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Title: EFFECTS OF BARK DEBRIS ON BENTHIC MACROFAUNA OF YAQUINA BAY, OREGON

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Benthic samples were collected during the summer, winter and spring seasons from upper Yaquina Estuary, a region used by Georgia-Pacific Corporation for log dumping and storage. Samples came from an active log dump and storage areas as well as areas not associated with log handling activity. The samples were analyzed for total macrofauna (>1.0 mm) and sediment parameters. One of the sediment parameters measured was total organic or volatile solids which was used as an indicator of bark deposits. Diversity indices were calculated on total macrofauna collected during the three sampling periods and on the polychaete and crustacean subgroups. A similarity index was also calculated for all combinations of summer sampling stations.

Multiple regression analysis of diversity with seven sediment parameters and water depth was generally insignificant. The trends in total summer macrofauna and crustacean diversities showed an increase in diversity with increasing volatile solids. A similar increase was noted in the summer macrofauna density. Winter and spring macrobenthic diversities were not significantly correlated to any of the parameters measured. Although population densities generally declined during these two seasons there was a positive correlation of density with water depth. This indicates that organisms associated with the more saline bottom waters were protected from severe osmotic stresses caused by the overlying river water.

The results of the summer similarity analysis showed four groups of highly similar stations. Two groups were in fairly coarse sandy sediment, while the other two were in finer sand and silt sediments. One group of the latter two was associated exclusively with the log handling areas.

The results indicate that bark debris in Yaquina Estuary did not result in decreased diversity or density of macrofauna but seem to result somewhat in an altered species type. Possible explanations for these results are discussed.

Effects of Bark Debris on Benthic Macrofauna of Yaquina Bay, Oregon

by

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EFFECTS OF BARK DEBRIS ON BENTHIC MACROFAUNA OF YAQUINA BAY, OREGON

I. INTRODUCTION

Because of unique physical and geographical characteristics, estuaries are important areas for human habitation (Cronin, 1967). They provide natural harbors and transportation routes to inland areas. They are high in biological productivity, and are consequently rich in foods harvested by man (Cronin, 1967). As human populations have increased during this century, the uses of estuarine resources have generally become greater and more diversified; and as a result, multiple use conflicts have become more common. Resolution of these conflicts often requires additional studies to define their exact nature and severity.

One of the principal industries in the Pacific Northwest is the forest products industry. The siting of lumber mills and pulp and paper mills on the estuaries, because of an abundance of fresh water and the ease of waste disposal, is probably one of the major sources of estuarine resource use conflict in this area. One of the long term estuarine uses of this industry which has received little attention until recent years is the practice of log storage in bays and sloughs. There are estimated to be 2,000 acres of such log storage areas in Oregon estuaries alone (Schaumburg, 1972). The need for log storage results from the climatic conditions of the area which usually limit the harvest of timber to summer and fall months. This makes it necessary to store sufficient timber to insure year round operation of the lumber, plywood and pulp mills.

The advantages of water storage over land storage include ease of movement, minimum utilization of land and a minimum log loss due to end-checking and attack by land borne insects. The environmental problems that could occur from log dumping and storage in public water ways, other than aesthetic and spatial, include the release of toxic materials and increase of biochemical oxygen demand in the water from log and bark leachates.

Schankland and Schuytema (1971) found very low dissolved oxygen levels (1.6-5.7 mg/liter) in sloughs of the lower Columbia River used for log storage, but where water movement was obvious, no values below 90 percent saturation were found. A similar study, conducted by the Oregon Department of Environmental Quality (1971), showed that Isthmus Slough in Coos Bay, also with negligible water movement and heavy log storage, was very low in dissolved oxygen. The dissolved oxygen levels in Isthmus Slough were considerably below levels required by state water quality standards and constituted a potential threat to the indigenous aquatic life.

The toxicity of log leachates was tested by Atkinson (1971) using juvenile chinook salmon (Oncorhynchus tshawytscha) and Kamloops rainbow trout (*Salmo gairdneri*). Using water which had been exposed to a log for seven days he found what he described as light toxicity from Douglas fir logs and no toxicity from either Ponderosa pine or Hemlock. Buchanan (unpublished), using ground fresh bark pieces with the cambium attached as the source of toxicant, found that western Hemlock (*Tsuga heterophyllia*) bark was quite toxic to Pink Salmon smolts (*Oncorhynchus gorbuscha*) and Sitka spruce (*Picea sitchensis*) bark was quite toxic to the larva of shrimp (*Pandalus borealis*) and Dungeness crab (*Cancer magister*). The difference between Atkinson's and Buchanan's results, which may be explained by the differences in leachate preparation or tolerance differences of the different species examined, seems to indicate that the issue of toxicity remains unresolved and additional information is needed before the severity of the environmental problems created by the leachable substances can be fully evaluated.

Another potentially significant environmental problem associated with log handling results from the benthic deposit of bark lost from logs during unloading operations or storage in the water. The resulting increased organic load in the sediment may produce anoxic conditions and lead to the formation of H_2S, either of which can be very detrimental to the benthic community.

Williamson (1970), studying the problem of bark deposits in Yaquina Estuary and Klamath River, Oregon, showed that up to

21.7 percent of Douglas fir bark was lost during unloading and storage operations. He found that the bark quickly loses its buoyancy and sinks, and that the rate of sinking is dependent on the size of the pieces. Pieces up to 1/2 inch in diameter had all sunk within 20 days but of the pieces four inches or greater in diameter, only 27 percent had sunk in that time.

Bark build up in the sediment was measured by Williamson as an increase in the volatile solids content. In Yaquina Estuary, log dump and log storage sites had considerably higher levels of sediment volatile solids than other areas. The log dump had the highest bark concentrations, ranging from 13.7-43.5 percent volatile solids, while the control areas had only 3.8-9.5 percent.

In Alaska, the majority of logging operations utilize protected bays and inlets for unloading and storage. Ellis (1973), using SCUBA techniques, conducted a qualitative study in areas of operational and abandoned log dumps as well as areas free from logs. He found considerable wood debris, black mud and a reduction or near absence of animal and plant life at dump sites. In areas peripheral to the sites, animal and plant life appeared plentiful and diverse. The study showed that there was a considerable variation from one dump site to another, but that dump sites generally appeared to be less productive than the adjacent areas.

Schaumburg (1972), using an in situ benthic respirometer, found, in fresh water, that a Douglas fir bark deposit had 2.5 g/m^2/day greater oxygen utilization than an equivalent control area. This amounted to an eightfold increase in the oxygen consumption rate. Comparable data were obtained by Stein and Denison (1966) using similar techniques with cellulose deposits.

Servisi, Martens and Gordon (1970) found, in simulated gravel redds containing ten percent bark by weight, that anoxic conditions occurred when water velocities over the sediments were low. Bark particles were also instrumental in decreasing the water circulation within the redds. Under these circumstances Sphaerotilus growth occurred on the decaying bark resulting in conditions unfavorable for alevin survival.

The present study was concerned with that area of Yaquina Estuary in which Williamson's work showed high concentrations of submerged bark debris. The purpose of the study was to determine the effect that bark deposits have on the benthic communities. Evaluation of effects was limited to the macroinvertebrate components of the benthos. Diversity indices were calculated and compared with environmental parameters, including volatile solids, using multiple regression techniques in an effort to evaluate the impact of the high bark concentrations. Similarity indices were also used to compare sites having high and low bark concentrations.

The macrobenthos, while only a subsystem of the estuarine ecosystem, is important as an indicator of the total system. Since the organisms are sessile and fairly long lived (Odum, 1959), they, in effect, provide a history of recently prevailing conditions. The assumption that actions of the abiotic environment and coactions between the biotic component result in a characteristic assemblage of organisms (Wilhm, 1967) has been used in freshwater (Patrich, 1953; Wilhm, 1967) and marine systems (Filice, 1959; Copeland, 1970; Armstrong, Storrs and Pearson, 1970) to assess the health of an area.

The concept of species diversity is based on the hypothesis that diversity increases with increasing stability of the environment and decreases with decreasing stability and has been used by many workers (Wilhm and Dorris, 1968; Copeland, 1970; Armstrong _et_ _al._, 1970; Boesch, 1972) to describe the nature of the environment being studied. Pollutants acting as a stress on the organisms in question will result in decreased species diversity. One advantage of this concept is that large amounts of data about species number and abundance can be reduced to a diversity index which provides a basis of comparison with similar collections of organisms from other areas (Wilhm, 1967).

II. MATERIALS AND METHODS

Sampling Design

Because of the gradients and fluctuations in physical environmental parameters common to estuaries, the study region was restricted to a 2.8 nautical mile (nm) portion of the upper Yaquina Estuary (Figure 1). By restricting the study region in this manner, station variation of such difficult to monitor factors as salinity, temperature, and dissolved oxygen could be kept to a minimum. In addition, sampling stations were confined, in most instances, to the channel edge to minimize the effect of varying current velocity and sediment type. All sampling stations were also confined to subtidal regions to eliminate the effect of tidal exposure.

The remaining major environmental variables, several sediment parameters and water depth, could be more conveniently measured. Therefore, an attempt was made to assess the variation in the macrobenthic component of the community attributable to these factors only using a multiple regression statistical analysis. It was hoped that a regression equation could be developed which would enable the prediction of the benthos by knowing the bark concentration, other sediment parameters and depth.

The study area, shown in Figure 2, had its lower boundary at buoy marker 36 and the upper boundary approximately 0.7 nm above

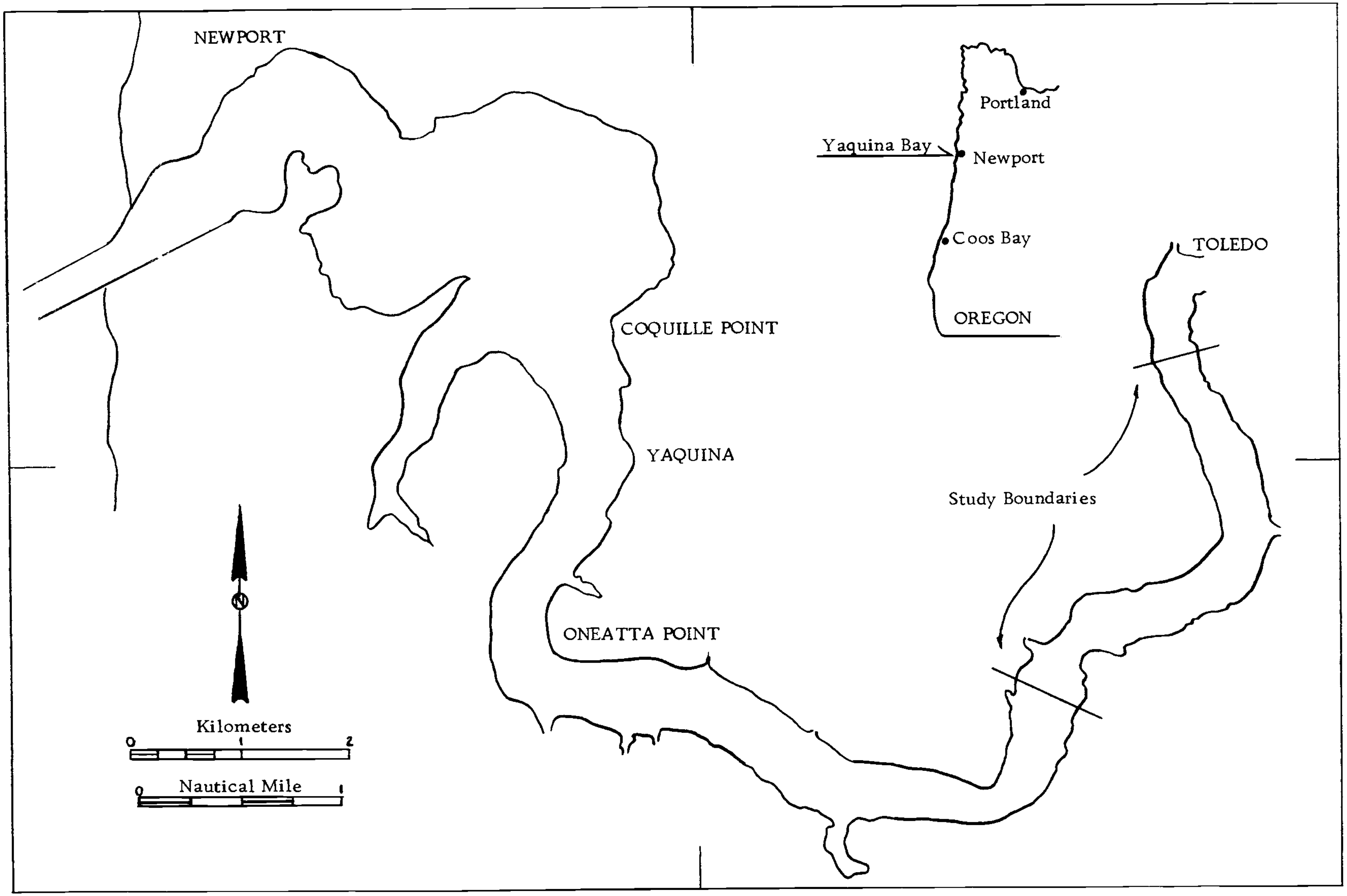

Figure 1. Map of Yaquina Estuary showing study boundaries.

