt Bay, California.

formalin for at least 2-3 days, then transferred to 60% ethanol for permanent storage. Coring devices smaller in diameter than the one used here are advantageous because more samples can be processed, resulting in more degrees of freedom than would be provided by fewer large samples. In addition, this approach covers a wider range of habitat (Elliott 1977). However, due to the various sized shell in the deposition areas, a larger than optimal coring device was used in all sites (Lewis and Stoner 1981). Lewis and Stoner (1981) and McIntyre et. al. (1984) recommended the use of a 0.5mm mesh sieve for the sampling of macrobenthos because larger sieve sizes tend to underestimate the number of individuals in a species. Ferraro et. al. (1989) found that laboratory processing time was 2.5 times greater using a 0.5mm vs. a 1.00mm mesh, without an increase in statistical power. Consequently a 1.0mm mesh size was chosen for this study.

Samples were taken in the summer and winter months to include periods of minimum (February) and maximum (June-July) benthic invertebrate abundance in Humboldt Bay (Carrin 1973). Wet weight biomass was determined for each sample using a top-loading balance. Individuals from each sample were enumerated to determine abundance. Specimens were classified to the lowest possible taxonomic level using the following keys: Hartman (1968, 1969), Kozloff (1974), Fauchald (1977), Light (1978), Smith and Carlton (1980), Hobson and Banse (1981). For incomplete specimens of polychaete worms and amphipod crustaceans, only those with heads were counted. For incomplete bivalve specimens, only those with an umbo and stomach were counted. Unidentified specimens and specimens taken only to the level of genus, unless unique to all samples or to a particular site, respectively, were not included in subsequent calculations.

Determination of how many samples to collect has been debated in benthic ecological work (Elliott 1977, Green 1979, Downing 1979, McIntyre et al. 1984, Vezina 1988). The time and cost of processing benthic samples being a well established and problematic consideration in investigations. Five preliminary samples were taken from the East Bay Eelgrass Control and Oyster Bed #2-1 sites each in April 1992 to determine the number of samples required for statistical analyses. This was determined by examining the asymptotic behavior of the resultant species-area curves (Figure 6). The asymptotic form of the oyster bed curve indicated that five samples would be sufficient to attain a representative sample of the community. The eelgrass site appeared to be continuing to increase at five samples, though incrementally less so. Based on these observations, it was decided that six samples would be taken from all sites. A shell deposition site was not included in preliminary sampling.

The number of samples necessary to achieve a specific level of precision can be determined for particular sampling situations from an algorithm dependent upon the relationship of the sampling variance to the sample mean obtained from

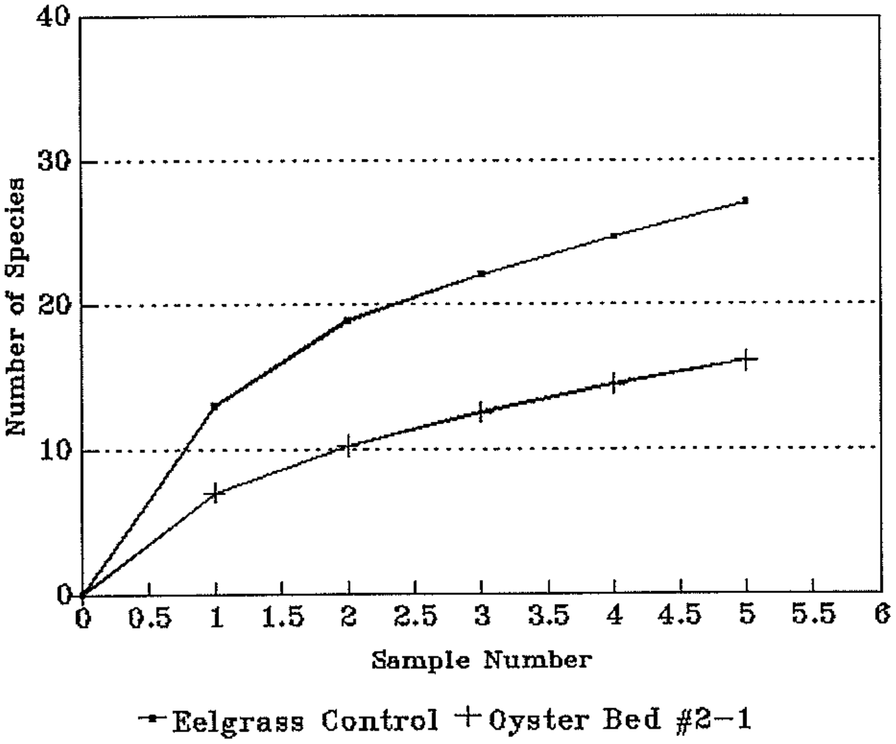


Figure 6. Preliminary samples from Eelgrass Control Site and Oyster Bed #2-1 of Lower Bay Sites in Humboldt Bay, California, Spring 1992.

preliminary sampling (Elliott 1977). General equations describing the relationship of sampling variance to sample mean derived from pooled quantitative studies have been established for freshwater benthos (Downing 1979), epiphytic invertebrates (Downing and Cyr 1985), stream benthos (Morin 1985), and lacustrine macrophytes (Downing and Anderson 1985). Vezina (1988) produced a similar equation for marine benthos, derived from 20 quantitative surveys of marine soft bottom communities. This equation was then used to construct an algorithm to determine the number of samples necessary to attain a specific level of precision, based only on an estimate of the mean. The algorithms presented by Elliot (1977) and Vezina (1988) were compared by determining precision for the eelgrass control site and oyster bed #2-1, based on six samples per site. Although Vezina's algorithm does not require preliminary sampling, it does require an estimate of the mean, typically derived from published studies. The mean used here was derived from the preliminary samples to see if a different precision resulted using different algorithms. The algorithm presented by Elliot (1977) is;

$$n_r = s^2 / mD^2$$

While the algorithm developed by Vezina (1988) is;

$$n_r = 1.641 m^{-0.781} D^{-2}$$

Here, D=desired precision (as a percent estimate of the true mean), m=sample mean, n_r=number of replicates, s^2=sample variance.

Precision is the relationship of the standard error to the sample mean (Elliot 1977). A low precision is representative of greater accuracy in estimating the population or true mean, in this case, organism abundance. Results of these calculations for oyster bed #2-1 were D=0.186 from Elliot's algorithm and D=0.164 using Vezina's algorithm. For the eelgrass control site, D=0.125 for both algorithms. Six samples resulted in adequate levels of precision for each site. Results from both algorithms were very similar, indicating that given a realistic estimate of the mean, the time and cost of processing preliminary samples could be avoided. It should be noted that seasonal variation could change mean values, resulting in varying estimates of the number of samples necessary to attain a specific level of precision.

ANALYSIS

ANOVA

The following null hypotheses were tested to determine if oyster bottom culture and shell deposition affected benthic community structure;

1) No differences in abundance, biomass, and diversity of the benthic macrofauna exist between the lower Arcata Bay sites; including an eelgrass control in east bay, a shell deposition site near Indian Island, and an oyster bottom culture site in east bay.
2) No differences in abundance, biomass, and diversity of the benthic macrofauna exist between the upper Arcata Bay sites; including near the Mad River Slough a mudflat control site, a shell deposition site, and an oyster bottom culture site.

Two way ANOVA models with the factors of season containing two levels(summer and winter), and site containing three levels(control, shell deposition and oyster bottom culture), were used to test the null hypotheses for significant differences between the sites in upper and lower Arcata Bay for the response factors abundance, biomass, and diversity. Because multiple tests were conducted on the same data set, it was necessary to use a corrected alpha level for each test to account for error compoundment (Dunn and Clark 1974). This was accomplished by dividing the desired alpha level, 0.05, by the number of tests run. For this study the alpha level for each test was; $0.05/3 = 0.017$, where 3 represents the number of response factors tested for each data set. Response factors were tested for differences between the sites in upper and lower Arcata Bay, separately. This was done to offset any potential changes in abundance, biomass, or diversity that may have arisen due to the effect of sampling the upper and lower Arcata Bay sites during different tidal series.

Diversity was calculated using the Shannon Index:

$$H' = -\sum_{i=0}^{n} p_i \, lg_2 \, p_i$$

This index is widely used by ecologists even though it assumes that the actual number of species in a community is known (Pielou 1977), and tends to underestimate the true value in the sampled area (McManus and Pauly 1990). The index is commonly used because it follows a normal distribution at higher sample sizes, and thus can be subjected to parametric statistics (Magnurran 1988). For the purposes of this study, the value of the index was the elucidation of community structure, rather than a precise estimate of diversity.

Following the ANOVA test results, sites were grouped using Tukey's test, one of the more conservative multiple comparison procedures (Dowdy and Weardon 1991). The Tukey test protects the Type I error rate by using a single error rate, or alpha level, for the entire experiment (Dowdy and Weardon 1991). If ANOVA results found significant interactions the Tukey test was not conducted because multiple comparison tests are designed to elucidate significant main effects only (Hicks 1982).

Abundance and biomass data were initially viewed employing Box Plots, which indicated non-normality, except for lower bay abundance (Fig. 7a & 7b, respectively). Abundance and biomass were then transformed using the fourth root transformation (Downing 1979; Field et al. 1982). After transformation, Box Plots were observed for abundance and biomass and it was determined that transformation was successful in approximating a normal distribution, except for upper bay biomass, which still exhibited outliers (Fig. 8a & 8b). A Box Plot for diversity was also examined, and it was determined that these data sufficiently approximated normality (Figure 9). Because the ANOVA model is robust to even moderate deviations from normality (Hicks 1982; Dowdy and Weardon 1991), it was subsequently used to test for differences in all the response factors. For comparative purposes upper bay

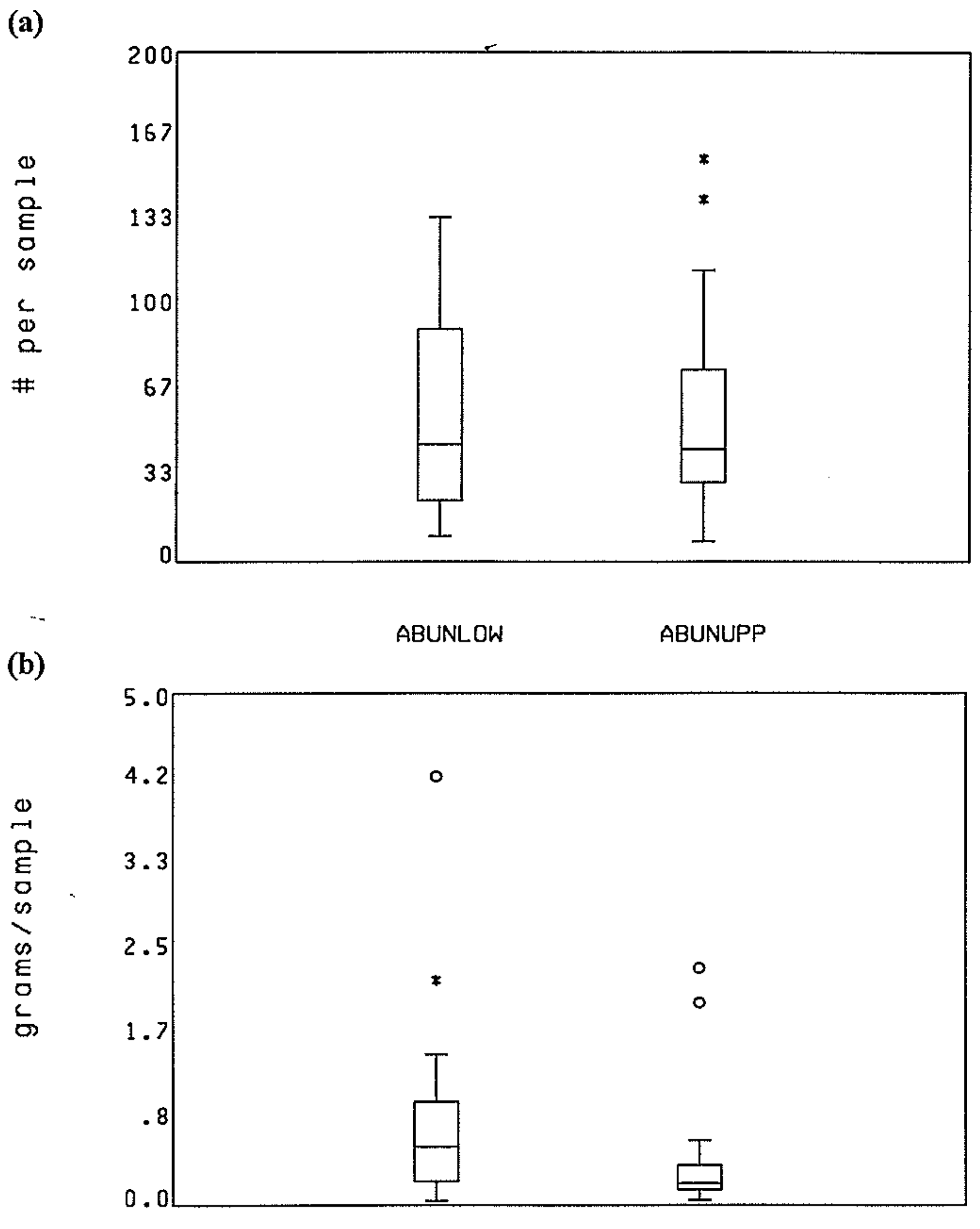


Figure 7. a) Box plot of raw abundance data. ABUNLOW=Abundance Lower Bay Sites; ABUNUPP=Abundance Upper Bay Sites.
b) Box plot of raw biomass data. BIOLOW=Biomass Lower Bay Sites; BIOUPP=Biomass Upper Bay Sites.