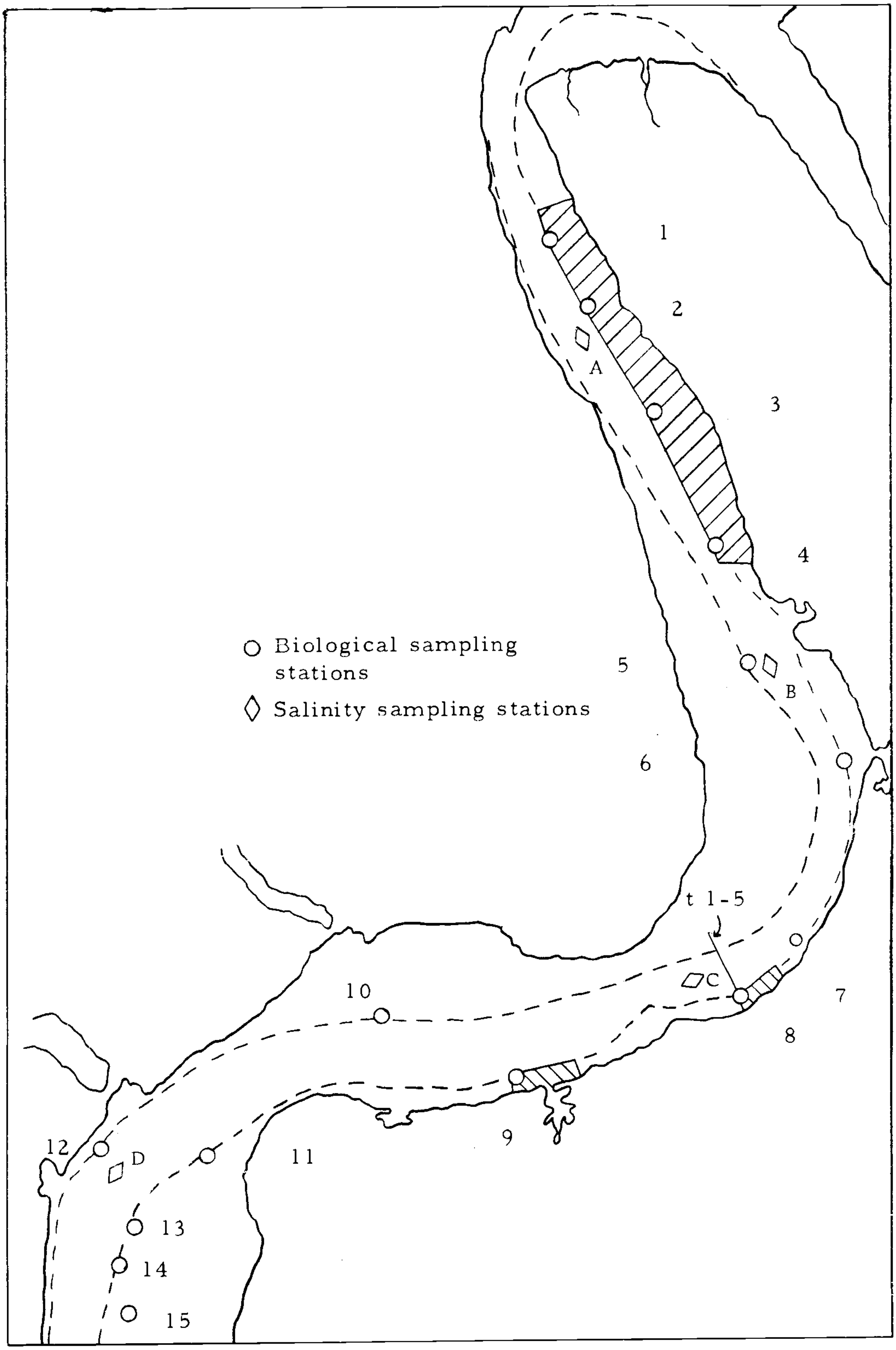

Figure 2. Map of upper Yaquina Estuary with sampling stations indicated. Lined region indicates log handling areas.

channel marker 47. The Georgia-Pacific Log Dump is located in the center of the study area on the south shore roughly 1.4 nm from either boundary. Benthic samples were collected during three seasons: summer, July 15-September 3, 1971; winter, December 20, 1971-January 7, 1972; and spring, May 18-19, 1972.

Two sampling schemes were followed in the summer period. The first, used during late July and early August, 1971, consisted of taking four grabs at each of 15 sampling stations designated numerically with station 1 at the upper boundary of the study and station 15 at the lower boundary. Five additional stations, designated t-1 through t-5, were sampled along a transect perpendicular to the channel in the mid-portion of the study area (Figure 2).

The second sampling scheme, employed during late August and early September, entailed choosing three bark and three "control" areas from the 15 stations mentioned above. The bark corresponded to stations 4, 8 and 10 and the control to 5, 11, and 13. In each of these six areas three sampling sites were randomly selected from a square grid ten meters on a side with nine equidistant points and four grabs were taken at each site. The resulting 18 samples were designated with a number corresponding to the number of the original station and a letter designating the quadrate site. For instance, 4'a, 4'b, and 4'c are samples taken from station 4 and a, b and c, indicate samples within the quadrate. Therefore, although the total number of summer samples taken was 38, the actual geographic locations sampled were only 20.

Of the 20 sampling stations from the summer samples ten stations were chosen for continued sampling during the year. The majority of the sampling stations were near stationary structures such as buoys or pilings to insure relocation of the site for return sampling. The winter sample numbers correspond to the station numbers of the summer but are prefaced with a "w". The spring sample numbers correspond similarly with the winter and summer but are prefaced with an "s". Both biological and sediment samples were routinely taken at each site.

Continuous monitoring of salinity, temperature and dissolved oxygen would be required to fully characterize the variation in these parameters at each sampling station. Since this was not feasible, data available from past studies as well as data collected periodically during the study period were utilized for approximation of these conditions. Sampling stations where hydrographic data was collected are indicated in Figure 2 by the letters A through D.

Biological Sampling

Benthic samples were collected with a 0.05 m^2 Shipek grab weighing 45 kg. The grab was gently lowered to the bottom with a winch, raised up approximately 30 cm and then allowed to free fall to the bottom. This procedure insured a release of the cup which usually failed to release if lowered to the bottom without the free fall. The grab was retrieved and the cup emptied into an 8 liter plastic bucket. No attempt was made to quantify the volume of the grab; but, if it was not full a note was made of its approximate fullness, e.g., 3/4 full or 1/2 full. If less than 1/2 full the grab was rejected and another taken. Four grabs were taken at most sampling sites but in some instances during the winter and spring periods only three were taken. The replicate grabs were pooled for analysis in most instances.

The contents of the cup were immediately washed through a 1 mm copper screen and material retained on the screen was placed in plastic containers. The samples were fixed with $Na_2B_4O_7$ buffered ten percent formalin containing 0.001 percent Rose Bengal and stored for further sorting in the laboratory.

In the laboratory the samples were re-washed through a 1.0 mm stainless steel Tyler screen. Using a water bath and a high intensity light the organisms were collected as they were slowly washed loose of the debris. The Rose Bengal, added to the sample at the time of initial preservation, stained only the animals and gave them greater contrast from the debris. The animals were separated into broad taxonomic groups and stored in 70 percent ethanol until later when they were further identified to genus and species.

Light et al. (1961) was used for general identification and cross reference with more specific taxonomic literature. Hartman (1968, 1969) was used almost exclusively for polychaete identification, Keen (1963) for bivalves and Shoemaker (1949) and Barnard (1954) for amphipods. Generally only the anterior halves of the polychaetes were counted. However, in some instances posterior segments were enumerated when it was possible to make positive identification and be certain that double counts were not being made.

Sediment Sampling

Sediment samples were initially taken with a coring apparatus designed by Williamson (1970). Two cores were taken for volatile solids and organics analysis and two for particle size analysis. The cores were collected and immediately frozen in acetone and dry ice. While still in the field, sediment cores were extruded, labeled and stored in an ice chest containing dry ice. This method proved inadequate for several reasons: it was time consuming, awkward and reflected a sediment distribution different than that of the grab sampler. In later studies a fifth grab sample was taken and used in lieu of the cores for the sediment analysis. Since the cup held a much greater volume than was needed for analysis a metal partition was placed in the cup after the sample was collected and only 1/2 of the volume was retained. The sample was placed in a freezer prior to analysis. This later method greatly increased the sampling speed allowing many more samples to be taken within a day's time.

For the sediment particle size analysis some of the summer samples were thawed, dried at 100°C and weighed to the nearest tenth of a gram on a Mettler top loading balance. The samples were then wet-sieved using Tyler screens of size 4, 10, 40 and 200. Since the screening technique proved to be time consuming, a different procedure was used on the remaining summer and all of the winter and spring samples. The wet sample was passed through a 1.0 mm screen to determine percentage coarse sediments. Subsequently the pipette method was used to determine fine sediments less than 64 microns as suggested by Krumbein and Pettijohn (1938) and the intermediate sediments were determined with an Emery settling tube as outlined by Emery (1938).

The size classes obtained from either of the two methods were transformed to Phi scale, that is, $\phi = -\log_2 \xi$, where ξ is the diameter in mm. This transformation yields a more symmetrical normal distribution curve which is important in statistical analysis. Cumulative percentage curves were drawn based on size class distributions. Mean sediment size $\left(M = \frac{\phi 16 + \phi 50 + \phi 84}{3}\right)$, standard deviation $\left(\sigma = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}\right)$ and skewness $\left[S_k = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}\right]$ were calculated according to the methods of Folk and Ward (1957). Standard deviation or sorting is the degree to which the particle sizes vary from the mean while skewness measures the symmetry of the particle size distribution.

Bark content of sediments was estimated as total volatile solids. Volatile solids content was defined as the percent loss in weight of a sample after ignition at 600°C for one hour. The analysis was carried out on total sediment samples and in some cases after separation into fractions. The fractions were collected by passing a sediment sample through Tyler sieves, sizes 16, 48, and 200, then analyzing the volatile solids of the fraction remaining on each screen. That portion passing the #200 sieve was estimated by difference from the total volatile solids.

Hydrography

Salinity determinations were made on water samples collected at the surface by dipping and from the bottom with a Frautschy water sampler. Salinity estimates were made in the field using specific gravity methods (Mangelsdorf, 1967). Accuracy of this method is approximately ± 0.7 o/oo. Temperature and dissolved oxygen were measured *in situ* with a YSI model 51A portable oxygen meter. This instrument uses a polarographic oxygen probe and a thermistor. The instrument has an accuracy of ± 0.25 ppm for the oxygen probe and ± 0.7°C for the thermistor. Oxygen and temperature readings were also taken for both bottom and surface waters. The hydrographic data was obtained at various intervals between high and low tide.

Community Analysis

There are a variety of diversity indices that have been proposed in the past. The choice of index to be used depends on the data available and the question being asked. One of the more commonly used indices is the Shannon Weaver index ($H' = -\Sigma P_i \ln P_i$) derived from information theory. This index expresses the degree of uncertainty of choosing one species from a series. In this equation P_i is the proportion of the ith species in the population and can be estimated by n_i/N (n_i=number in ith species, N = total number or organisms).

The Shannon-Weaver index is sensitive to both species richness and species equitability and is fairly insensitive to variation in sample size (Sanders, 1968; Swartz, 1972). Because of these characteristics it has been used extensively by pollution biologists and synecologists where it is necessary to compare collections of organisms of unequal sample size. In this study, diversities were calculated for the total assemblage of animals collected at each station as well as for the polychaete and crustacean subgroups using the Shannon-Weaver formula.

A similarity index for comparing two sites was calculated for all combinations of sampling sites within each season. The formula used was ΣW_i, where W_i is the lower percentage of the ith species common to both collections. This formula is a modification of one proposed by Bray and Curtis (1957).