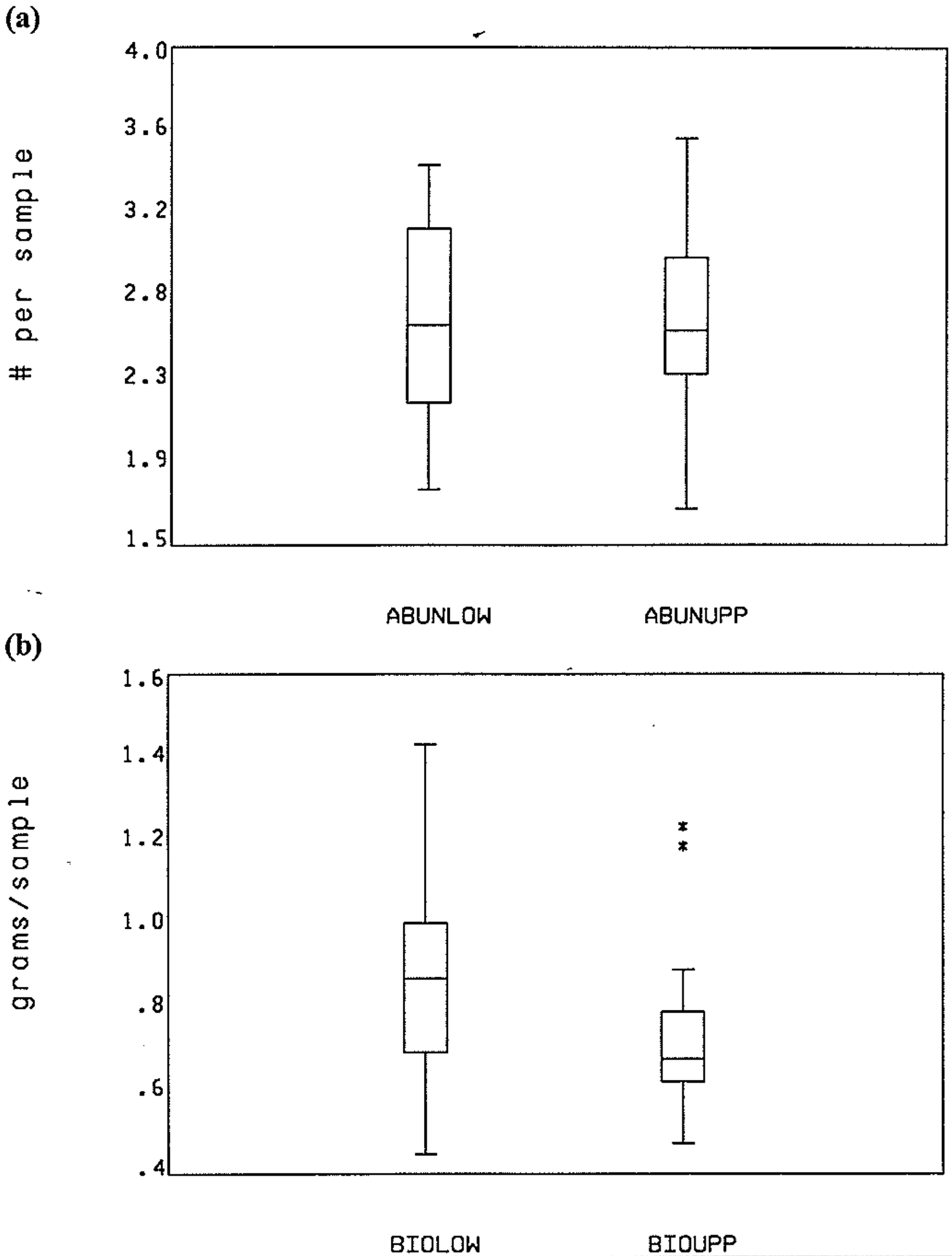


Figure 8. a) Box plot of 4th root transformed abundance data.
b) Box plot of 4th root transformed biomass data.

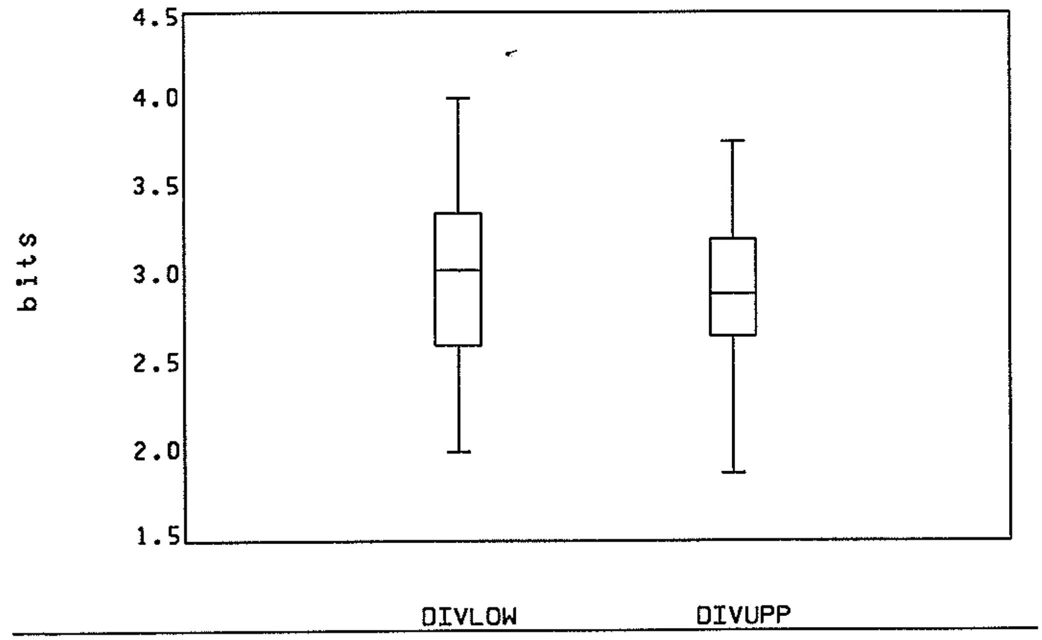


Figure 9. Box plot of diversity data. DIVLOW=Diversity Lower Bay Group. DIVUPP=Diversity Upper Bay Group.

biomass was also tested using the non-parametric Kruskal-Wallis One-Way ANOVA by Ranks Test (Dowdy and Weardon 1991) to confirm results. ANOVA calculations were carried out using two statistical packages; Number Crunching Statistical System (NCSS) (Hintze 1992) and Statistical Analysis Software (SAS) (SAS Institute 1985). Kruskal-Wallis test calculations were conducted using NCSS.

Dominance and Frequency

Dominance (DOM) was calculated as:

$$DOM = (n_i x100) \div N$$

Where; n_i = Number of individuals of species i.

N = Total number of individuals.

Frequency (FREQ) was calculated as:

$$Freq = (mx100) \div M$$

Where; m = Number of samples a given species occurs in.

M = Total number of samples.

These two indices were derived directly from raw data by calculations in Lotus 1-2-3.

Index/volume curves

Delineation of small scale, within site, community structure was assessed by observation of the behavior of two index/volume curves; diversity/volume, and similarity/volume. Construction of these curves necessitated the derivation of the average value of all possible combinations for successively larger sample sizes, or in this case, sampling volumes. The relevance of this technique was to eliminate random effects, resulting in curve smoothing (Weinberg 1978). Combinatorial data points for the similarity/volume curves were derived such that no sample occurred twice in a comparison (Weinberg 1978, Kronberg 1987).

Martin et al. (1993) and Ballesteros (1986, 1991) showed that Shannon Index/Area curves can be fitted by least squares linear regression to the Michaelis-Menton function:

$$y = Ax / (B + x)$$

Following transformation:

$$1/y = B/A * 1/x + 1/A$$

The reciprocal of the y-intercept can then be used to estimate the alpha, or within site diversity of the community (as opposed to the beta, or between site diversity), because by increasing the sampling volume to infinity:

$$\lim_{x \to \infty} [Ax / (B + x)] = A$$

As a result, the diversity expected, if the entire community were sampled, can be estimated. Ballesteros (1986, 1991) and Martin et al. (1993) assumed that diversity became stabilized when the slope of the diversity/area curve reached a value of 0.001. Martin et al. (1993) demonstrated that the size of an area coincident with a specific slope is attained by deriving the Michaelis-Menton function, then substituting the value of the slope (z) for y' to obtain an estimate of the x parameter, in this case volume:

$$x = -B + \sqrt{AB/z}$$

The substitution of 0.001 for z thus yields the required sample volume to reach diversity stabilization.

The Sorensen Index (Sorensen 1948), is a qualitative similarity index measure calculated as:

$$I_S = 2\,C_{pq} / (n_p + n_q)$$

Where C_{pq} = the number of species common to samples p and q.

n_p = the number of species in sample p.

n_q = the number of species in sample q.

The value of I_s ranges from 0, total dissimilarity, to 1 total similarity.

The construction of curves derived from the Sorensen Index allowed comparison of qualitative similarity between sites, elucidating underlying patterns of community structure. Programs were written in *APL* to compute diversity and to generate the combinatorial data points for the index/volume curves.

Cluster analysis

Cluster analysis was performed on species composition data for each bay group. Data matrices were comprised of 35 samples and the top 20 species from each group for each season. This number of species accounted for over 90% of the total number of individuals in each seasonal group, assuring that the dominant species of each group were represented. This scheme considered the seasonal variation of species, and filtered out rare species which could have formed clusters that are not necessarily related to the co-occurrence of the dominant species (Legendre and Legendre 1983).

Similarities were computed using the Canberra Metric Coefficient, and dendrograms were constructed using the unweighted pair-group method using arithmetic averages (UPGMA) (Romesburg 1984). Cluster analyses were carried out using the multivariate statistical package M.V.S.P. (Kovach 1990).

RESULTS

Organism Abundance, Biomass and Diversity

ANOVA results for the response factors organism abundance, diversity and biomass for each bay group are displayed in Tables 1, 2, and 3(a), respectively. During processing, two samples were lost, one oyster bed sample from the lower Arcata Bay winter sample series, and one mudflat control sample from the upper Arcata Bay summer sample series. Thus, an unbalanced design resulted which required interpreting significance values using the Type III output from SAS, an approach designed specifically for this case (Shaw and Mitchell-Olds 1993). One significant seasonal effect was detected, between the upper Arcata Bay sites for the response factor diversity (P=0.0138), with marginally significant effects detected for lower Arcata Bay diversity (P=0.0658) and upper Arcata Bay biomass (P=0.0753). One significant interaction (season by site) was detected for the response factor diversity from the lower Arcata Bay sites (P=0.0043), while a marginally significant result was obtained for lower Arcata Bay abundance (P=0.0831). Five of the six ANOVA's detected significant main effects for the factor site. The only test which did not result in a significant difference between sites was with respect to biomass

Table 1. ANOVA test results for abundance of benthic macrofauna from Humboldt Bay, California.

Lower Bay Source	DF	SS	F-Value	P-Value[a]
Season	1	0.0778	1.17	0.2888
Site	2	5.0633	37.97	**0.0001
Season*Site	2	0.3618	2.71	*0.0831
Error	29	1.9334		
Totals	34	7.4253		

****

Upper Bay Source	DF	SS	F-Value	P-Value[a]
Season	1	0.0049	0.04	0.8372
Site	2	2.7473	11.96	**0.0002
Season*Site	2	0.0679	0.30	0.7461
Error	29	3.3300		
Totals	34	6.1301		

[a] - significance level=0.017.

** - Highly significant difference.

* - Marginally significant difference.

Table 2. ANOVA test results for diversity of benthic macrofauna from Humboldt Bay, California.