Regression Analysis

Multiple regression analysis was calculated using a CDC 3300 computer employing the *SIPS Program at Oregon State University. The regress subsystem within the *SIPS system enables the calculation of multifactor regression models as well as *STEP, a program that adds the variable with the highest correlation coefficient to data at each step and variables already entered are continuously examined at every step to determine if the contribution of the entering variable is insignificant and should be ignored.

III. DESCRIPTION OF THE ESTUARY

The Yaquina Estuary, which opens to the sea at $44^{o}37'$ N. Lat. and $120^{o}04'$ W. Long., on the central Oregon coast, is a true estuary. According to Pritchard (1967) a true estuary may be defined as "...a semi-enclosed coastal body of water which has free connection with the sea and within which sea water is measurably diluted with fresh water derived from land drainage." The Yaquina Estuary extends to Elk City at the confluence of the Yaquina River and Elk Creek. These are the only permanent streams of any consequence entering the bay (Kulm, 1965). The drainage basin is relatively small, comprising approximately 240 sq. miles (Goodwin, Emmett and Glenne, 1970), and is located on the western slopes of the coast range.

Climatic conditions on the Oregon coast are characterized by fairly dry summers and wet winters with a moderate seasonal variation in temperature. The annual mean precipitation for Newport is 68.2 inches (Holbrook, 1972). However, deviations of 20 inches or more from the mean are not uncommon (Kulm, 1965). Approximately 70 percent of the precipitation occurs from November through March, the maximum falling in December and January and the minimum falling during July and August (Thum, 1972). Temperatures in summer are warm and winters are mild with a very narrow range of

13.8°C between January mean minimum temperatures and August mean maximum (Holbrook, 1972; Thum, 1972). The year 1971 in which most of this study was conducted (1971-1972) had a total rainfall of 24.24 inches above normal with the major increases occurring in the months of September, November and December, 1971. Associated with the above average rainfall were two periods of extreme flooding in early 1972, one in January and another in February.

Tidal Characteristics

The tides in Yaquina Bay are semi-diurnal with a pair of highs and lows of unequal amplitude and duration. In the study area, located 8.0 to 10.8 nautical miles from the mouth of the bay, there is a lag of 35 to 50 minutes in high and low slack water from that measured at the Marine Science Center in Newport. There is also a tidal amplification between Newport and Toledo. For example, a 9.0 ft. tidal range at Newport will have a 9.5 ft. tidal range in Toledo (Goodwin *et al.*, 1970).

Tidal current through the area, as measured by Goodwin *et al.* (1970) during a period of minimal river flow in late July was 0.75 ft/sec for ebb tide and 0.5 ft/sec for floodtide. Considerable differences in velocity would be expected during times of maximal freshwater flow.

Salinity Structure

Yaquina Bay is a positive type estuary with a salinity gradient from the mouth to the head. In the summer with minimum runoff, the estuary extends to approximately Elk City, 18. 5 nautical miles from the mouth (Kulm, 1965). During peak runoff in winter, however, the estuary's reach is reduced by six to eight nautical miles resulting in an overall length in winter of 12. 5 to 10. 5 nautical miles from the mouth.

Yaquina Estuary has been classified by Burt and McAlister (1959) using Pritchard's scheme (Pritchard, 1955) as a type B, or partially mixed, system during February through May and as a type D, or well-mixed system from June through January.

Salinities are fairly constant in the study area during the summer, varying approximately 5 o/oo from the lower boundary to the upper boundary for a given tidal condition (Figure 3). In the Venice system of classification (Carriker, 1967) this region of the estuary would be classed as polyhaline during the summer (18 o/oo-30 o/oo). During the winter rainy season, however, a gradient develops with the upper region classed as oligohaline (0. 5 o/oo-5 o/oo), while the lower region would be classed as oligo-polyhaline (0. 5 o/oo-25 o/oo) (Figure 4). Classification of these areas is based on the salinity range of the bottom water.

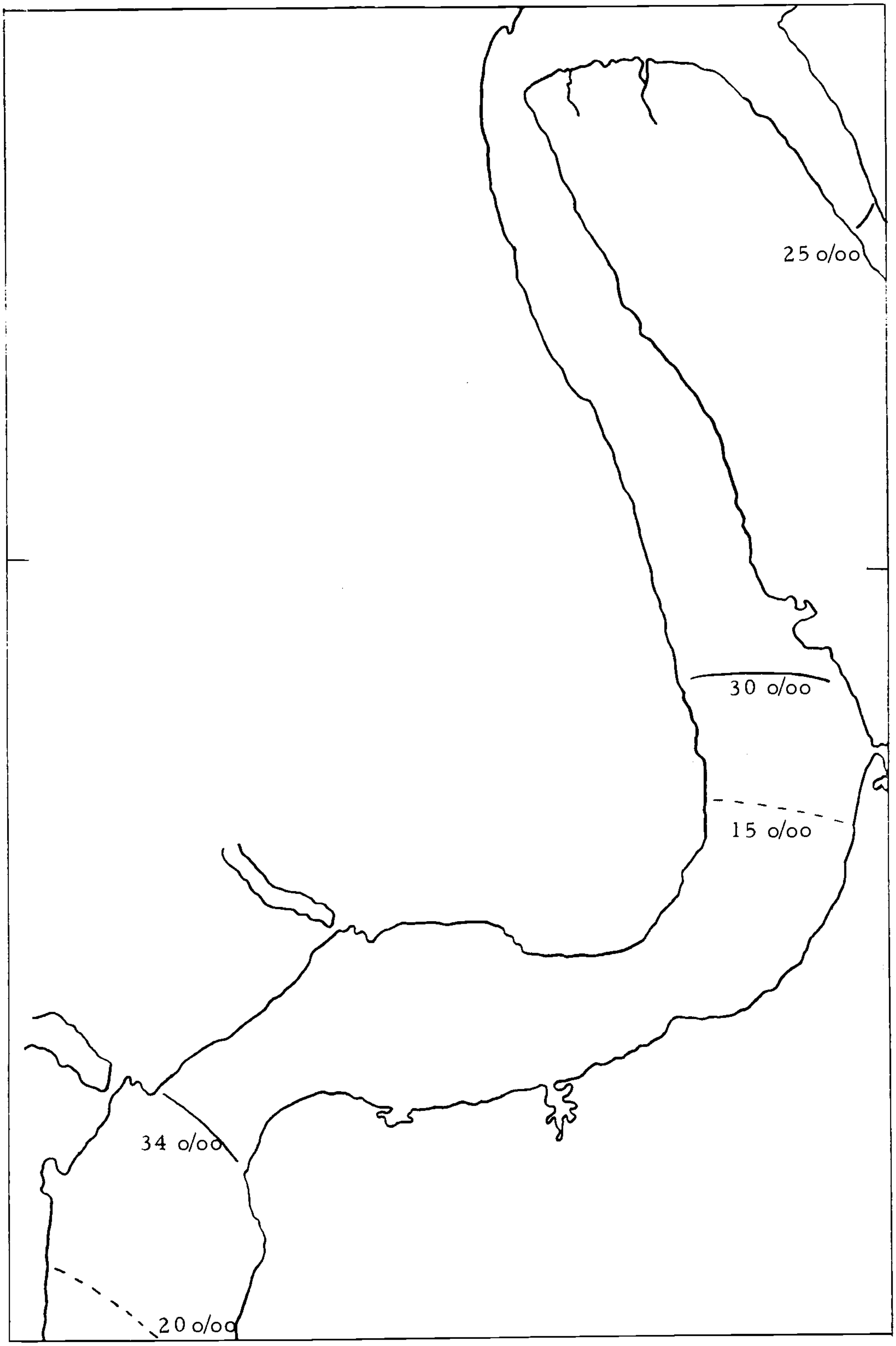

Figure 3. Maximum and minimum bottom salinity isohalines which can be expected during August and September. Solid lines indicate salinity at high tide, broken lines salinity at low tide.

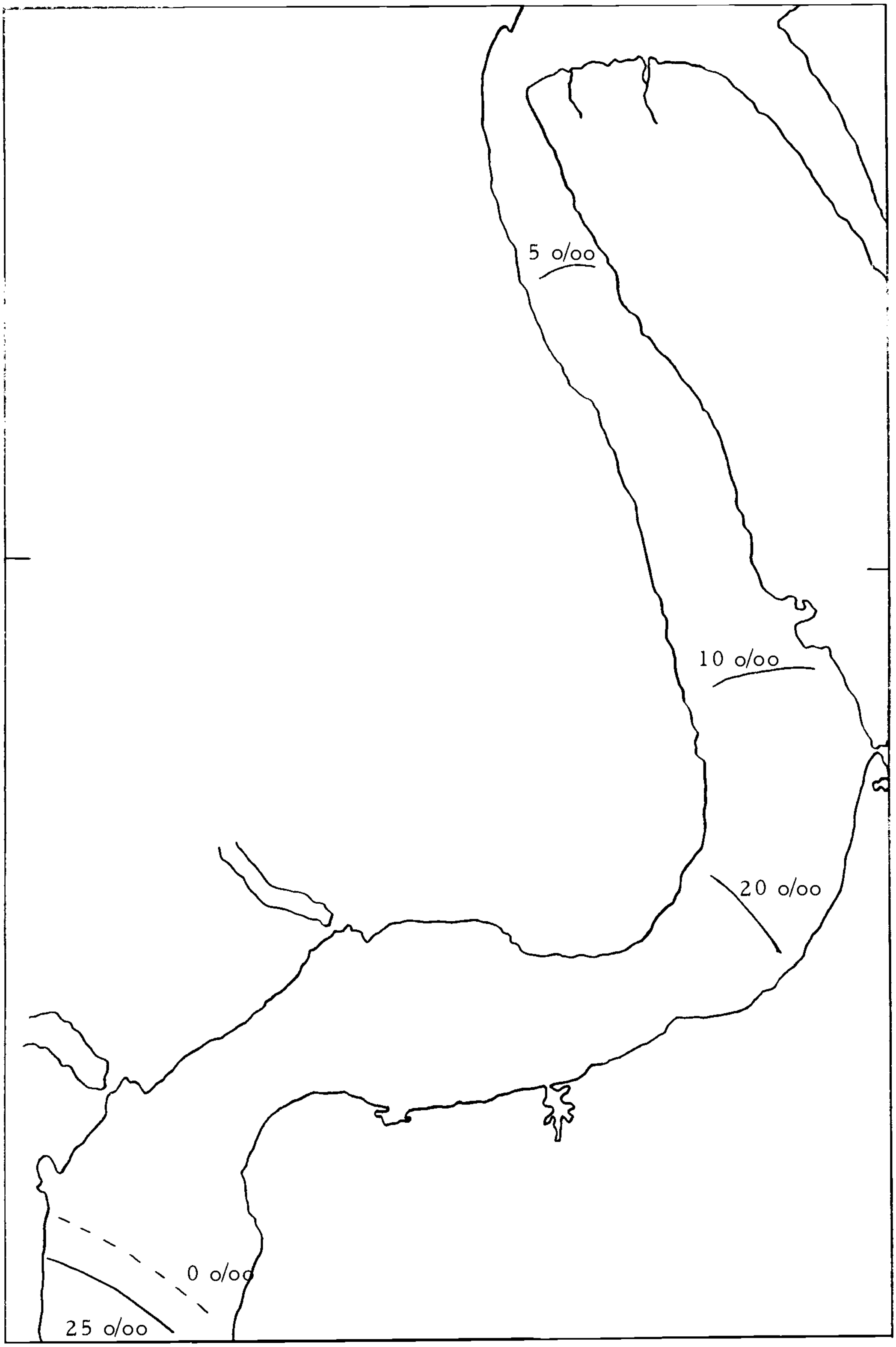

Figure 4. Maximum and minimum bottom salinity isohalines expected during winter. Solid lines indicate salinity at high tide, broken lines salinity at low tide.

Due to the increase in fresh water influx the well-mixed conditions in the summer develop into a stratified system in the winter with a well-developed salt wedge. Figure 5 shows the difference in salinity between surface and bottom water during the latter season. The stratification that is quite pronounced at high tide diminishes and becomes minimal or non-existent at low tide as the salt wedge moves down the estuary. As a result of this the organisms in the shallower water, while exposed to low salinities for greater periods of time, are not going to be subjected to as wide a salinity variation as the deeper organisms.

Temperature

The shallow nature of Yaquina Bay, as well as the relatively small volume of water which it contains compared to the ocean, results in wide temperature fluctuations which are caused in part by fluctuating air temperature, variable insolation and prevailing oceanic and fluviatile conditions. Figure 6 shows mean water temperature and range for the upper region of the Yaquina Estuary. In this region water temperature seems more affected by insolation and fluviatile conditions than by the oceanic water. Summer temperatures with a maximum usually in August are in the high teens to low 20's (°C), considerably warmer than down bay waters which are more directly affected by the cold, upwelling water common to the Oregon

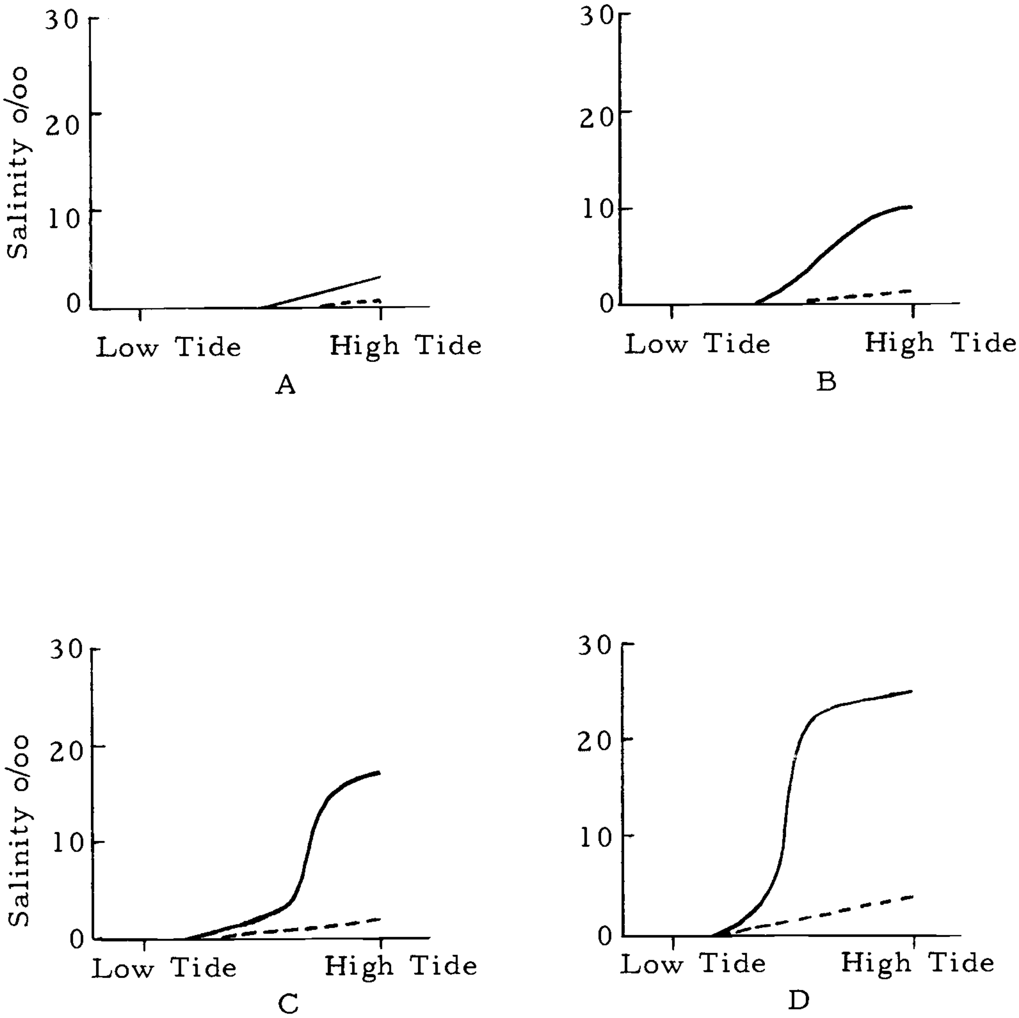

Figure 5. Salinity patterns recorded on Dec. 1, 1971 at four locations in Yaquina Estuary. These positions A-D are shown in Figure 2. This pattern occurred in conjunction with a spring tide (+10.0 ft to -1.7 ft.) and 4.3 inches of rain which had fallen the week previously. Solid lines indicate bottom salinity, broken lines surface salinity.

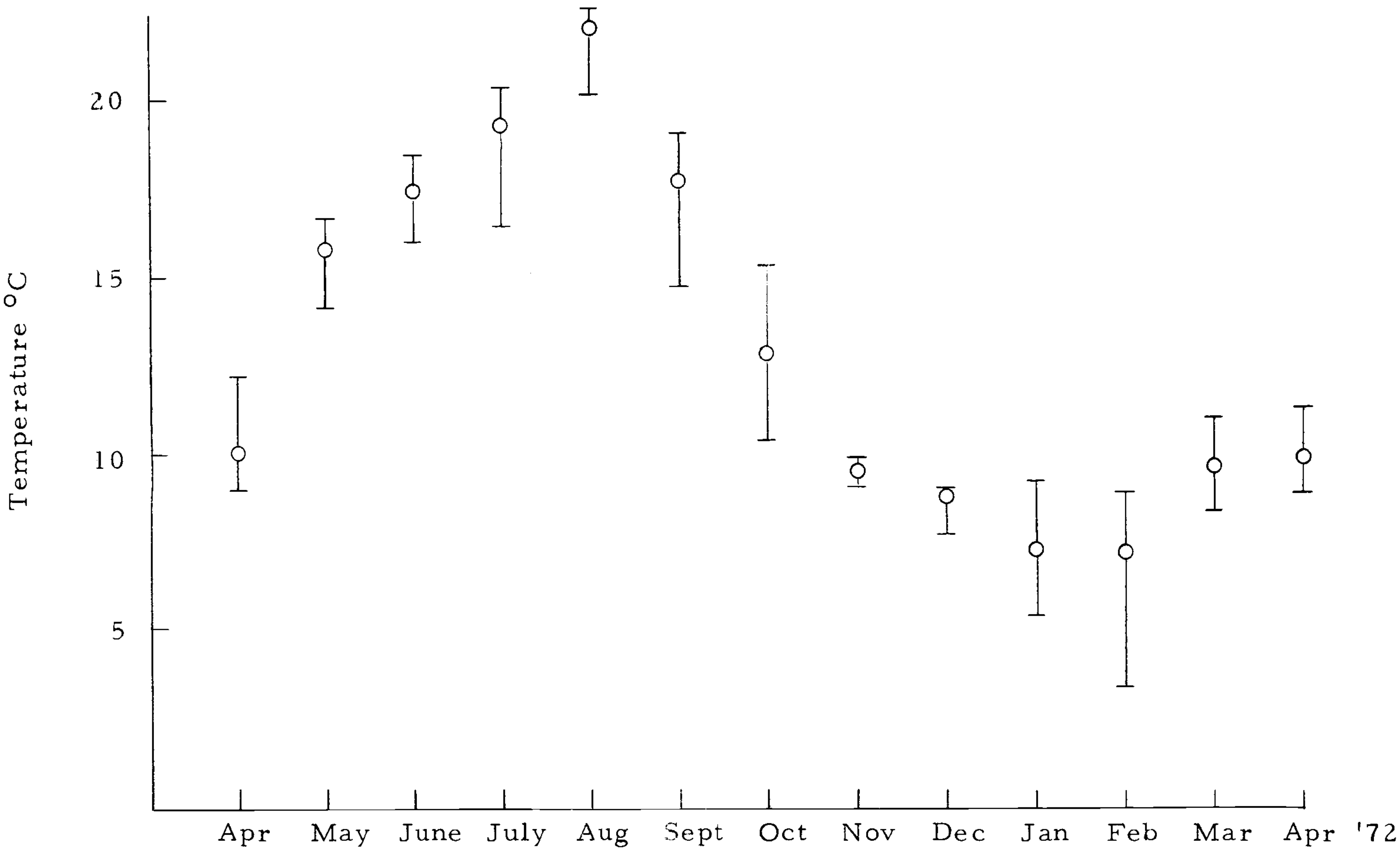

Figure 6. Bottom water temperature mean and range for upper Yaquina Estuary from April 1971 to April 1972 recorded at buoy marker 39. Data from Frolander (1972).

coast in the summer. In the fall, water temperatures in the upper estuary decrease rapidly and are equal to down bay water temperatures by middle to late October. Winter temperatures in this region are usually lower than those found down bay with minimums usually 6-8°C, normally occurring in January or February. By May, temperatures begin to exceed those found down bay, reaching their maximum in August (Frolander, 1972).

Dissolved Oxygen

Dissolved oxygen within the region studied was lowest during the summer when water temperatures were high and fluviatile effect was minimal and highest during the winter when water temperatures were lower. The lowest levels of dissolved oxygen were found with low tide in the summer, 57-70 percent saturation (3.6 ml/l) (Frolander, 1972). During high tide the dissolved oxygen usually remains at about 80-85 percent of saturation. The winter tides have little effect on dissolved oxygen which remains constant at 85-95 percent saturation (Frolander, 1972). There is no particular longitudinal variation in dissolved oxygen observed within the area studied.

Sediments

Sediments of Yaquina Bay were characterized by Kulm (1965) from the mouth to the head of the estuary. The sediments above

Oneatta Point, which included those in the study area, were fluviatile in origin. Latitudinal transects that coincided with the study area showed the sediment particle size to decrease from mid-channel to either side with the fine sediments occurring only on the edges of the channel. The results of the sediment analysis in this study bear out this fact and will be discussed later in the paper.

IV. ANALYSIS OF THE SEDIMENTS

Of the two general sediment analyses made, particle size and volatile solids, the particle size was the least variable both within the season and between season samples. Volatile solids were quite variable both within the season and between seasons. There was a trend in the variability between seasons with the summer volatile solids high with respect to the winter sample, and then increasing again in the spring samples--in some cases higher than the summer sample. This may be attributed to the increased activity of algae and phytoplankton in spring and summer. Appendix I shows the sediment parameters for all sampling sites, as well as a description of the particle size based on Shepard's descriptive system, Figure 7 (Shepard, 1954). In this classification system the majority of the stations were classified as sand or silty-sand with a few classified as sandy-silt.

The distribution of the mean particle size for all sampling stations appeared to be bimodal with the trough between maxima at 3.00 to 3.75 Ø (Figure 8). This distribution may be a reflection of the selected sampling of log and non-log areas. It is interesting that of the 21 stations having a mean particle size greater than 3.75 Ø only four are located in non-log handling areas. If the 17 log stations, indicated by the cross-hatched areas in Figure 8, are removed, the distribution is much closer to normal. Since the log dump and storage

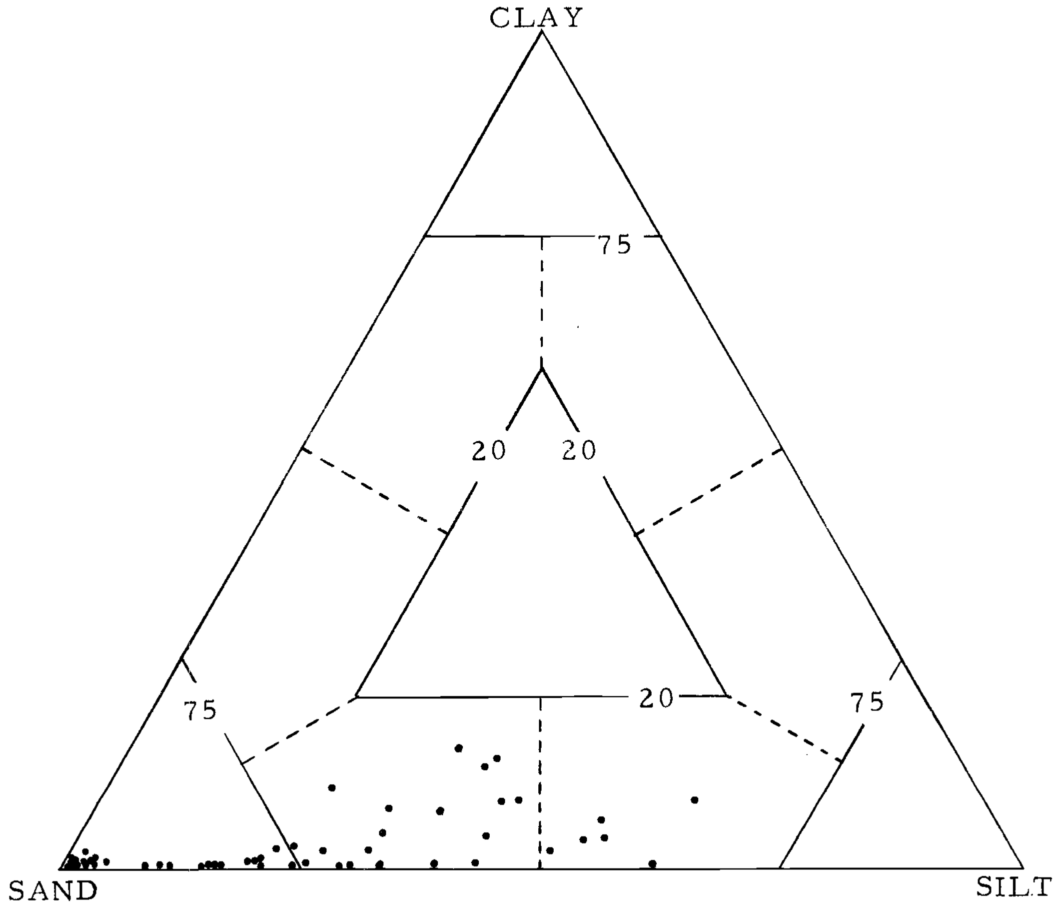

Figure 7. Sand-silt-clay ratios for all stations.