Lower Bay Source	DF	SS	F-Value	P-Value[a]
Season	1	0.5555	3.66	*0.0658
Site	2	2.2956	7.55	***0.0023
Season*Site	2	2.0126	6.62	***0.0043
Error	29	4.4062		
Totals	34	9.2019		

****

Upper Bay Source	DF	SS	F-Value	P-Value[a]
Season	1	0.6151	6.88	**0.0138
Site	2	2.5697	14.37	***0.0001
Season*Site	2	0.2552	1.43	0.2564
Error	29	2.5934		
Totals	34	5.8864		

[a] - significance level=0.017.
*** - Highly significant difference.
** - Significant difference.
* - Marginally significant difference.

Table 3. (a) ANOVA test results for biomass of benthic macrofauna from Humboldt Bay, California. (b) Comparison of ANOVA and Kruskal-Wallis test statistic results for response factor biomass in Upper Bay Sites.

(a)

Lower Bay Source	DF	SS	F-Value	P-Value[a]
Season	1	0.0642	1.84	0.1854
Site	2	0.1388	1.99	0.1549
Season*Site	2	0.0754	1.08	0.3523
Error	29	1.0118		
Totals	34	1.3014		

****

Upper Bay Source	DF	SS	F-Value	P-Value[a]
Season	1	0.0667	3.40	*0.0753
Site	2	0.3131	7.99	**0.0017
Season*Site	2	0.0141	0.36	0.7003
Error	29	0.5685		
Totals	34	0.9572		

[a] - significance level=0.017.
** - Highly significant difference.
* - Marginally significant difference.

(b)

Response Factor	ANOVA F	 P-value	Kruskal-Wallis Test H-value	 P-value
Biomass	7.99	0.0017	1.86	0.003

difference. The robustness of ANOVA was verified, because significant non-normality would lead to spurious results (Dowdy and Weardon 1991). Groupings derived from Tukey tests are displayed in Table 4. The result of a significant interaction for lower bay diversity and a marginally significant interaction for lower bay abundance meant that significant results for main effects (season and site) of these specific tests were not reliable, and the Tukey test could not be used to group sites (Y. Kim pers. comm.; Hicks 1982). Consequently, profile plots were produced for these response factors (Figure 10)(Hicks, 1982). For abundance in the upper Arcata Bay sites, the mudflat control and oyster bed were grouped together, and were significantly different from the shell site. With respect to biomass in the upper Arcata Bay sites, the shell site and oyster bed were grouped together, as were the oyster bed and mudflat control. A significant difference existed between the shell site and mudflat control. In the upper Arcata Bay sites, all sites were grouped separately with respect to diversity, with the mean of the oyster bed being significantly different from both the shell site and mudflat control.

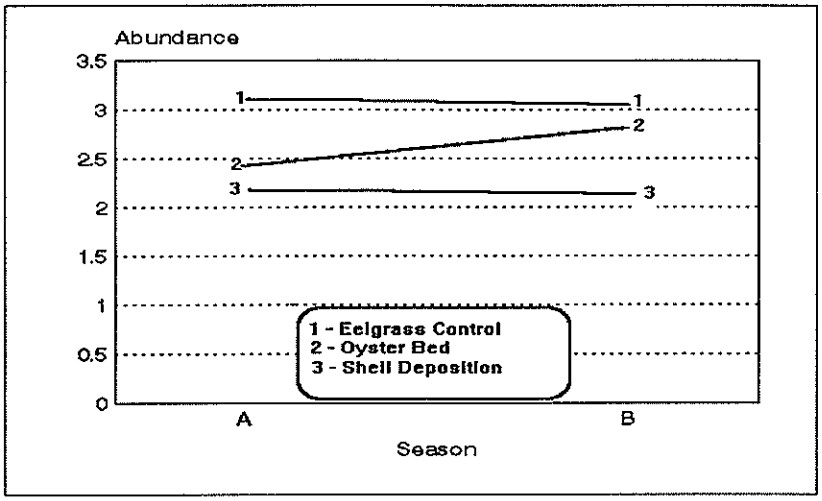
Organism Dominance and Frequency

Species composition tables along with calculations for dominance and frequency are listed in appendices A-L. The number of species comprising 80% of the total number of individuals per site per season is listed in Table 5. Summer results showed that the mudflat control was dominated by four species, whereas all

Table 4. Tukey Test groupings for response factors abundance, biomass, and diversity for benthic macrofauna in Humboldt Bay, California. Sites descend left to right according to mean value.

LOWER BAY	UPPER BAY
ABUNDANCE	
Marginally Significant Interaction	Mudflat Control Oyster Bed #4-1 Shell Site
BIOMASS	
All Sites Grouped	Shell Site Oyster Bed #4-1 Mudflat Control
DIVERSITY	
Significant Interaction	Oyster Bed #4-1 Shell Site Mudflat Control

(a)



(b)

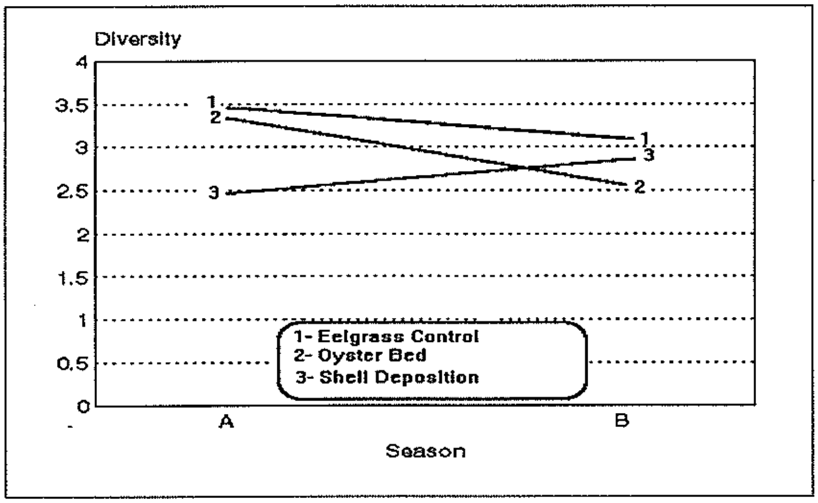


Figure 10. (a) Profile plot of marginally significant interaction for Lower Bay abundance; (b) Profile plot of significant interaction for Lower Bay diversity.

Table 5. Species dominance comprising 80% of the total number of individuals per site, and number of dominant species with frequency of greater than 80%. Benthic macrofauna from Humboldt Bay, California, Summer 1992 and Winter 1993.

SITE	NUMBER OF DOMINANT SPECIES Summer	 Winter	FREQUENCY > 80% Summer	 Winter
Lower Bay Group				
Eelgrass Control	10	9	7	7
Oyster Bed $^{\#}$2-1	10	5	10	5
Shell Deposition	10	10	1	1
Upper Bay Group				
Mudflat Control	4	6	4	5
Oyster Bed $^{\#}$4-1	10	7	8	7
Shell Deposition	9	11	2	4

other sites reflected a more equitable dominance. Winter results showed a decrease in the number of species comprising 80% of the total number of individuals by 50% for the lower Arcata Bay oyster bed, while the upper Arcata Bay oyster bed decreased by 30%. The mudflat control increased in dominance by 33%. Values for the eelgrass control and both shell deposition sites from the winter sample series remained equivalent to summer results.

The number of dominant species per sampling period per site displaying a frequency of greater than 80% are also listed in Table 5. The number of dominant species displaying a frequency of greater than 80% (example; lower Arcata Bay eelgrass control in summer, 7/10=70%) ranged from 10%-36% in the shell deposition sites. At all other sites this occurrence was at least 70%.

Organism Diversity/volume curves

Shannon Index/volume curves for the lower and upper Arcata Bay sites during the summer and winter sampling periods are displayed in Figures 11 & 12, respectively. For both the upper and lower Arcata Bay sites the control and oyster bed site curves were more horizontal or asymptotically shaped than those of the shell sites. The differing shapes of these curves were reflective of the pattern diversities of the communities. That is, a greater increase in diversity as sample volume increases is indicative of a higher pattern diversity. Curve form for each site remained similar during both seasons. In lower Arcata Bay the shell deposition site near Indian Island

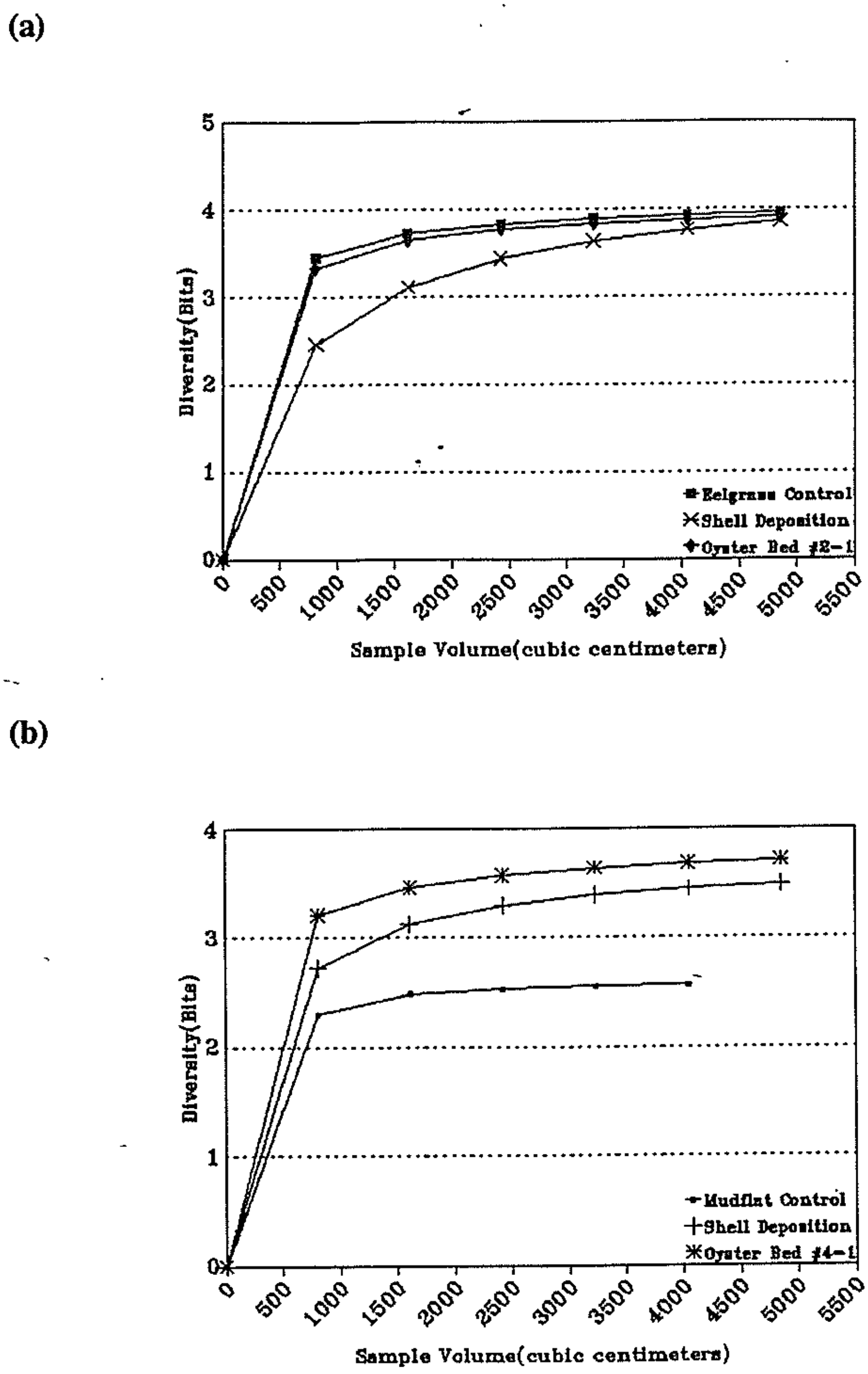


Figure 11. Diversity/volume curves for benthic macrofauna from (a) Lower Bay Sites and (b) Upper Bay Sites in Humboldt Bay, California, Summer 1992.