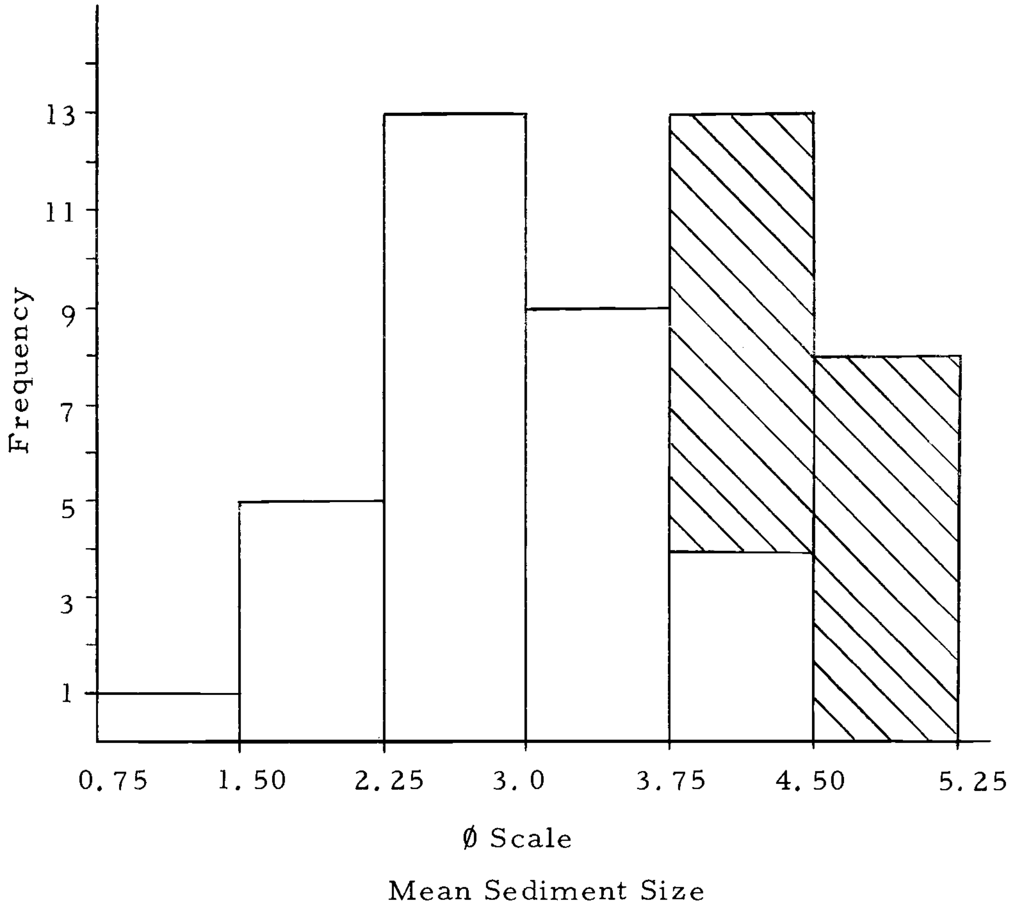

Figure 8. Distribution of mean Ø sediment particle size for all samples.

areas are situated on the edge of the channel the finer sediments found there may be a natural occurrence because of reduced scouring. On the other hand, the pilings used to form the log booms or the debris on the bottom may act to increase the deposition of fine particles.

The degree of sorting, or standard deviation, is a measure of particle size variation around the mean. The standard descriptive nomenclature for sorting based on Folk and Ward (1957) is indicated in Table 1. The sediments in the study area, as a whole, would be classified as poorly to very poorly sorted. The exceptions to this are the fairly coarse sandy sediments which ranged from very well sorted to well sorted. Some of the fine sand and silty-sand sediments were classified as moderately well sorted. The silty sediments were poorly sorted. The sites with fairly constant mean sediment particle size through the study year show a rather constant sorting value.

Table 1. Relation of standard deviation of sediment particles to degree of sorting.

Standard Deviation (σ)	Sorting
0.00-0.35	Very well sorted
0.35-0.50	Well sorted
0.50-0.71	Moderately well sorted
0.71-1.0	Moderately sorted
1.0 -2.0	Poorly sorted.
2.0 -4.0	Very poorly sorted
$>$ 4.0	Extremely poorly sorted

The range of the skewness as calculated by Folk and Ward (1957) is -1.0 to +1.0 with -0.1 to +0.1 considered as symmetrical. A positive skew is 0.1 to 0.3 while 0.3 to 1.0 is considered very positively skewed. The same follows for negative numbers. If a distribution is negatively skewed it is considered to have a tail of coarse particles while if it is positively skewed it has a tail of fine particles.

With the exception of one, all stations sampled were either symmetrical or positively skewed. The symmetrical distribution of sediments was quite rare, however, only 8 out of 50, and was correlated somewhat with sandy sediments. There was considerable variation in the skew of the sediment distribution from one season to the next, but no pattern was evident.

Bark concentration of the sediments was estimated by Williamson (1970) as the percentage of volatile solids. He showed that volatile solids in the sediments were highly correlated with nearness to the log dump and log storage areas. The results of the volatile solids analysis in this study were in agreement with those of Williamson (1970). There was essentially no overlap in volatile solid content between the log and non-log areas (Figure 9). One consideration not taken into account by Williamson, however, was that there is a natural increase in organics with decreasing particle size (Mironov and Bordovsky, 1959; Bader, 1962). This relationship is attributed in part to the adsorption of organic molecules to the surface of clay

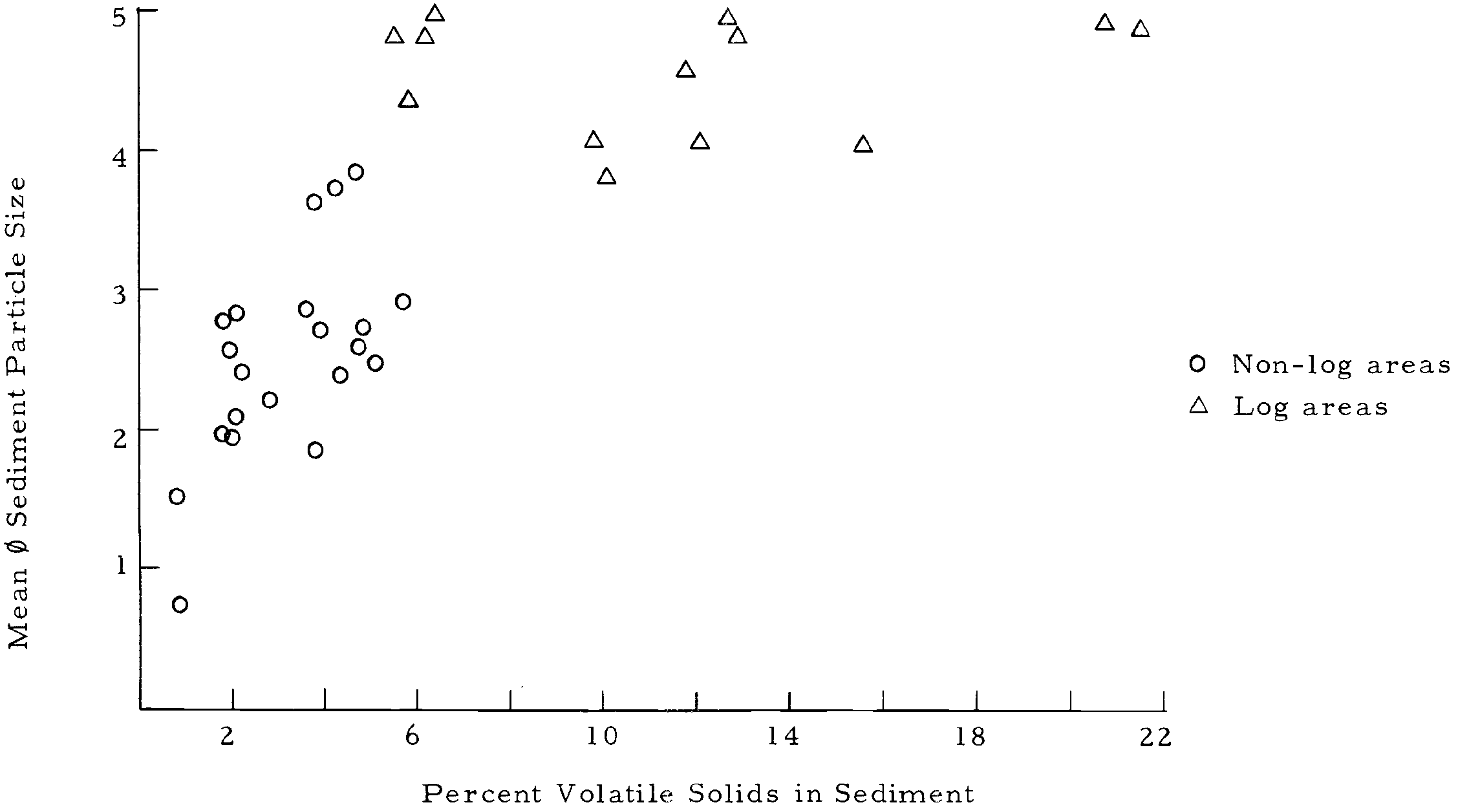

Figure 9. Relation of volatile solids to mean ∅ sediment particle size.

particles (Bader, 1962) but also the sedimentary processes which are responsible for small particle sizes also allow for the settling and accumulation of detritus from the water column (Carriker, 1967). As a result the fine sediment regions are rich in particulate organics as well as organics adsorbed to the sediment particles. As shown earlier, the sediment particle size in this study was smaller in the log than in the non-log areas (Figure 8 and also Figure 9).

Since the log dump and storage areas were fine sediment regions an attempt was made to differentiate between organics attributed to the bark debris and organics resulting from natural processes. Sediment screening prior to volatile solids analysis was done to determine the size classes of the volatile material. For comparative purposes the stations were divided into high and low volatile solids areas. Those stations greater than 7.0 percent volatile solids were considered high, those below 7.0 percent, low, corresponding roughly to log and non-log handling areas, respectively.

The major difference between the high and low volatile solids areas occurred with the particles greater than 1.0 mm in diameter (Table 2). In this size class the volatile solids constituted 28.3 percent of those in the total sample for the high volatile solids sediments as compared to 13.1 percent for the low volatile solids sediments ($P < 0.001$). This suggests that a large proportion of the total volatile solids from the high volatile solids areas was composed of particulate bark and wood debris.

Table 2. Percentage of screened sediment volatile solids to the total volatile solids. The difference in mean values between high and low volatile solids areas is given with the t values.

Screen Size mm	Percentage Volatile Solids High V.S. Areas	Low V.S. Areas	$\Delta\overline{X}$	t
1.0	28.3	13.1	15.2	3.68***
.297	22.9	28.9	6.0	1.86
.074	17.5	23.6	6.1	1.60
<.074	31.5	39.7	8.2	1.67

*** $P < 0.001$

V. RESULTS AND DISCUSSION

Analysis of Sampling Procedure

The reliability of the sampling procedure was tested by plotting species numbers against number of grabs. It was assumed that the number of species would approach an asymptote as the number of samples increased. The summer areas 4', 5', 8', 9', 10' and 13' lended themselves to this test since three stations, each having four replicate grabs, were sampled within an area approximately 10 M^2 yielding essentially 12 replicate samples. Figure 10 shows increase in species number with increase in replicate samples for these six sites.