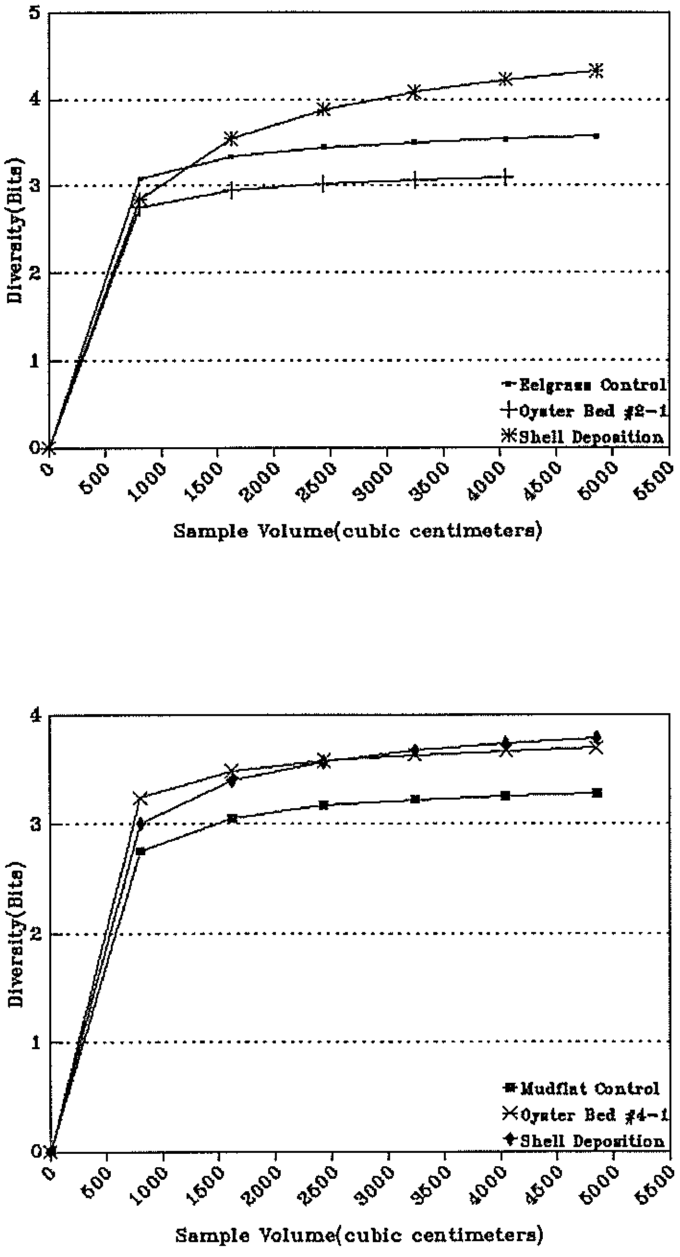


Figure 12. Diversity/volume curves for benthic macrofauna from (a) Lower Bay Sites and (b) Upper Bay Sites in Humboldt Bay, California, Winter 1993.

exhibited a higher pattern diversity, demonstrated by an increased diagonal form, during the winter sampling period. The eelgrass control and oyster bed both showed a lower pattern diversity during the winter period (Figure 11). The upper Arcata Bay shell deposition site and mudflat control displayed higher pattern diversities during the winter sampling period, with the oyster bed remaining nearly the same (Figure12).

The fitted Michaelis-Menton Functions with estimates of alpha diversity, along with volumes corresponding to diversity stabilization (slope values of 0.001), are listed in Table 6. As indicated in the curves for lower Arcata Bay, the shell deposition site near Indian Island exhibited the highest value of alpha diversity and of volume corresponding to diversity stabilization, for both sampling periods. In upper Arcata Bay the shell deposition site along with the oyster bed recorded the highest alpha diversities. The shell site recorded the highest volume corresponding to diversity stabilization for both sampling periods.

Organism Similarity/volume curves

Sorensen Index/volume curves are displayed in Figures 13 & 14. These curves compare the qualitative similarity from comparisons of successively larger samples (volumes) for each site. The similarity values used in graphic construction are listed in Table 7. For both sampling periods in lower Arcata Bay the shell deposition site recorded the lowest similarity values. Similarity at this site increased

Table 6. Fitted Michaelis-Menton Functions showing alpha diversity (bold) and diversity stabilization values for benthic macrofauna in Humboldt Bay, California, from Summer 1992 and Winter 1993.

SITE	ALPHA DIVERSITY Summer	ALPHA DIVERSITY Winter	DIVERSITY STABILIZATION Summer	DIVERSITY STABILIZATION Winter
Lower Bay Group				
Eelgrass Control	$y=\mathbf{4.064}x/(14.333+x)$ $r^2=0.999$	$y=\mathbf{3.677}x/(15.682+x)$ $r^2=0.998$	2270	2240
Oyster Bed #2-1	$y=\mathbf{4.037}x/(17.361+x)$ $r^2=0.999$	$y=\mathbf{3.187}x/(12.619+x)$ $r^2=0.999$	2470	1880
Shell Deposition	$y=\mathbf{4.327}x/(62.167+x)$ $r^2=0.999$	$y=\mathbf{4.791}x/(55.040+x)$ $r^2=0.999$	4570	4580
Upper Bay Group				
Mudflat Control	$y=\mathbf{2.652}x/(12.342+x)$ $r^2=0.993$	$y=\mathbf{3.418}x/(19.071+x)$ $r^2=0.999$	1690	2360
Oyster Bed #4-1	$y=\mathbf{3.814}x/(15.427+x)$ $r^2=0.999$	$y=\mathbf{3.792}x/(13.751+x)$ $r^2=0.999$	2270	2150
Shell Deposition	$y=\mathbf{3.688}x/(28.675+x)$ $r^2=0.999$	$y=\mathbf{3.969}x/(25.907+x)$ $r^2=0.999$	2940	2950

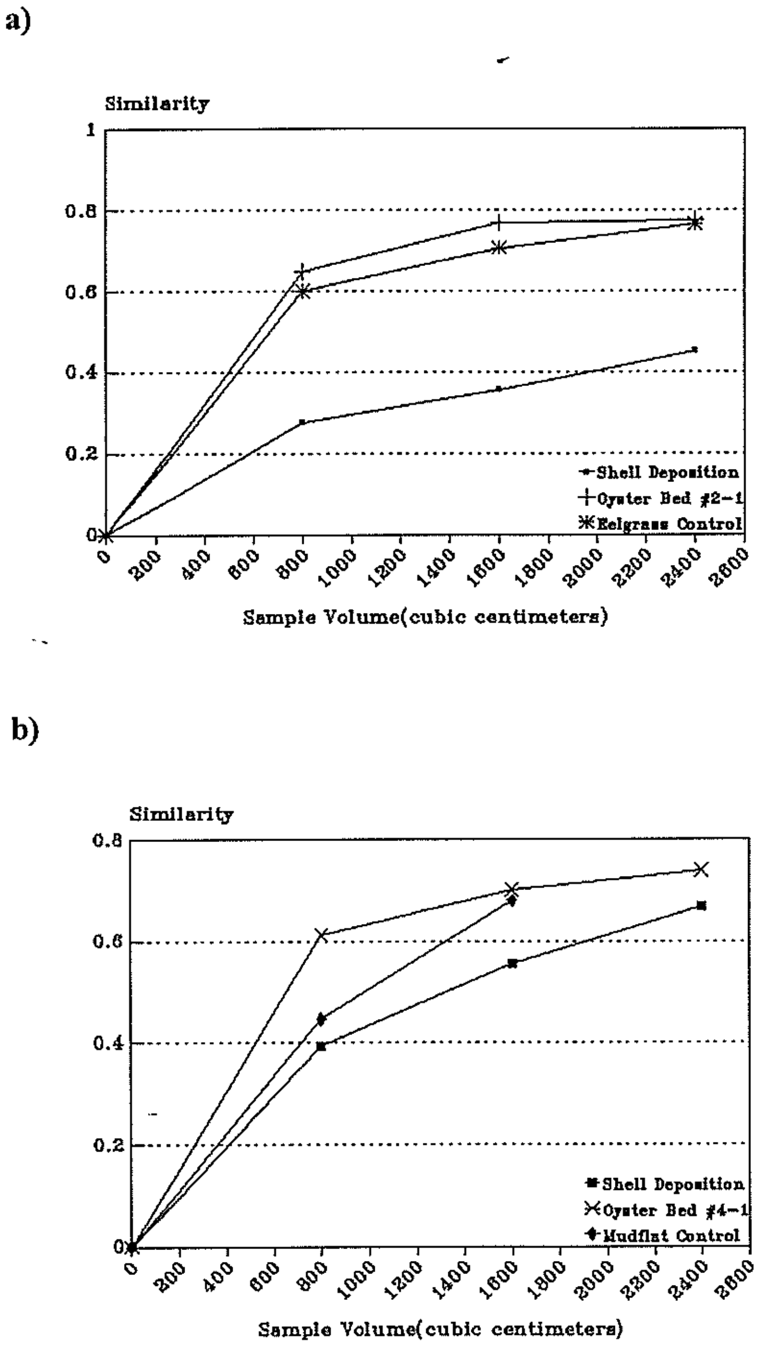


Figure 13. Sorensen Index/volume curves for benthic macrofauna from (a) Lower Bay Sites and (b) Upper Bay Sites in Humboldt Bay, California, Summer 1992.

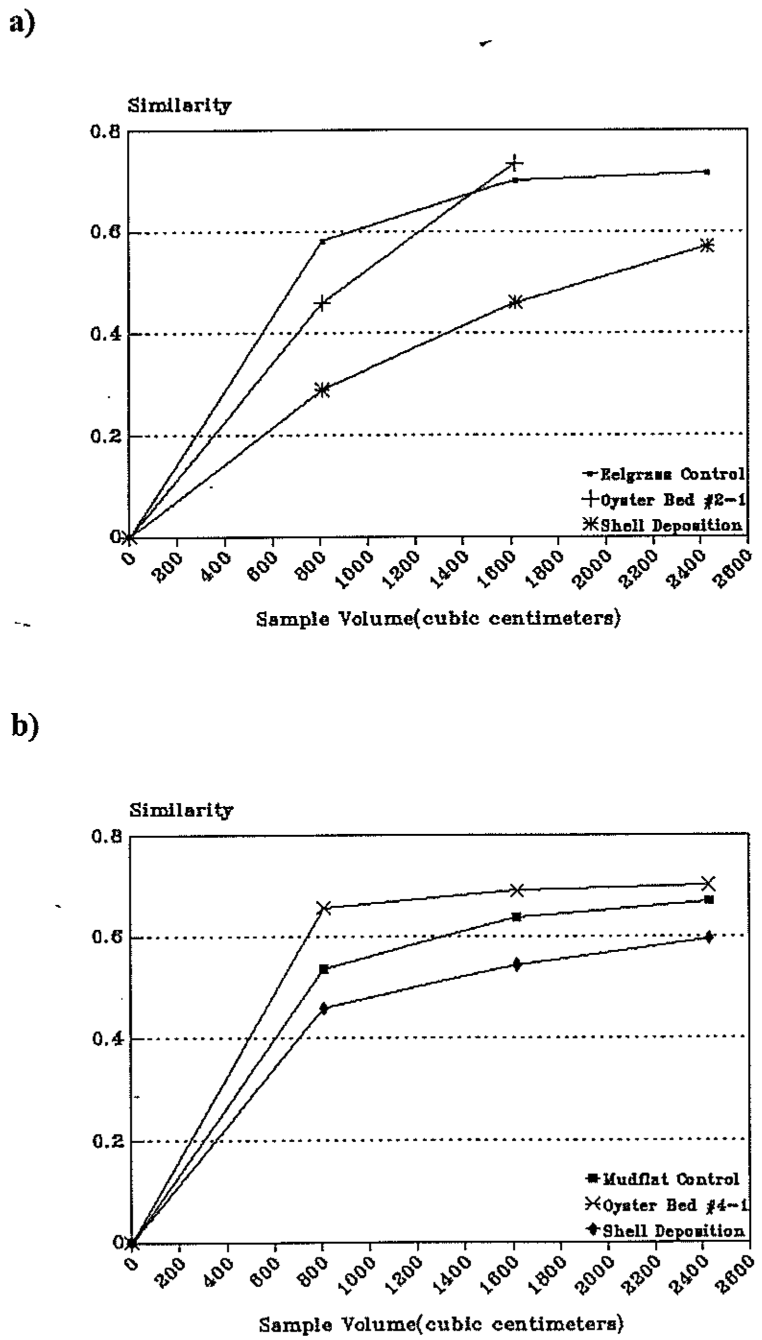


Figure 14. Sorensen Index/volume curves for benthic macrofauna from (a) Lower Bay Sites and (b) Upper Bay Sites in Humboldt Bay, California, Winter 1993.

Table 7. Combinatorial Sorensen Index values for benthic macrofauna from Humboldt Bay, California, Summer 1992 and Winter 1993.

SITE	SEASON	SIMILARITY VALUE 1	2	3
LOWER BAY				
Eelgrass Control	Summer	0.60	0.70	0.76
	Winter	0.58	0.70	0.71
Oyster Bed #2-1	Summer	0.65	0.76	0.77
	Winter	0.45	0.73	
Shell Deposition	Summer	0.28	0.35	0.45
	Winter	0.29	0.46	0.57
UPPER BAY				
Mudflat Control	Summer	0.45	0.68	
	Winter	0.53	0.64	0.67
Oyster Bed #4-1	Summer	0.61	0.70	0.74
	Winter	0.66	0.69	0.70
Shell Deposition	Summer	0.39	0.56	0.67
	Winter	0.46	0.54	0.59

more rapidly during the winter. The eelgrass control and oyster bed were equitable in value at larger sample comparisons for both sampling periods, although the winter sampling period comparison was obstructed by the loss of a sample from the oyster bed site. Similarity was noticeably reduced at low sample comparisons from the oyster bed during the winter sampling period. The upper Arcata Bay sites maintained their relative positions during both sampling periods, with similarities from all sites increasing less rapidly during the winter. As in lower Arcata Bay, the shell deposition site in upper Arcata Bay increased in similarity less rapidly than the other sites, though to a lesser degree.