On the average, the first four grabs collected at each of the six sites accounted for 77 percent of the total species encountered in all 12 grabs at that site. The additional 23 percent of the species, however, represented the rarer species and probably never exceed one or two percent by numbers of the total collection. This can be clearly seen from the data in Table 3 where an analysis of the 12 grabs from area 13' is tabulated. For example, the fifth grab from area 13' shows the addition of one new species. However, this species was represented by only two individuals which accounted for only 0.38 percent of the total number of organisms in the five grabs. An occasional variation from this general response may occur by encountering an

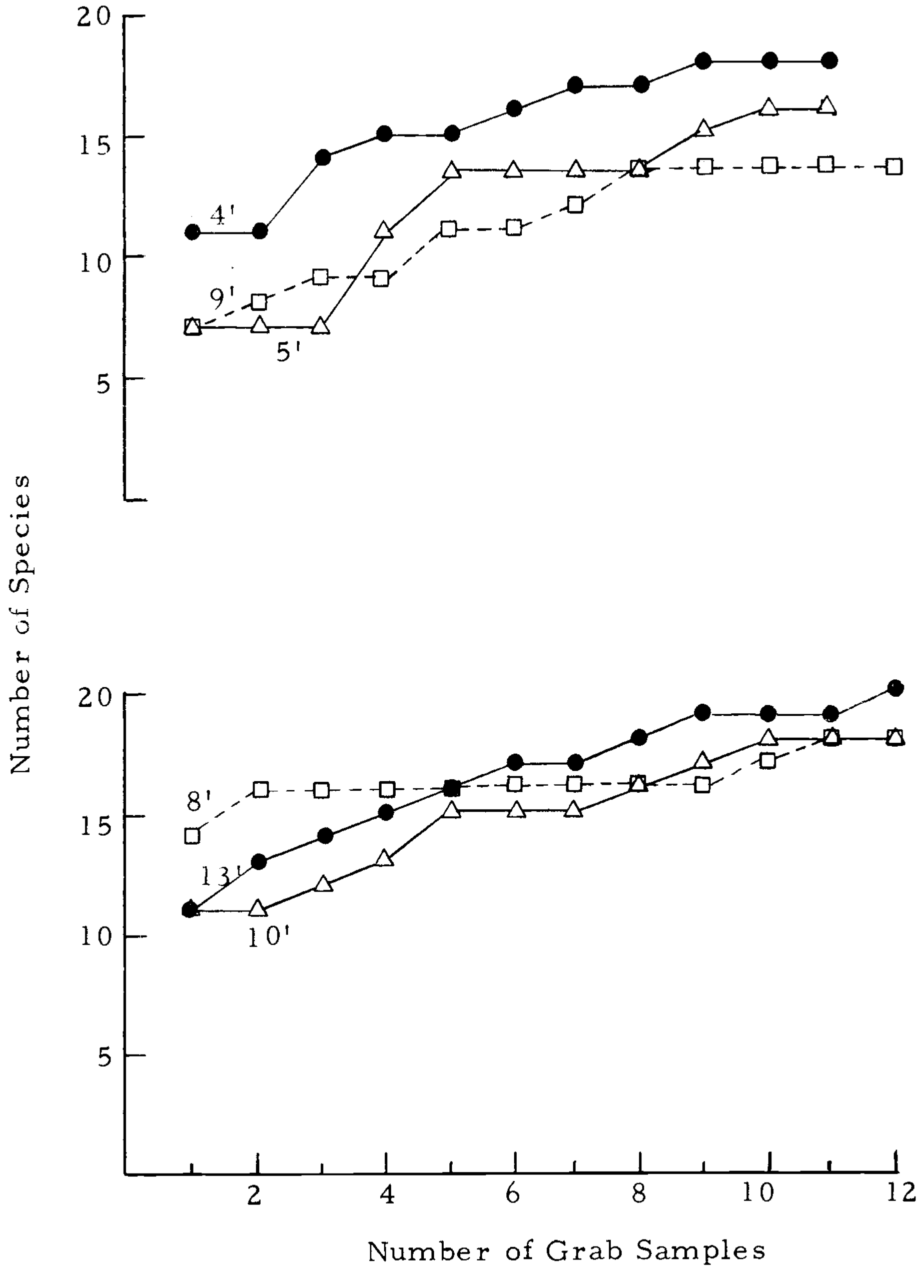

Figure 10. Cumulative number of species with increased sampling. Each line represents one of six sampling areas.

Table 3. Number of new species added, number of organisms contributed by new species and the percent of total organisms the new species represent as consecutive grabs were taken in area 13'.

Grab Number	Number of species present per grab	Number of organisms present per grab	Number of new species added by consecutive grab	Number of organisms added by new species	Percent increase in number of total organisms attributed to new species
1	11	189	11	189	100
2	11	49	2	3	1.26
3	9	265	1	2	0.66
4	12	117	1	3	0.71
5	11	110	1	2	0.38
6	12	115	1	2	0.29
7	13	180	0	0	0
8	14	144	1	1	0.10
9	13	144	1	1	0.09
10	8	51	0	0	0
11	12	158	0	0	0
12	14	113	1	1	0.07

organism with a very aggregated distribution. This occurred in Area 4' in which large numbers (35) of Balanus glandula were encountered in the third grab associated with a piece of wood debris.

Since only rare species are normally encountered after the first four grabs there would be little effect on the diversity or similarity indices used in this study. Both of these indices are calculated on the ratio of one species number to all the organisms in a collection. On this basis it was felt that four replicate grabs taken from each station was adequate for the analysis used in this study.

Distribution and Abundance of Species

Table 4 ranks the species encountered in the study by their frequence of occurrence at the 63 stations sampled and by total number. Phylogenetic relationships of all these species are tabulated in Appendix II. The bivalve Macoma inconspicua was the most ubiquitous of all species. This species was found at all sampling stations during all three sampling periods. Another very common bivalve was Mya arenaria which was found in 51 of the 63 samples. Among the crustaceans, Corophium salmonis and Corophium spinicorne were the most common, occurring in 40 and 35 samples, respectively. Notomastus tenuis was the most dominant polychaete, present in a total of 53 samples; however, five other species of polychaetes occurred in more than 30 of the 63 total stations sampled. The

Table 4. Relative abundance and frequency of occurrence of benthic species collected in 63 samples from upper Yaquina Estuary during summer, winter, and spring sampling periods.

Species	Relative Abundance				Frequency of Occurrence		
	Total number of organisms	Percent of total number	Cumulative percent of total number	Rank by number	Number of samples in which species occurred	Percent occurrence in 63 samples	Rank by occurrence
Corophium salmonis	2472	16. 3	16. 3	1	40	63. 5	4
Macoma inconspicua	2406	15. 9	32. 2	2	63	100. 0	1
Corophium spinicorne	1885	12. 4	44. 6	3	35	55. 6	8
Mya arenaria	1423	9. 4	54. 0	4	51	81. 0	3
Amphisamytha bioculata	1271	8. 4	67. 4	5	37	58. 7	7
Pseudopolydora kempi	1236	8. 2	70. 6	6	39	61. 9	5
Polydora socialis	923	6. 1	76. 7	7	33	52. 4	9
Notomastus tenuis	885	5. 8	82. 5	8	53	84. 1	2
Balanus glandula	811	5. 4	87. 9	9	20	31. 7	13
Cossuridae im)	430	2. 8	90. 7	10	20	31. 7	14
Corophium brevis	316	2. 1	92. 8	11	14	22. 2	15
Anisogammarus confervicolus	316	2. 1	94. 9	12	27	42. 8	11
Neanthes diversicolor	265	1. 7	96. 6	13	39	61. 9	6
Streblospio benedicti	135	0. 9	97. 5	14	21	33. 3	12
Eteone lighti	132	0. 9	98. 4	15	31	49. 2	10
Eohaustorius estuarius	47	0. 3	98. 7	16	9	14. 3	18
Capitella capitata	30	0. 2	98. 9	17	8	17. 7	20
Tanais (sp)	28	0. 2	99. 1	18	8	12. 7	21
Nephtys (sp)	23	0. 2	99. 3	19	10	15. 9	17
Diptera larvae	22	0. 1	99. 4	20	9	14. 3	19
Ceribratulus (sp)	22	0. 1	99. 5	21	12	19. 0	16
Cryptomya californica	18	0. 1	99. 6	22	4	6. 3	24
Goniada brunneata	15	0. 1	99. 7	23	8	12. 7	22
Achelia nudiuscula	10	0. 1	99. 8	24	2	3. 2	28
Arenicola marina	10	0. 1	99. 9	25	5	7. 9	23
Ampithoe (sp)	4	0. 1	99. 9	26	3	4. 8	26
Gnorimosphaeroma lutea	4	0. 1	---	27	3	4. 8	27
Crago franciscorum	4	0. 1	---	28	4	6. 3	25
Harpacticoida	2	0. 1	---	29	2	3. 2	30
Macoma balthica	2	0. 1	---	30	2	3. 2	29
Cumacea	1	0. 1	100. 0	31	1	1. 6	31

crustaceans and the polychaetes were equal in total species present with 12 but the crustaceans slightly outnumbered the polychaetes in total numbers accounting for 39 percent as opposed to 36 percent of the total organisms. The bivalves had four species and made up most of the remaining 25 percent of the total.

Although the crustaceans as a group were slightly more dominant in total number, the polychaetes were more diverse and as a group tended to be less dominated by a few species and better distributed through the study area in distance as well as season.

On the edge of the channel, sediment particle size is usually small and there is a fairly high silt content. The common species in these areas, although varying somewhat from area to area, were usually a species of Corophium, tube dwelling polychaetes and the bivalves Macoma inconspicua and Mya arenaria. These animals are predominantly deposit feeders dependent to a large extent on stable sediment in which to build their tubes and burrows. The density of organisms in these areas was generally around 1500 animals/M^2 but ranged as low as 500/M^2 or as high as 5840/M^2.

In contrast to the channel-edge community was the community found in the predominantly sandy sediments in the channel. In the latter areas, where silt in the sediments was very low, the tube dwelling amphipods and polychaetes so common in the finer sediments were seldom found. Other than the ever-present tellinid

M. inconspicua and an occasional *Notomastus tenuis* and *M. arenaria* the only species which was regularly found in this area was the haustorid amphipod *Eohaustorius estuarius*. The density of organisms as well as the number of species in this region was markedly reduced from that of the finer sediment areas. Animal density was frequently about $100/M^2$ but was observed to be as low as $25/M^2$ and as high as $1100/M^2$. From the reduced density common to this area it seems likely that *E. estuarius* is the only species that inhabits this environment with any success, the others probably surviving under marginal conditions.

Species abundance was greatest during the summer season and species distribution seemed to be more dependent on sediment characteristic than either depth or longitudinal position in the study area during this period. With the onset of the winter rainy conditions, however, species numbers decreased and location longitudinally as well as with depth seemed to become more important, possibly reflecting the effect of changed salinity and temperature patterns. A few of the species present in the summer samples, particularly *M. inconspicua*, seemed to favor the winter conditions, actually increasing in number in the winter samples. There was an introduction of a new species, a crinomid fly larva, in the winter samples presumably corresponding to the particular life stage of the organism. The majority of the species, however, were more abundant in the summer, their numbers greatly reduced or absent in the winter samples.

The greatest seasonal change in species number and composition occurred in three of the upper stations, stations 2, 3, and 4, and one of the lower stations, station 13. This change is perhaps best shown by changes in dominant species from summer to winter. Dominance was calculated as suggested by Boesch (1971) by scoring the five most common species in each grab: five for the most abundant species, four for the next most abundant, and so on. These scores were then summed for the four grabs collected at each sampling station. Those species with the highest scores, expressed as the mean for the four grabs, were then considered the dominant species at that site.

The list of the dominant species during each season at the four stations above is shown in Table 5. The dominant species in all four stations during the summer include the amphipod Corophium salmonis, several species of sedentary polychaetes and usually either of the two bivalves M. inconspicua, or M. arenaria. The dominant species in the winter samples for these stations changed from predominantly polychaete dominated to bivalve dominated. In the winter, the amphipod C. salmonis was absent from stations 2 and 13 and totaled six individuals in the other two stations, 3 and 4. Amphisamytha bioculata, the most dominant species in stations 3 and 4 during the summer, had a total of only six individuals for the two stations during

Table 5. Dominant species at stations 2, 3, 4, and 13 during the summer, winter and spring sampling periods.

Station Number	Dominant species and score in descending order*					
	Summer		Winter		Spring	
2	C. salmonis	4.5	M. inconspicua	4.75	M. inconspicua	4.75
	A. bioculata	4.0	N. diversicolor	2.25	---	
	M. inconspicua	3.2	A. confervicolus	1.75	---	
3	A. bioculata	5.0	Crinomid larvae	3.25	M. inconspicua	2.75
	C. salmonis	2.75	M. inconspicua	2.25	---	
	M. arenaria	2.50	N. diversicolor	1.50	---	
4	A. bioculata	2.63	M. inconspicua	5.0	M. inconspicua	4.75
	P. kempi	2.60	A. bioculata	2.25	N. tenuis	4.0
	N. tenuis	2.50	M. arenaria	2.0	A. bioculata	2.50
13	C. salmonis	5.0	M. inconspicua	5.0	N. tenuis	4.75
	P. kempi	3.15	P. kempi	3.75	M. inconspicua	4.25
	P. socialis	3.15	M. arenaria	3.0	M. arenaria	2.25

* Dominant species were determined as suggested by Boesch 1971. The mean score for each species was calculated by scoring the five most common species in a grab then summing the scores and dividing by the number of grabs. The species with the greatest number in each grab was scored 5, the next most abundant 4, and so on.

the winter. The other dominant polychaetes from these stations were either absent or greatly reduced in number in the winter samples. Although the total densities during the winter were much lower than during the summer, the number of *M. inconspicua* was only slightly reduced at station 2 and greater at the other three stations.

The spring species dominance did not change significantly over that found in the winter samples. *Macoma inconspicua* was still the dominant species in the upper three stations, although the density had decreased somewhat. At station 13, *M. inconspicua* was replaced as the dominant species by *Notomastus tenuis* but was still a significant component of the community. The other species that had been dominant in the summer at this station as well as the upper three stations were still absent or in very small numbers.

Effects of Environmental Factors on the Macrobenthic Community

Summer Diversity

It was felt that variation in sediment size and bark debris would be the most significant variable affecting benthic diversity since the hydrographic conditions in the summer were fairly stable. A multiple regression statistical analysis was used to explain variation in diversity. The independent variables used in the analysis are listed in Table 6.

Table 6. Multiple regression analysis of the relationship between summer diversity and sediment parameters and water depth.

Independent[b] Variable	Variable Number	Transformation	Slope (b)	Entering F Value	Entering[a] Step
Mean sediment size (0)	1		---[c]	---	
Sorting	2		$1.3x10^{-1}$	0.34	2
Skewness	3		---	---	
Percent mud	4		---	---	
Sand/mud ratio	5		$1.9x10^{-2}$	0.35	3
Total V.S.	6		$5.0x10^{-2}$	0.24	4
V.S. < 74 μ	7		---	---	
Depth	8		---	---	
		1 x 6	$5.3x10^{-3}$	3.84	1
	Intercept	1.38	Final F	1.05 (P< 0.50)	
	R^2	.185	(Total d.f. 28)		

[a] The entering step indicates the order variables entered the equation. At each step this is determined by next entering the variable adding the greatest to the unexplained variation. The entering F value indicates the significance of the variable to the equation. The transformation 1x6 refers to the product of variable 1 and variable 6.

[b] Mean sediment size 0, sorting, skewness and gross volatile solids are defined in the text. Percent mud indicates the weight of particles less than 74 μ compared to the total sediment. Sand/mud ratio is the ratio by weight of particles greater than 74 μ to those less than 74 μ. Volatile solids < 74 μ refers to the organic content of sediments less than 74 μ in particle diameter. Depth is expressed as meters below mean lower low water.

[c] Variable added less than 2% to the R^2 value, therefore not included in the equation.

Although diversity was not significantly regressed to any of the variables measured, the four variables which best explained the variation in diversity are listed in Table 6. The R^2 value or variation explained by the regression equation was only 18.5 percent. The variable accounting for the greatest explained variation was the product of mean Ø sediment size and volatile solids. Figure 11 shows diversity plotted against this variable. The points are somewhat scattered especially close to the ordinate, corresponding poorly to a straight line relationship. However, there is an obvious trend of increasing diversity with increase in the product of mean Ø sediment size and volatile solids.

In Figure 12, a and b, diversity is plotted against sediment size and volatile solids separately. Of the two graphs the clearest regression for diversity plotted against the independent variables occurs with volatile solids (Figure 12, b). Both graphs show that the majority of the samples with high diversity came from areas of log handling irrespective of the volatile solids concentration in the sediment or the size of the sediment particle.

Hurlbert (1971) has suggested that diversity should not compare groups of organisms of different taxocenes. Therefore, diversities were also calculated for the polychaete and crustacean subgroups within each sample. The diversity variation within these two groups was analyzed in the same manner as the total sample. The bivalve

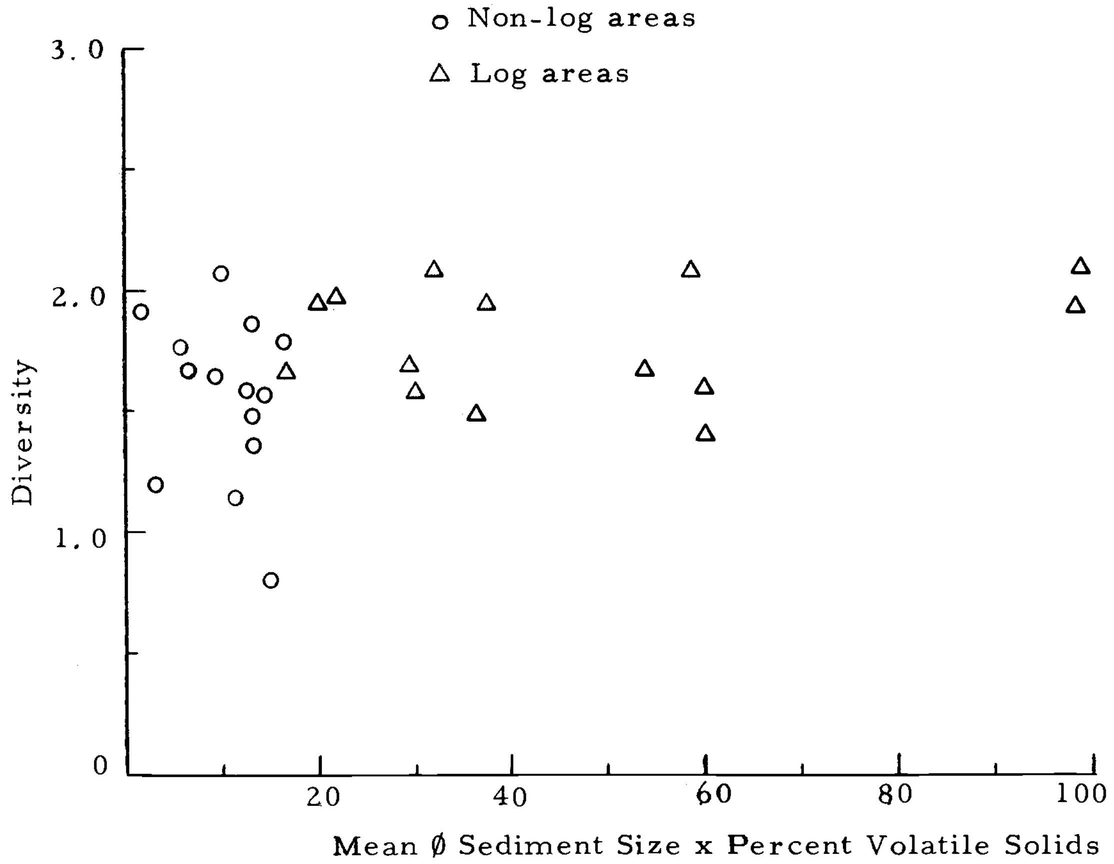

Figure 11. Diversity of summer samples in relation to product of mean ∅ sediment size and percent volatile solids.

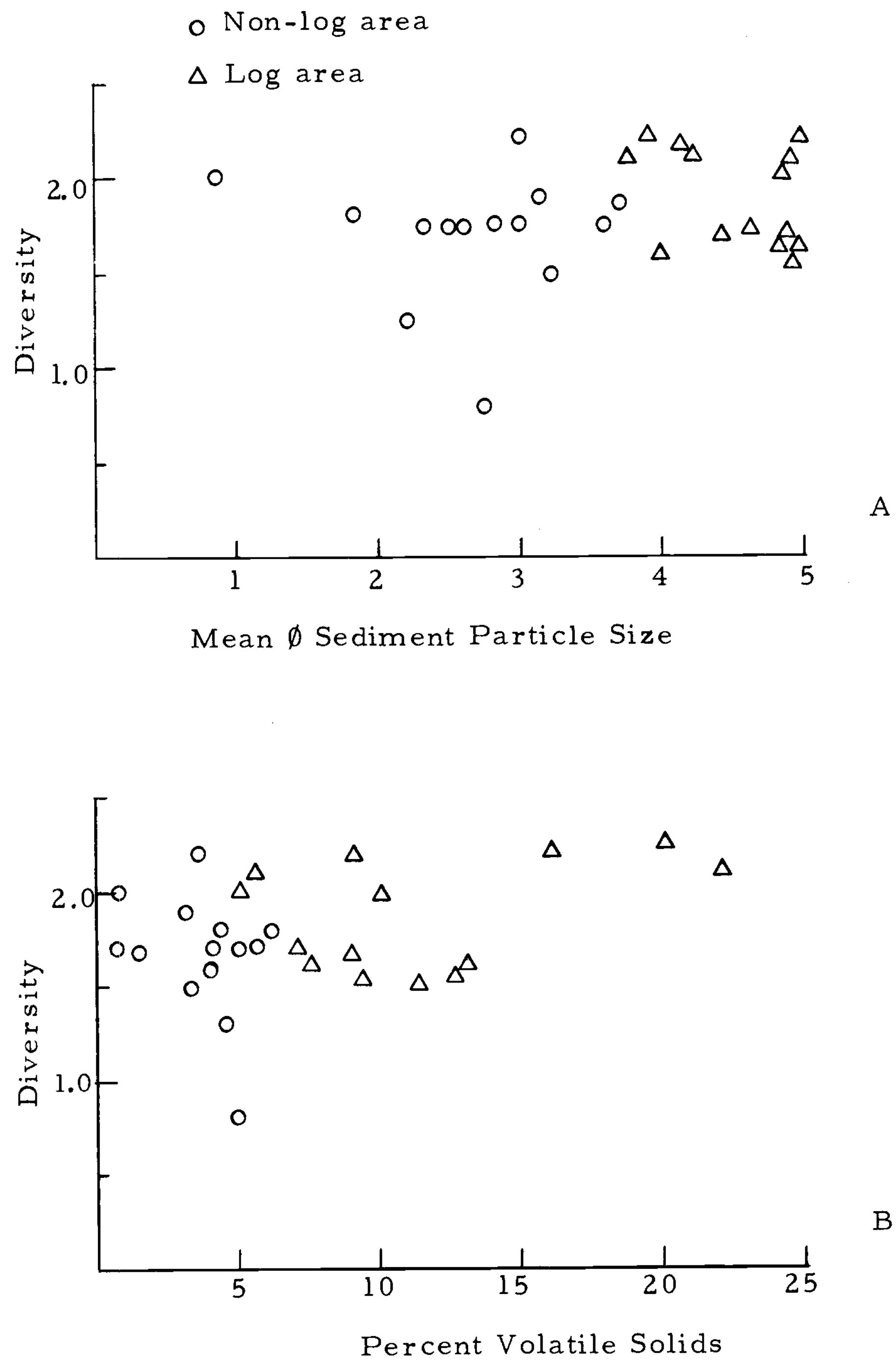

Figure 12. Diversity of summer samples in relation to mean Ø sediment size and percent volatile solids.

subgroup was ignored for these calculations because of the few bivalve species in the study.

The crustacean diversity showed a more significant relationship to the sediment parameters than did the total macroinvertebrate diversity. The regression equation (Table 7) was significant ($P < 0.05$); however, the R^2 was still low with only 30.1 percent of the variation explained. The crustacean diversity showed similar trends to the total, increasing with increasing volatile solids and decreasing sediment size as shown in Figure 13, a and b. The log handling areas also had the highest crustacean diversities.

The polychaete diversity was most significantly correlated to sorting of the sediment particles (Table 8). The slope of the regression line was positive, indicating an increase in diversity with an increase in sorting. This finding is in agreement, somewhat, with Nichols (1970) who cited sorting as an important sediment parameter in correlating groupings of similar polychaetes. Particle sorting was the only variable adding significantly to the regression of polychaete diversity; as it was, this variable accounted for only 15.4 percent of the variation observed and the addition of three more variables only increased the R^2 value to 19.0 percent. Figure 14 shows the relation of sediment sorting to polychaete diversity.

The summer crustacean diversity was low compared to the diversity of the total samples or the summer polychaete diversity.

Table 7. Multiple regression analysis of the relationship between summer crustacean diversity and sediment parameters and water depth.

Independent Variable	Variable Number	Trans-formation	Slope (b)	Entering F Value	Entering Step
Mean sediment size (0)	1		-2.3×10^{-1}	2.14	2
Sorting	2		2.1×10^{-1}	2.28	3
Skewness	3		---[a]	---	
Percent mud	4		---	---	
Sand/mud ratio	5		---	---	
Total V.S.	6		5.3×10^{-2}	5.75	1
V.S. < 74 μ	7		---	---	
Depth	8		---	---	

Intercept	6.61×10^{-1}	Final F 3.59 ($p < 0.05$)
R^2	0.301	(Total d.f. 28)

[a] Variable added less than 2% to the R^2 value, therefore, not included in the equation.