Community Similarity Among Sites

Dendrograms derived from cluster analysis are displayed in Figures 15 & 16. The lower Arcata Bay sites were partitioned into five groupings at the level of 89% of the similarity index. These groupings were generally divisible by site, with the exception of grouping number two which consisted of a mixture of all three sites and both seasons. The eelgrass control sites separated partially by season, due mainly to the seasonal variation of the amphipods *Caprella californica* and *Corophium acherusicum*, which were not found in the winter samples. Sample number six, LC6W, from the eelgrass control in winter did not contribute to a grouping, due to the relative dominance of two species; the spionid polychaete

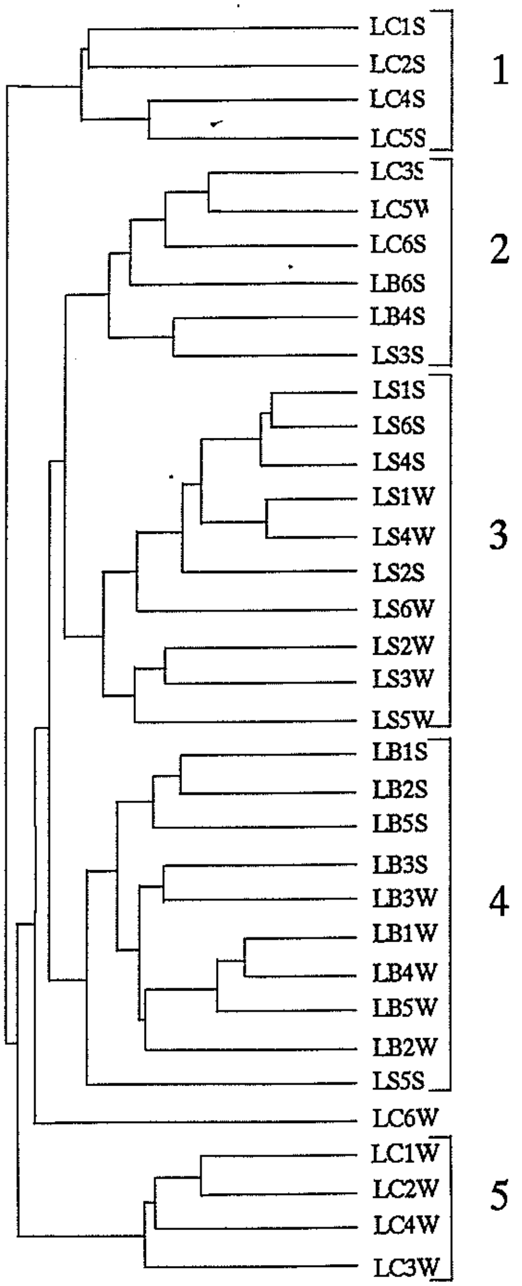


Figure 15. Dendrogram of benthic macrofauna from Lower Bay Sites in Humboldt Bay, California. Summer 1992 and Winter 1993. LCxS=Lower Bay Control Summer; LCxW=Winter LBxS=Lower Bay Oyster Bed Summer; LBxW=Winter LSxS=Lower Bay Shell Site Summer; LSxW=Winter

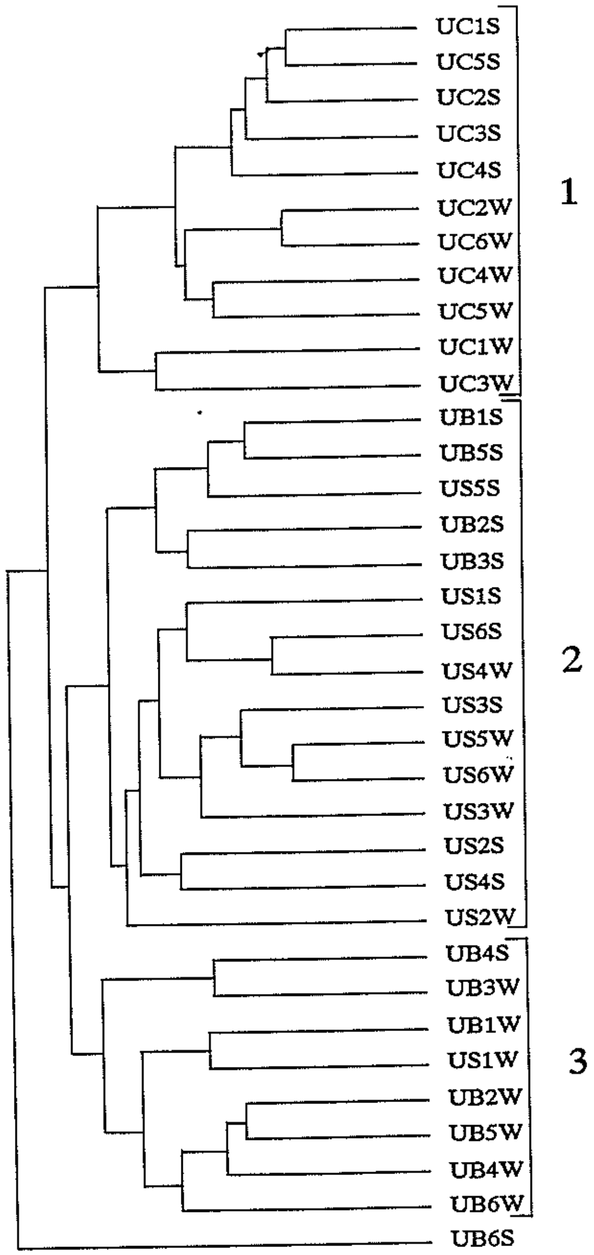


Figure 16. Dendrogram of benthic macrofauna from Upper Bay Sites in Humboldt Bay, California. Summer 1992 and Winter 1993.
UCxS=Upper Bay Control Summer; UCxW=Winter
UBxS=Upper Bay Oyster Bed Summer; UBxW=Winter
USxS=Upper Bay Shell Site Summer; USxW=Winter

Psuedopolydora paucibranchiata and capitellid polychaete *Mediomastus californiensis*.

The upper Arcata Bay sites were partitioned into three groupings at the level of 89% of the similarity index. The mudflat control site samples formed the first grouping, with the second grouping dominated by eleven of the twelve shell deposition site samples and four summer oyster bed samples. The third grouping was composed of seven of the eleven oyster bed samples, six of which were from winter, and a winter shell deposition sample. Sample number six, UB6S, of the summer oyster bed series did not contribute to a grouping, due to the absence of two of the top three dominant species from that site; *M. californiensis* and the cirratulid polychaete *Tharyx parvus*.

DISCUSSION

The eelgrass control site recorded the highest mean values for abundance, biomass, and diversity of the lower Arcata Bay sites. A marginally significant interaction with respect to abundance obscured a highly significant difference between sites. Whether the marginal significance of the interaction is meaningful would require experimental repetition. From the profile plot in Figure 10a it appeared that oyster bed variation was the probable cause. The profile plot for diversity of the lower Arcata Bay sites was very complicated, implying a strong season-site interaction for all sites. In upper Arcata Bay the mudflat control site appeared to exhibit characteristics indicative of a physically controlled habitat; high abundance, low biomass, and low diversity, as implied from ANOVA results. In such an environment the dominant species are classified as R-Selected; species which, among other characteristics, are small in size, have high reproductive rates, and the ability to colonize rapidly (Smith 1974). These characteristics were evident in the species tables, (Appendices I and J), for the mudflat control during summer and winter. Only a few species dominated, in particular the tanaidacean *Leptochelia dubia* and the spionid polychaete *Psuedopolydora pauchibranchiata,* in summer.

Table 5 shows the number of species comprising 80% of the total number of individuals per site per season. In the upper Arcata Bay sites, these were the lowest in the mudflat control for both seasons. In contrast, for the summer values obtained for the other upper and lower Arcata Bay sites, it was evident that the mudflat habitat was comparatively different. These summer values reflected the structural nature of these habitats. The low values obtained for the mudflat control were indicative of the spatial homogeneity of the environment. This conclusion was further illuminated by the low alpha diversity values generated for this site(Table 6), especially in summer, and the steep increase in similarity, notably in summer (Figures 13 & 14). The low similarity at low sample volumes in the mudflat control was attributed to the occurrence of species which are rare or perhaps more contiguous in distribution than the dominant species. Diversity/volume curves (Figures 11 & 12) demonstrated that further increase in sampling volume added few species, except for rarities or highly aggregated species, and similarity/volume curves supported this. The mudflat site is a relatively uniform habitat, except for the presence of various sized channels which intersect it (Fig. 3). These channels contained some structure in the form of eelgrass, but were not a major component of the habitat. In contrast, all other sites sampled were spatially heterogeneous. The presence of eelgrass, oysters, and deposited shell elements added a third dimension to those habitats. With an added structural dimension, it appeared that a greater equality of dominance resulted. The exception was the values obtained from Table 5 for the winter series. In these samples both oyster beds exhibited a decrease in the number of dominant species, markedly in the lower bay site. The lower Arcata Bay oyster bed also displayed a decrease in alpha diversity. Therefore, it appeared that oyster bed dominance may vary seasonally. The relative stability of the other sites across seasons indicated a greater variation in the oyster beds.

Significant and marginally significant seasonal results for upper Arcata Bay biomass and diversity may have been indicative of the closer proximity of this area to freshwater runoff. During the winter sampling period Humboldt County experienced a normal winter rainfall, which followed a six year drought. This event may also have influenced the marginally significant and significant interactions for lower Arcata Bay abundance and diversity, respectively.

From the species tables of appendices A-L the dominance values of each site were further examined by inspection of the frequency tabulations. For both control sites and both oyster beds the frequency of the dominant species was 80% or higher. The frequency of the dominant species in the shell sites did not follow this pattern, where the frequency of most dominant species from these sites fell below 80%. This result indicated a greater spatial heterogeneity of habitat than in the eelgrass control site or in the oyster beds. These results were confirmed by the high alpha diversity values for these sites (Table 6), and the low similarity values (Figures

13 & 14; Table 7). The presence of shells in the deposition sites attracted not only species associated with benthic intertidal mudflat habitats, but also species commonly found in the rocky intertidal habitat such as the limpet *Collisella digitalis*, and species more commonly associated with structure such as the brittle star *Opithorix spiculata*, and the rock cockle *Protothaca staminea*. With low per site diversity and abundance, higher biomass, and high alpha diversity values, the shell deposition sites were indicative of spatially heterogeneous communities. The shell site near Indian Island appeared to be even more heterogeneous than the upper bay shell site. This was confirmed by my personal observations of eelgrass protruding up through shell at this site, visable on Figure 4. This added a structural component not present at the upper bay shell site, thus the potential for attracting a greater array of species.

The results from cluster analysis demonstrated that both the shell deposition sites and oyster beds harbored species complexes unlike those of the unaltered communities. The spionid polychaetes *Psuedopolydora paucibranchiata* and *P. kempi* signified differences between the control sites and oyster beds. *P. paucibranchiata*, which favors finer sediments than *P. kempi* (Smith and Carlton 1980), was a dominant species in the control sites, whereas *P. kempi* was more dominant in the oyster beds (Appendices A,B,C,D,G,H,I,J). Sediment distribution work in Humboldt Bay by Thompson (1971) suggested that the resuspension of finer sediments in oyster bottom culture sites from dredging causes the finer sediments to be lost, resulting in a larger sand fraction. The sediment distribution map derived from Thompson's work in Arcata Bay, and which clearly shows this overlap, is reproduced in Figure 17.

A larger question which looms over oyster culture activities in intertidal mudflats is the possibility that the practices associated with them are detrimental to energetic transfer across trophic levels. Clearly, structural differences existed between the control sites and the culture sites. In Tomales Bay, Kelly et al. (1994) found that Western Sandpipers (*Calidris mauri*) and Dunlin (*Calidris alpina*) significantly avoided bottom and suspended oyster culture areas, while Willets (*Catoptrophorus semipamatus*) occurred in significantly greater numbers in both culture areas. Holmberg (1975) found that *L. dubia* and the bivalve *Transennella tantilla* were favored in the diets of five of the seven studied shorebird species found feeding on the mudflats near the Mad River Channel in upper Arcata Bay. These species were found to be very common in the mudflat control in upper Arcata Bay (Appendices I & J). In the upper Arcata Bay oyster bed site the abundance of *T. tantilla* was reduced (Appendices G & H), and in the upper Arcata Bay shell deposition site the abundance of both species was very low (Appendices K & L). In addition, Holmberg (1975) found that the diet of the Dunlin was composed mainly

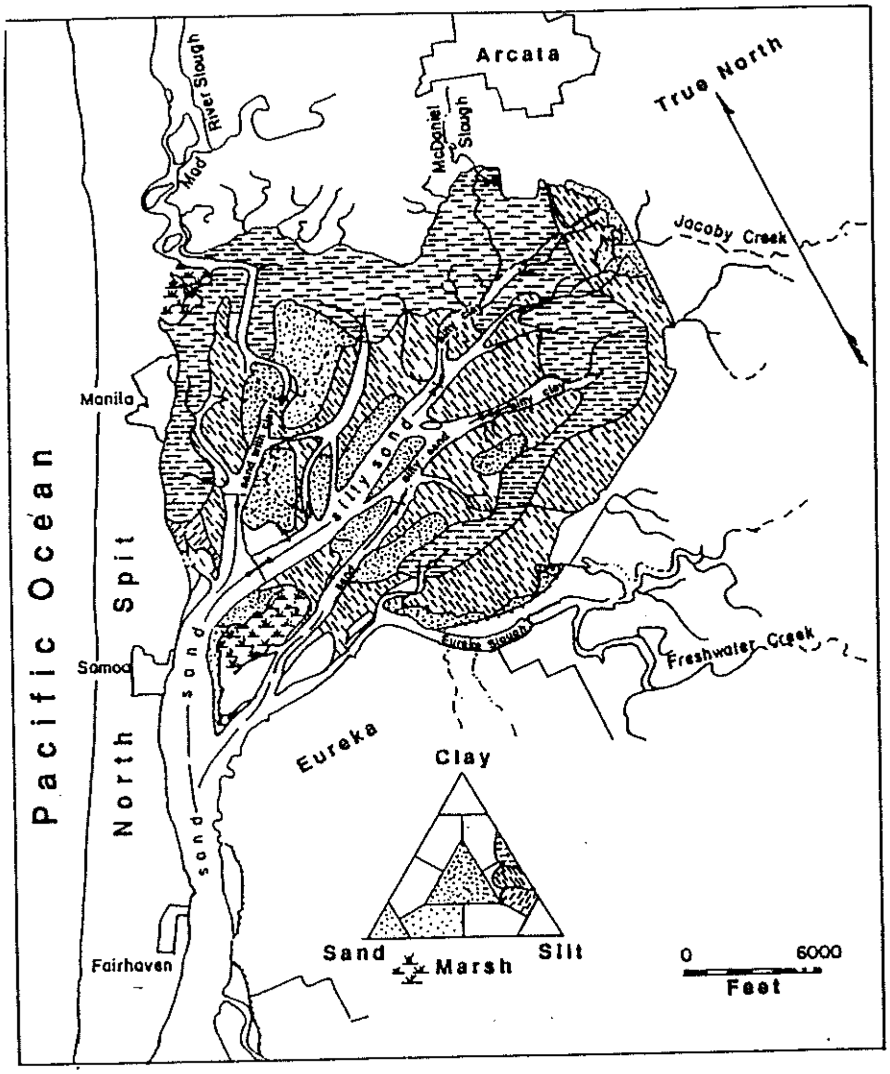


Figure 17. Sediment distribution in Arcata Bay (from Thompson 1971).

of eelgrass seeds, the growth of which was found to be impeded by oyster dredging (Waddel 1964).

Although successfully used in mitigation for economically important species such as the Dungeness crab (*Cancer magister*) (Mcgraw et al. 1988; Armstrong et al. 1991, 1992; Fernandez et al. 1993), and in shellfish culture (Day and Lawton 1987; Haven et al.1987; Mann et al. 1990; Toba et al. 1991) it was demonstrated in this study that crushed shell resulted in a significant alteration of benthic community structure. In effect, it changed a natural infaunal community into an infaunal/epifaunal mosaic. In contrast, eelgrass beds created a very rich community, one which yielded the highest mean values of abundance and diversity, with an equitable biomass. While containing a rich assemblage, these beds created a high production zone that was accessible by species which normally feed in intertidal mudflats. As demonstrated in this study, high diversity is not necessarily indicative of a preferable habitat, because it has been shown that diversity has little ecological meaning (Hurlbert 1971). An example would be the replacement of a community composed of a few ecologically distinct species by a community with numerous less distinct species, as is often the case in forestry practices. A local example would be the Redwood forest.

Human-induced introductions of non-indigenous benthic organisms have proliferated in soft sediment estuaries on the Pacific Coast primarily due to the geologically recent formation of these habitats (Carlton 1975, 1987, Chapman 1988). Due to plate tectonics, the Pacific Coast of North America has been continually rising, creating and destroying soft sediment habitat, preventing establishment of distinguished soft sediment communities. In contrast, the subsiding coastline of the Atlantic Coast, where flooded, soft sediment estuaries are extensive, fosters well defined soft sediment communities. Niche exploitation has been considered the probable mode of establishment, although it is possible that introduced species outcompeted less aggressive native species. While introductions of non-commercially important species have been well studied in terrestrial and freshwater environments, only recently has the phenomena of introductions in the marine realm been given much attention (Carlton 1975, 1987, Chapman 1988). The major mechanisms of Pacific Coast introductions appear to be from fouling communities comprised of encrusting species such as barnacles, larvae in seawater ballast, and the importation of commercial shellfish and fish (Carlton, 1975, 1985 and 1987). The two major sources appear to be the east coast of North America and the east coast of Asia, specifically Japan (Carlton 1987). Carlton (1979b), surmised that 90% of the invertebrate species of San Francisco Bay may have been introduced. The topic of introduced species in Humboldt Bay has yet to be fully addressed.

The dominant species from samples I collected in Arcata Bay included two spionids, *P. paucibranciata* and *P. kempi*, which together comprised over 30% of the total number of individuals taken during the summer and winter sample series. These two species were introduced from Japan simultaneously with the Pacific oyster, *Crassostrea gigas* (Carlton 1975). As mentioned above, *P. kempi* favors sandier sediments than *P. paucibranciata*, which correlates with its greater presence in oyster beds.

The Japanese aorid amphipod *Grandidierrella japonica* was initially described from the Arasiri River, Hokkaido and nearby Mokoto-numa Lake (Chapman and Dorman 1975). It was first documented outside of Japan along the Central Pacific Coast of California by Chapman and Dorman (1975), from samples taken in San Francisco Bay, Tomales Bay, and Bolinas Lagoon in 1971. This species was documented in Humboldt Bay by Theiss & Assoc. (1992) from intertidal samples taken near the Louisiana-Pacific dock in the Samoa channel. I collected numerous individuals of *G. japonica*, mainly from the upper bay shell deposition site, where this species ranked third in abundance in summer and winter samples. It was also present in the upper bay control site and oyster bed in summer and winter. In the lower bay sites it was found only in the shell deposition site during winter.

The gammarid amphipod *Melita nitida* was first described from the New England coast, and was redescribed from lectotypes by Mills (1964b). Chapman (1988) concluded that *M. nitida* existed in Humboldt Bay based on its distribution in estuaries north and south of the bay. The presence of this species in Humboldt Bay was verified from my shell deposition samples in both summer and winter. Two other species were well represented in my samples, both from the Atlantic Coast of the United States. The spionid polychaete *Streblospio benedicti* and the amphipod *Corophium acherusicum* were both introduced with the implantation of the eastern oyster *Crassostrea virginica* (Carlton 1979b).

The percent of introduced species in the samples I collected ranged from 12% to 45%. Because very little published information exists pertaining to introduced invertebrate species in Humboldt Bay (Chapman, personal communication), more work is essential. The results of this study will serve as a suitable template for future investigations. Oyster culture in Arcata Bay not only alters community structure in areas under its influence, but has in fact molded the structure of the entire intertidal benthic community.

RECOMMENDATIONS

The deposition of oyster shell throughout the bay is a growing concern among bay resource users (R. Warner California Department of Fish and Game; T. Mulligan Humboldt State University; pers. comm.). Because shell deposition results in a change in community structure and may alter the ambient flow of energy across trophic levels, unapproved shell depositions should be halted, with existing sites removed or mitigated. The shell deposition site near Indian Island, composed of only shell when this project started, has grown into a very large seed holding site. Further investigations into the ecological impacts of oyster culture activities in Humboldt Bay should be pursued, with longer term and more holistic approaches desirable. With respect to this study, extended investigations would confirm or refute my conclusions, and would serve to elucidate aspects of habitat structure not addressed here.

Short sighted development in and around Humboldt Bay is continuing at a rapid pace. Specifically, aquaculture ventures which proclaim a need for clean water must be closely monitored with appropriate permit scrutiny. Results shown here indicate that they too can significantly impact the ecology of estuarine systems.

Hopefully this study provides at least some guidelines for future bottom culture activities proposed in Pacific Coast and other U.S. estuaries.

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APPENDIX A. Species Composition, Dominance, and Frequency of Benthic Infauna from Lower Bay Oyster Bed Site in Arcata Bay, California from Summer 1992.

	SAMPLES							
SPECIES	1	2	3	4	5	6	DOM	FREQ
Mediomastus californiensis	12	11	12	3	2	0	19.0	83
Psuedopolydora kempi	4	4	8	3	8	5	15.2	100
Tharyx parvus	1	11	1	1	2	0	7.6	83
Nephtys caecoides	3	4	2	1	2	2	6.7	100
Leitoscoloplos pugettensis	5	0	2	1	3	3	6.7	83
Euclymene zonalis	4	0	6	1	1	2	6.7	83
Streblospio benedicti	4	3	1	1	3	0	5.7	83
Cirratulus cirratus	2	2	3	0	3	1	5.2	83
Euclymene cf zonalis	2	2	1	2	2	0	4.3	83
Psuedopolydora paucibranchiata	1	1	3	2	0	1	3.8	83
Leptochelia dubia	1	0	0	0	2	4	3.3	50
Transennella tantilla	2	0	0	1	2	1	2.9	67
Polycirrus californicus	2	2	1	0	0	0	2.4	50
Maldanid Sp. E	2	1	0	0	0	0	1.4	33
Micromaldane ornithochaeta	0	1	1	0	0	1	1.4	50
Macoma nasuata	3	0	0	0	0	0	1.4	17
Glycinde polygnatha	1	1	0	0	1	0	1.4	50
Photis brevipes	2	0	0	0	0	0	1.0	17
Corophium acherusicum	0	0	1	0	0	1	1.0	33
Chaetozone spp.	0	0	1	0	0	0	0.5	17
Euclymene reticulata	1	0	0	0	0	0	0.5	17

APPENDIX A.(Continued) Species Composition, Dominance, and Frequency of Benthic Infauna from Lower Bay Oyster Bed Site in Arcata Bay, California from Summer 1992.

Clymenura columbiana	0	0	0	0	0	1	0.5	17
Chaetozone acuta	0	0	1	0	0	0	0.5	17
Aoroides intermedius	0	0	1	0	0	0	0.5	17
Amaenea occidentalis	0	0	0	1	0	0	0.5	17
TOTALS								
SPECIMENS	52	43	45	17	31	22		
SPECIES	17	11	14	11	12	11		

APPENDIX B. Species Composition, Dominance, and Frequency of Benthic Infauna from Lower Bay Oyster Bed in Arcata Bay, California from Winter 1993.

	SAMPLES						
SPECIES	1	2	3	4	5	DOM	FREQ
Psuedopolydora kempi	16	22	15	34	11	31.4	100
Mediomastus californiensis	10	2	6	20	15	17.0	100
Tharyx parvus	5	9	17	8	6	14.4	100
Streblospio benedicti	5	21	3	5	5	12.5	100
Euclymene zonalis	5	0	4	5	2	5.1	80
Cirratulus cirratus	1	1	6	3	1	3.8	100
Haploscoloplos elongatus	2	4	0	3	1	3.2	80
Polycirrus californicus	1	0	1	3	2	2.2	80
Exogone lourei	0	1	2	3	0	1.9	40
Euclymene cf zonalis	0	0	0	4	2	1.9	40
Psuedopolydora paucibranchiata	0	0	3	0	0	1.0	20
Nephtys caecoides	0	2	1	0	0	1.0	40
Cossura spp.	1	0	0	1	1	1.0	60
Chaetozone acuta	0	0	3	0	0	1.0	20
Macoma nasuata	0	0	1	0	1	0.6	40
Lysilla sp.	0	0	0	0	2	0.6	20
Micromaldane ornithochaeta	0	0	0	0	1	0.3	20
Idoteid	0	0	1	0	0	0.3	20
Glycinde polygnatha	0	0	0	0	1	0.3	20
Eteone californica	0	0	0	1	0	0.3	20

APPENDIX B.(Continued) Species Composition, Dominance, and Frequency of Benthic Infauna from Lower Bay Oyster Bed Site in Arcata Bay, California from Winter 1993.

TOTALS					
SPECIMENS	46	62	63	90	51
SPECIES	9	8	13	12	14

APPENDIX C. Species Composition, Dominance, and Frequency of Benthic Infauna from Lower Bay Eelgrass Control Site in Arcata Bay, California from Summer 1992.

	SAMPLES							
SPECIES	1	2	3	4	5	6	DOM	FREQ
Mediomastus californiensis	14	13	14	15	33	15	18.2	100
Psuedopolydora paucibranchiata	27	21	11	13	15	10	17.0	100
Euclymene zonalis	10	8	13	17	14	12	13.0	100
Caprella californica	13	3	0	26	14	0	9.7	67
Polycirrus californicus	9	2	4	8	5	6	6.0	100
Psuedopolydora kempi	2	8	3	7	2	5	4.7	100
Corophium acherusicum	2	1	2	11	4	2	3.8	100
Transennella tantilla	5	8	3	1	0	4	3.7	83
Leitoscoloplos pugettensis	4	9	0	2	1	3	3.3	83
Leptochelia dubia	0	0	0	3	4	4	2.0	50
Euclymene cf zonalis	7	0	0	0	2	1	1.7	50
Nephtys caecoides	3	2	2	1	0	1	1.6	83
Macoma nasuata	0	3	0	2	1	2	1.4	67
Polydora socialis	1	0	0	1	4	1	1.2	67
Tharyx parvus	1	1	0	2	2	0	1.1	67
Streblospio benedicti	1	4	0	1	0	0	1.1	50
Micromaldane ornithochaeta	2	2	0	1	0	1	1.1	67
Lumbrinereis zonata	2	0	0	3	0	1	1.1	50
Cirratulus cirratus	2	0	0	1	2	0	0.8	50
Platynereis bicanalicuata	1	0	0	3	0	0	0.7	33
Photis brevipes	0	1	0	3	0	0	0.7	33

APPENDIX C.(Continued) Species Composition, Dominance, and Frequency of Benthic Infauna from Lower Bay Eelgrass Control Site in Arcata Bay, California from Summer 1992.

Capitilla capitata	0	4	0	0	0	0	0.7	17
Aoroides intermedius	1	0	0	3	0	0	0.7	33
Glycinde polygnatha	0	1	0	1	1	0	0.5	50
Exogone lourei	0	0	0	0	1	2	0.5	33
Eteone californica	0	0	1	2	0	0	0.5	33
Tanais spp.	0	0	0	1	0	1	0.4	33
Nemeratean sp. A	0	0	0	2	0	0	0.4	17
Eudorella pacifica	0	1	0	1	0	0	0.4	33
Drilonereis falcata	1	1	0	0	0	0	0.4	33
Maldanid Sp. E	1	0	0	0	0	0	0.2	17
Spiophanes berkleyorium	0	0	0	0	0	1	0.2	17
Pontogeneia rostrata	0	0	0	1	0	0	0.2	17
Oweniia fusiformis	0	0	0	0	0	1	0.2	17
Macoma inquinata	1	0	0	0	0	0	0.2	17
Mytilus edulis	1	0	0	0	0	0	0.2	17
Idotea resecata	0	0	0	1	0	0	0.2	17
Hesperone complanata	0	0	0	1	0	0	0.2	17
Harmothoe lunulata	0	0	0	1	0	0	0.2	17
TOTALS								
SPECIMENS	111	93	53	135	105	73		
SPECIES	23	19	9	30	16	19		

APPENDIX D. Species Composition, Dominance, and Frequency of Benthic Infauna from Lower Bay Eelgrass Control Site in Arcata Bay, California from Winter 1993.

	SAMPLES							
SPECIES	1	2	3	4	5	6	DOM	FREQ
Mediomastus californiensis	22	25	24	32	8	45	29.0	100
Psuedopolydora paucibranchiata	23	28	17	19	12	23	22.7	100
Euclymene zonalis	12	12	4	4	6	0	7.1	83
Psuedopolydora kempi	4	5	5	10	2	4	5.6	100
Polycirrus californicus	3	9	4	3	5	0	4.5	83
Tharyx parvus	1	1	1	1	0	16	3.7	83
Streblospio benedicti	1	2	2	7	0	7	3.5	83
Euclymene cf zonalis	4	2	9	1	0	0	3.0	67
Micromaldane ornithochaeta	5	5	0	2	0	0	2.2	50
Transennella tantilla	3	1	0	0	0	6	1.8	50
Platynereis bicanalicuata	1	1	1	5	0	2	1.8	83
Lumbrinereis zonata	2	7	0	1	0	0	1.8	50
Exogone lourei	0	2	0	4	0	2	1.5	50
Leitoscoloplos pugettensis	1	0	0	2	2	2	1.3	67
Nephtys caecoides	2	1	1	1	1	0	1.1	83
Cirratulus cirratus	0	0	0	0	0	6	1.1	17
Leptochelia dubia	1	1	0	1	0	2	0.9	67
Macoma nasuata	3	1	0	0	1	0	0.9	50
Photis brevipes	0	2	0	3	0	0	0.9	33
Glycinde polygnatha	1	0	0	0	1	2	0.7	50

APPENDIX D.(Continued) Species Composition, Dominance, and Frequency of Benthic Infauna from Lower Bay Eelgras Control Site in Arcata Bay, California from Winter 1993.

Nemeratean sp. B	1	1	0	0	0	2	0.7	50
Cirratulidae	0	0	0	0	0	3	0.5	17
Eudorella pacifica	0	1	0	1	0	0	0.4	33
Eteone californica	0	0	0	0	0	2	0.4	17
Cossura spp.	0	0	0	0	0	2	0.4	17
Ampithoe lacertosa	0	2	0	0	0	0	0.4	17
Prothothaca staminea	1	0	0	0	0	0	0.2	33
Shsitomeringos japonica	0	1	0	0	0	0	0.2	17
Polydora socialis	1	0	0	0	0	0	0.2	17
Pholidae	0	0	0	0	0	1	0.2	17
Mytilus edulis	0	0	0	0	0	1	0.2	17
Lyonsia californica	0	1	0	0	0	0	0.2	17
Corophium spp.	0	0	1	0	0	0	0.2	17
Chaetozone acuta	0	0	0	1	0	0	0.2	17
Nemeratean sp. C	0	1	0	0	0	0	0.2	17
TOTALS								
SPECIMENS	92	112	69	98	38	128		
SPECIES	20	23	11	18	9	18		

APPENDIX E. Species Composition, Dominance, and Frequency of Benthic Infauna from Lower Bay Shell Deposition Site in Arcata Bay, California from Summer 1992.

	SAMPLES							
SPECIES	1	2	3	4	5	6	DOM	FREQ
Mediomastus californiensis	4	2	1	5	14	9	25.7	100
Cirratulus cirratus	9	0	0	7	1	0	12.5	50
Tharyx parvus	0	0	5	0	10	0	11.0	33
Corophium acherusicum	2	0	0	3	0	5	7.3	50
Macoma inquinata	0	0	0	8	0	0	6.6	17
Psuedopolydora paucibranchiata	0	4	3	0	0	0	5.1	33
Hemigraspus oregonensis	5	0	0	0	0	2	5.1	33
Lysilla sp.	0	0	0	0	3	1	2.9	33
Macoma nasuata	1	1	0	0	1	0	2.2	50
Transennella tantilla	0	1	1	0	0	0	1.4	33
Shistomeringos japonica	0	0	0	1	1	0	1.4	33
Prothothaca staminea	0	0	0	2	0	0	1.4	17
Psuedopolydora kempi	0	0	2	0	0	0	1.4	17
Platynereis bicanalicuata	0	0	0	0	0	2	1.4	17
Opithorix spiculata	0	0	1	0	0	1	1.4	33
Nephtys caecoides	0	0	1	0	1	0	1.4	33
Caprella californica	0	0	0	0	2	0	1.4	17
Collisella digitalis	0	0	0	0	0	2	1.4	17
Sthenelais fusca	0	0	0	0	0	1	0.7	17
Euclymene cf zonalis	0	0	0	0	1	0	0.7	17

APPENDIX E.(Continued) Species Composition, Dominance, and Frequency of Benthic Infauna from Lower Bay Shell Deposition Site in Arcata Bay, California from Summer 1992.

Pontogeneia rostrata	0	0	0	0	1	0	0.7	17
Polydora socialis	0	1	0	0	0	0	0.7	17
Photis brevipes	0	0	0	1	0	0	0.7	17
Leitoscoloplos pugettensis	0	0	0	0	1	0	0.7	17
Glycinde polygnatha	0	0	1	0	0	0	0.7	17
Exogone lourei	0	0	0	0	0	1	0.7	17
Eudorella pacifica	0	0	0	0	1	0	0.7	17
Drilonereis falcata	0	0	0	0	1	0	0.7	17
Aoroides intermedius	0	0	0	0	1	0	0.7	17
TOTALS								
SPECIMENS	21	9	15	28	39	24		
SPECIES	5	5	8	7	14	9		

APPENDIX F. Species Composition, Dominance, and Frequency of Benthic Infauna from Lower Bay Shell Deposition Site in Humboldt Bay, California from Winter 1993.

	SAMPLES							
SPECIES	1	2	3	4	5	6	DOM	FREQ
Mediomastus californiensis	9	1	8	4	3	0	19.2	83
Tharyx parvus	0	8	0	0	2	0	7.7	33
Psuedopolydora paucibranchiata	0	1	1	0	5	1	6.2	67
Cirratulus cirratus	0	2	2	0	1	3	6.2	67
Leitoscoloplos pugettensis	3	2	0	3	0	0	6.2	50
Polycirrus californicus	0	1	5	0	1	0	5.4	50
Hemigraspus oregonensis	3	0	0	2	0	1	4.6	50
Exogone lourei	0	0	1	0	5	0	4.6	33
Euclymene zonalis	0	0	6	0	0	0	4.6	17
Platynereis bicanalicuata	0	3	1	1	0	0	3.8	50
Psuedopolydora kempi	0	4	0	0	0	1	3.8	33
Transennella tantilla	0	0	0	1	3	0	3.1	33
Macoma balthica	0	0	1	0	3	0	3.1	33
H. paludicola	0	1	0	0	2	0	2.3	33
Glycinde polygnatha	0	1	0	0	2	0	2.3	33
Armandia brevis	3	0	0	0	0	0	2.3	17
Streblospio benedicti	0	0	0	0	1	1	1.5	33
Prothothaca staminea	1	0	0	0	1	0	1.5	33
Shistomeringos japonica	0	0	0	0	2	0	1.5	17
Pilargis maculata	0	0	0	0	0	2	1.5	17

APPENDIX F.(Continued) Species Composition, Dominance, and Frequency of Benthic Infauna from Lower Bay Shell Deposition Site in Humboldt Bay, California from Winter 1993.

Nemeratean sp. B	0	0	0	0	2	0	1.5	17
Cirratulidae	0	1	0	0	0	0	0.8	17
Sphinophanes berkleyorium	0	1	0	0	0	0	0.8	17
Macoma inquinata	0	0	0	0	0	1	0.8	17
Macoma spp.	0	0	0	1	0	0	0.8	17
Lumbrinereis zonata	1	0	0	0	0	0	0.8	17
Grandidierella japonica	0	0	0	1	0	0	0.8	17
Clinocardium nuttali	0	0	0	0	1	0	0.8	17
Anisogammarus sp.	1	0	0	0	0	0	0.8	17
Nemeratean sp. D	1	0	0	0	0	0	0.8	17
TOTALS								
SPECIMENS	22	26	25	13	34	10		
SPECIES	8	12	8	7	15	7		

APPENDIX G. Species Composition, Dominance, and Frequency of Benthic Infauna from Upper Bay Oyster Bed in Arcata Bay from Summer 1992.

	SAMPLES							
SPECIES	1	2	3	4	5	6	DOM	FREQ
Tharyx parvus	6	31	0	46	3	7	23.4	83
Mediomastus californiensis	13	24	10	13	2	4	16.6	100
Euclymene cf. zonalis	12	5	4	2	6	6	8.8	100
Leptochelia dubia	2	25	0	1	3	0	7.8	66
Psuedopolydora kempi	8	3	8	2	3	4	7.1	100
Psuedopolydora paucibranchiata	5	5	5	2	4	0	5.3	83
Streblospio benedicti	3	0	5	11	0	1	5.0	66
Leitoscoloplos pugettensis	5	5	3	0	3	2	4.5	83
Grandidierella japonica	4	1	3	0	5	3	4.0	83
Euclymene zonalis	7	2	2	0	1	3	3.8	83
Polycirrus californicus	4	1	1	0	2	2	2.5	83
Glycinde polygnatha	0	0	3	0	0	2	1.3	33
Exogone lourei	2	2	1	0	0	0	1.3	50
Corophium acherusicum	0	3	0	0	0	2	1.3	33
Nephtys caecoides	0	0	0	2	1	1	1.0	50
Cirratulus cirratus	0	3	1	0	0	0	1.0	33
Maldanid	0	0	0	1	0	2	0.8	33
Micromaldane ornithochaeta	1	0	0	2	0	0	0.8	33
Macoma nasuata	0	0	0	1	0	2	0.8	33
Transennella tantilla	0	0	0	0	0	2	0.5	17

APPENDIX G.(Continued) Species Composition, Dominance, and Frequency of Benthic Infauna from Upper Bay Oyster Bed in Arcata Bay from Summer 1992.

Eteone californica	0	1	0	1	0	0	0.5	33
Shistomeringos japonica	0	0	0	0	0	1	0.3	17
Prothothaca staminea	1	0	0	0	0	0	0.3	17
Polydora socialis	0	0	0	1	0	0	0.3	17
Platynereis bicaanalicuata	0	1	0	0	0	0	0.3	17
Macoma inquinata	0	1	0	0	0	0	0.3	17
Lumbrinereis zonata	0	1	0	0	0	0	0.3	17
Chaetozone acuta	0	0	0	0	1	0	0.3	17
Armandia brevis	0	0	0	0	1	0	0.3	17
TOTALS								
INDIVIDUALS	73	114	46	85	35	44		
SPECIES	14	17	12	13	13	16		

APPENDIX H. Species Composition, Dominance, and Frequency of Benthic Infauna from Upper Bay Oyster Bed in Arcata Bay from Winter 1993.

SPECIES	SAMPLES							
	1	2	3	4	5	6	DOM	FREQ
Mediomastus californiensis	10	23	15	17	5	4	21.4	100
Tharyx parvus	0	25	5	11	14	1	16.2	83
Euclymene cf zonalis	5	3	5	13	7	9	12.1	100
Streblospio benedicti	1	6	10	3	7	4	9.0	100
Leptochelia dubia	4	8	2	0	5	4	6.6	83
Psuedopolydora paucibranchiata	3	5	2	2	8	1	6.1	100
Psuedopolydora kempi	5	3	2	2	2	3	4.9	100
Exogone lourei	0	3	2	2	3	6	4.6	83
Leitoscoloplos pugettensis	0	4	0	3	1	5	3.8	67
Oligochaeta	0	0	0	12	0	0	3.5	17
Nephtys caecoides	1	1	0	1	1	1	1.4	83
Cirratulus cirratus	1	1	0	1	1	1	1.4	83
Grandidierella japonica	1	1	0	2	1	0	1.4	67
Glycinde polygnatha	0	1	2	0	0	0	0.9	33
Photis brevipes	0	0	1	0	0	2	0.9	33
Ostracod	0	0	1	0	0	1	0.6	33
Micromaldane ornithochaeta	0	0	0	0	1	1	0.6	33
Transennella tantilla	0	0	0	1	1	0	0.6	33
Prothothaca staminea	1	0	0	1	0	0	0.6	33
Macoma nasuata	1	0	0	0	0	1	0.6	33

APPENDIX H.(Continued) Species Composition, Dominance, and Frequency of Benthic Infauna from Upper Bay Oyster Bed in Arcata Bay from Winter 1993.

Polycirrus spp.	1	0	0	0	0	0	0.3	17
Polycirrus californicus	0	0	1	0	0	0	0.3	17
Platynereis bicanalicuata	1	0	0	0	0	0	0.3	17
Lasaea spp.	0	0	0	0	0	1	0.3	17
Cossura spp.	0	0	1	0	0	0	0.3	17
Corophium spp.	0	0	0	0	0	1	0.3	17
Capitilla capitata	0	0	1	0	0	0	0.3	17
Nemerateran sp. B	1	0	0	0	0	0	0.3	17
Insecta	0	0	0	1	0	0	0.3	17
Anaitides longipes	0	0	0	0	0	1	0.3	17
TOTALS								
SPECIMENS	36	84	50	72	57	47		
SPECIES	12	11	12	13	12	6		

APPENDIX I. Species Composition, Dominance, and Abundance of Benthic Infauna from Upper Bay Mudflat Control Site from Summer 1992.

	SAMPLES						
SPECIES	1	2	3	4	5	DOM	FREQ
Leptochelia dubia	72	6	40	27	27	42.1	100
Psuedopolydora paucibranchiata	16	11	11	17	20	18.3	100
Transennella tantilla	20	8	2	10	10	12.2	100
Mediomastus californiensis	13	1	13	8	9	10.7	100
Corophium acherusicum	14	7	2	4	0	6.6	80
Polydora socialis	5	2	0	8	1	3.9	80
Corophium insidiosum	0	0	0	0	6	1.4	20
Exogone lourei	0	0	0	3	2	1.2	40
Eteone californica	2	0	0	0	2	0.9	40
Grandidierella japonica	0	1	0	0	1	0.5	40
Glycinde polygnatha	0	1	0	1	0	0.5	40
Euclymene cf zonalis	0	0	0	2	0	0.5	20
Streblospio benedicti	0	0	1	0	0	0.2	20
Paracorophium spp.	0	0	1	0	0	0.2	20
Nephtys caecoides	0	0	0	1	0	0.2	20
Nemeratean sp B	0	0	1	0	0	0.2	20
TOTALS							
INDIVIDUALS	142	37	71	81	78		
SPECIES	7	8	8	10	9		

APPENDIX J. Species Composition, Dominance, and Frequency of Benthic Infauna from Upper Bay Mudflat Control Site collected from Arcata Bay in Winter 1993.

	SAMPLES							
SPECIES	1	2	3	4	5	6	DOM	FREQ
Leptochelia dubia	27	2	21	0	59	2	23.7	83
Psuedopolydora paucibranchiata	51	8	0	13	14	10	20.5	83
Mediomastus californiensis	9	7	12	8	21	12	14.7	100
Exogone lourei	9	0	5	9	34	1	12.4	83
Transennella tantilla	14	3	0	5	8	2	6.8	83
Platynereis bicanalicuata	4	0	11	0	9	0	5.1	50
Euclymene cf zonalis	11	2	2	0	1	6	4.7	83
Polydora socialis	0	3	0	1	5	0	1.9	50
Grandidierella japonica	1	1	2	1	0	1	1.3	83
Psuedopolydora kempi	1	0	0	3	2	0	1.3	50
Glycinde polygnatha	0	1	0	0	2	1	0.9	50
Micromaldane ornithochaeta	2	0	0	0	0	2	0.9	33
Oligochaeta	4	0	0	0	0	0	0.9	17
Photis brevipes	2	0	1	0	0	0	0.6	33
Eteone californica	1	0	0	2	0	0	0.6	33
Corophium acherusicum	2	0	0	1	0	0	0.6	33
Macoma nasuata	0	0	1	0	0	1	0.4	33
Streblospio benedicti	2	0	0	0	0	0	0.4	17
Mytilus edulis	0	0	2	0	0	0	0.4	17
Gastropoda	0	0	2	0	0	0	0.4	17

APPENDIX J.(Continued) Species Composition, Dominance, and Frequency of Benthic Infauna from Upper Bay Mudflat Control Site collected from Arcata Bay in Winter 1993.

Tharyx parvus	0	1	0	0	0	0	0.2	17
Sphinophanes berkleyorium	1	0	0	0	0	0	0.2	17
Polycirrus californiensis	0	0	0	0	1	0	0.2	17
Lyonsia californica	1	0	0	0	0	0	0.2	17
Nemeratean sp. C	0	0	1	0	0	0	0.2	17
Nemeratean sp. B	0	0	0	0	0	1	0.2	17
Lumbrinereis zonata	0	0	1	0	0	0	0.2	17
TOTALS								
SPECIMENS	142	28	61	43	156	39		
SPECIES	17	9	12	9	11	11		

APPENDIX K. Species Composition, Domianace, and Frequency of Benthic Infauna from Upper Bay shell Deposition Site in Arcata Bay from Summer 1993.

	SAMPLES							
SPECIES	1	2	3	4	5	6	DOM	FREQ
Euclymene cf zonalis	17	0	11	13	8	7	36.4	83
Leitoscoloplos puggettensis	6	1	2	2	3	3	11.0	100
Grandidierella japonica	7	0	1	0	9	0	11.0	50
Hemigraspus oregonensis	4	0	0	3	0	1	5.2	50
Mediomastus californiensis	2	1	0	4	0	0	4.5	50
Tharyx parvus	0	1	1	2	2	0	3.9	67
Cirratulus cirratus	0	1	0	1	0	3	3.2	50
Leptochelia dubia	0	0	1	1	2	0	2.6	50
Corophium acherusicum	3	0	1	0	0	0	2.6	33
Shistomeringos japonica	0	0	1	2	0	0	1.9	33
Psuedopolydora paucibranchiata	0	0	0	0	3	0	1.9	17
Micromaldane ornithochaeta	1	0	1	0	1	0	1.9	50
Melita nitida	0	0	2	0	0	1	1.9	33
Streblospio benedicti	0	0	0	2	0	0	1.3	17
Streblosoma bairdi	0	1	0	0	1	0	1.3	33
Psuedopolydora kempi	1	0	1	0	0	0	1.3	33
Melita spp.	2	0	0	0	0	0	1.3	17
Glycinde polygnatha	0	0	1	1	0	0	1.3	33
Caprella californica	0	0	0	0	1	1	1.3	33
Euclymene zonalis	0	1	0	0	0	0	0.6	17

APPENDIX K.(Continued) Species Composition, Dominance, and Frequency of Benthic Infauna from Upper Bay Shell Deposition Site in Arcata Bay from Summer 1993.

Opithorix spiculata	0	0	0	1	0	0	0.6	17
Nephtys caecoides	0	1	0	0	0	0	0.6	17
Ianiropsis kincaidi derjugini	0	0	0	0	0	1	0.6	17
Eupolymnia herterobranchia	0	1	0	0	0	0	0.6	17
Nemeratean sp. A	0	0	1	0	0	0	0.6	17
TOTALS								
SPECIMENS	43	8	24	32	30	17		
SPECIES	9	8	12	11	9	7		

APPENDIX L Species Composition, Dominance, and Frequency from the Upper Bay shell Deposition Site in Arcata Bay, California from Winter 1993.

SPECIES	SAMPLE 1	2	3	4	5	6	DOM	FREQ
Mediomastus californiensis	5	2	0	2	11	12	17.9	83
Euclymene cf zonalis	7	5	3	9	3	3	16.8	100
Grandidierella japonica	3	14	2	6	2	1	15.1	100
Leptochelia dubia	1	7	0	5	0	2	8.4	67
Tharyx parvus	2	3	1	0	2	1	5.0	83
Euclymene zonalis	0	7	0	0	1	1	5.0	50
Hemigraspus oregonensis	0	2	0	2	1	2	3.9	67
Leitoscoloplos pugettensis	0	1	0	1	2	1	2.8	67
Platynereis bicanalicuata	0	4	1	0	0	0	2.8	33
Cirratulus cirratus	1	0	0	4	0	0	2.8	33
Streblospio benedicti	0	3	1	0	0	0	2.2	33
Psuedopolydora kempi	1	0	1	0	0	1	1.7	50
Lumbrinereis zonata	0	0	0	0	3	0	1.7	17
Shistomeringos japonica	0	0	1	1	0	0	1.1	33
Collisella digitalis	0	1	0	0	0	1	1.1	33
Capitilla capitata	0	0	0	0	1	1	1.1	33
Armandia brevis	1	0	1	0	0	0	1.1	33
Ampithoe spp.	1	0	1	0	0	0	1.1	33
Polycirrus spp.	0	0	0	2	0	0	1.1	17
Terebellidae	0	0	0	0	1	0	0.6	17

APPENDIX L(Continued) Species Composition, Dominance, and Frequency from the Upper Bay shell Deposition Site in Arcata Bay, California from Winter 1993.

Prothothaca staminea	0	0	0	0	0	1	0.6	17
Psuedopolydora paucibranchiata	1	0	0	0	0	0	0.6	17
Pontogeneia rostrata	1	0	0	0	0	0	0.6	17
Polydora socialis	0	0	1	0	0	0	0.6	17
Microdeutopus	0	0	0	1	0	0	0.6	17
Melita nitida	0	0	1	0	0	0	0.6	17
Lembos spp.	1	0	0	0	0	0	0.6	17
Harmothoe imbricata	0	0	0	0	0	1	0.6	17
Glycinde polygnatha	0	0	0	0	1	0	0.6	17
Exogone lourei	0	1	0	0	0	0	0.6	17
Eteone californica	0	1	0	0	0	0	0.6	17
Ianiropsis analoga	0	0	0	0	0	1	0.6	17
TOTALS								
SPECIMENS	25	51	14	32	28	29		
SPECIES	11	12	10	9	10	13		