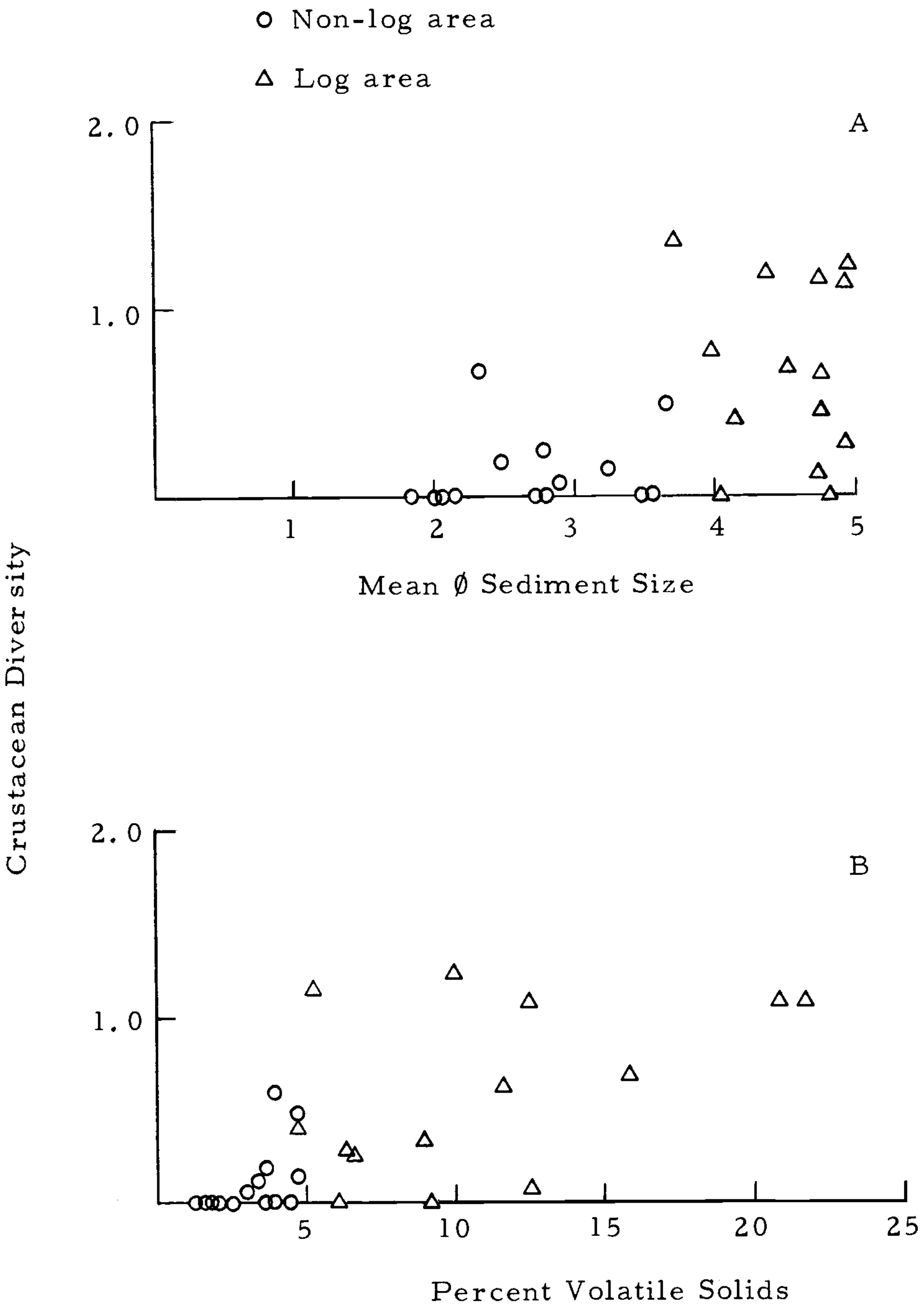

Figure 13. Summer crustacean diversity in relation to mean Ø sediment size and percent volatile solids.

Table 8. Multiple regression analysis of the relationship between summer polychaete diversity and sediment parameters and water depth.

Independent Variable	Variable Number	Trans-formation	Slope (b)	Entering F Value	Entering Step
Mean sediment size (0)	1		---	---	
Sorting	2		$2.9\mathrm{x}10^{-1}$	4.94	1
Skewness	3		---	---	
Percent mud	4		---	---	
Sand/mud ratio	5		$5.4\mathrm{x}10^{-3}$	0.46	2
Total V.S.	6		$1.5\mathrm{x}10^{-2}$	0.27	3
V.S. < 74 μ	7		---	---	
Depth	8		---	---	
Intercept		$9.72\mathrm{x}10^{-1}$		Final F	1.41 ($P<0.50$)
R^2		0.190		(Total d.f. 28)	

[a] Variable added less than 2% to the R^2 value, therefore, not included in the equation.

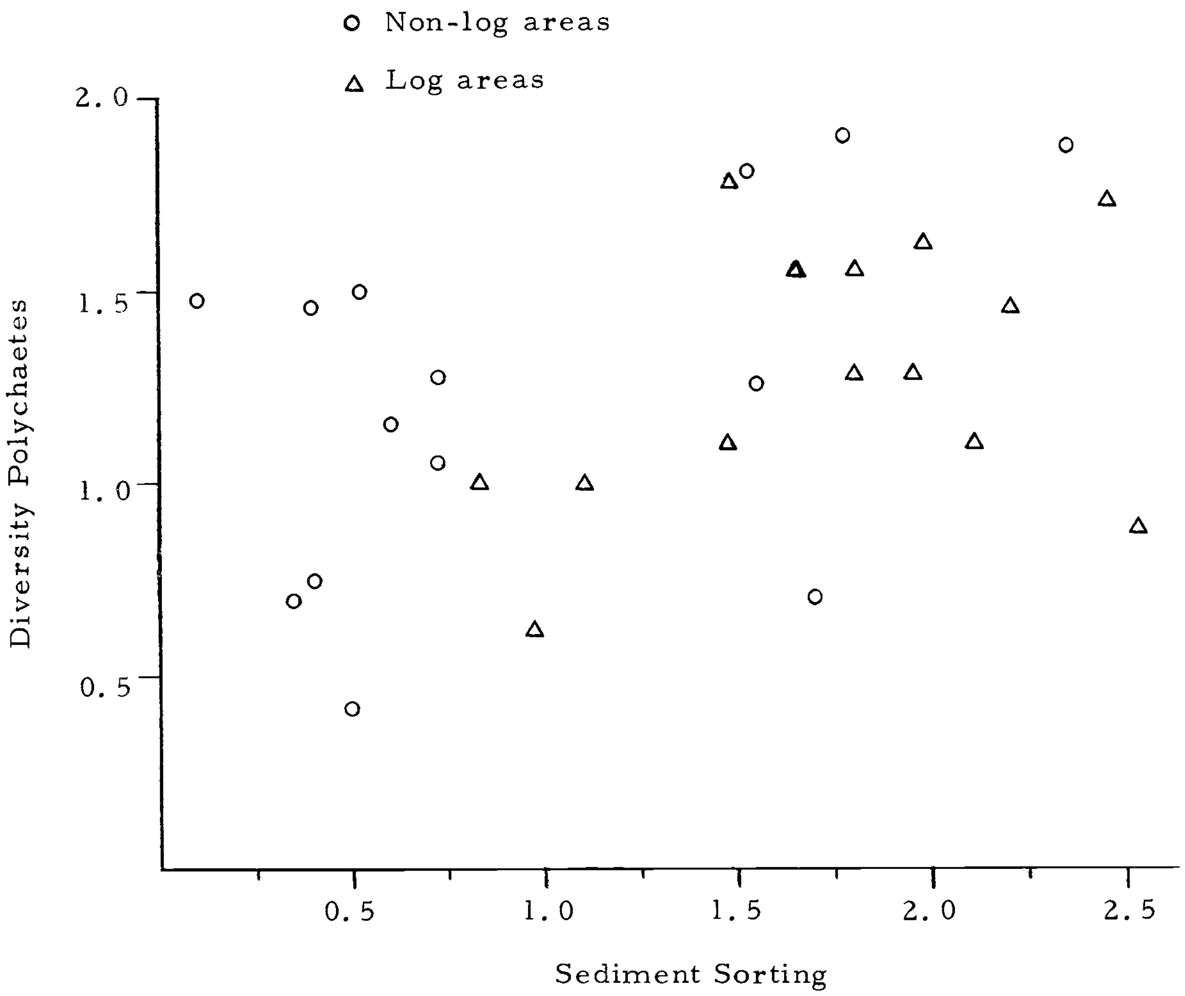

Figure 14. Summer polychaete diversity in relation to sediment sorting.

None of the samples had crustacean diversities higher than 1.25 and a total of ten stations recorded a zero diversity. In comparison the polychaete diversities were considerably higher with an upper value of 1.90 and no zero values. The polychaete diversities at stations 13'a, b and c were actually higher than the total sample diversity recorded for those stations, a situation that was never approached by the crustacean diversity.

The increase in diversity with increase in volatile solids and decrease in sediment size, observed in the crustacean subgroup and to a lesser extent in the total sample, was expected, to a degree. The increase in species abundance and density from sandy environments to "muddy-sand" has been well documented by Carriker (1967). Increased diversity in fine sediments may result because greater food abundance would tend to decrease interspecific competition. In addition, such environments would be compatible with both filter feeding and deposit feeding types of behavior. The positive correlation of diversity with organic content was not expected to extend into the bark areas, however, since large bark and wood debris would not be expected to provide a suitable source of food and reduced dissolved oxygen and toxic materials might be expected in these areas. Diversity in these areas did increase, however, possibly as a result of a more varied habitat provided by the larger bark particles.

The polychaete diversity showed no relation to sediment size or v.s. as did the crustacean diversity but did correlate with sorting. The reason for this relationship is not clearly understood; however, Nichols (1970) suggested on the basis of his work in Washington that niche availability increased with increased sediment sorting.

The regression analysis using diversity of the total samples, although not statistically significant, did show trends which are significant to the study. The results of the analysis did mean, however, that a predictive equation for species diversity was not possible with the data collected. Additional factors are apparently needed for such an equation, possibly information on biological interaction or additional information on abiotic factors. On the other hand, the diversity measure of the benthic invertebrates may not be sensitive to fine variation in the environment but instead only useful for comparison of areas where gross environmental differences exist.

Summer Density

The density of the macrofauna collected from each area was analyzed in the same way as diversity using density as the dependent variable and the same environmental parameters for independent variables.

The area closest to the log dump had the greatest density of animals found in the summer samples. The log storage areas also had fairly high densities, comparable to some of the fine sediment, non-log areas.

The analysis of total animal density showed a highly significant positive regression with the log of volatile solids ($P < 0.005$). Additional variables did not add significantly to the remaining unexplained variation. However, the R^2 value was increased to a value of 43.4 percent as shown in Table 9. Although the additional variables did not add significantly to the regression individually the final F value for the regression equation was significant ($P < 0.01$). Figure 15 shows a plot of summer density with mean ϕ sediment size.

The results of this analysis showed a more significant relation of density to physical parameters than was seen earlier with diversity. The unexplained variation, however, was still much too high for an equation capable of predicting density.

Although density alone is not a good indicator of healthy or polluted areas, some moderately polluted areas have been shown to have greater density than healthy areas (Filice, 1959), in conjunction with a diversity index it can be useful and informative. In this case the increase in density with increasing volatile solids correlates with the trends found in diversity. These results indicate that bark debris does not seem to reduce, and, in fact, may increase, the usability of that sediment by the macroinvertebrates. The densities in these bark areas may be further amplified by the relatively high food content

Table 9. Multiple regression analysis of the relationship between summer density and sediment parameters and water depth.

Independent Variable	Variable Number	Trans-formation	Slope (b)	Entering F Value	Entering Step
Mean sediment size (0)	1		1.6x10^2	2.1	3
Sorting	2		-9.6x10^1	1.22	4
Skewness	3		---[a]	---	
Percent mud	4		---	---	
Sand/mud ratio	5				
Total V.S.	6		---	---	
V.S. < 74 μ	7		5.8	3.13	2
Depth	8		---	---	
		Log 6	6.5x10^1	10.4	1

Intercept 70.6 Final F 4.57 ($P < 0.01$)

R^2 0.444 (Total d.f. 28)

[a] Variable added less than 2% to the R^2 value, therefore, not included in the equation.

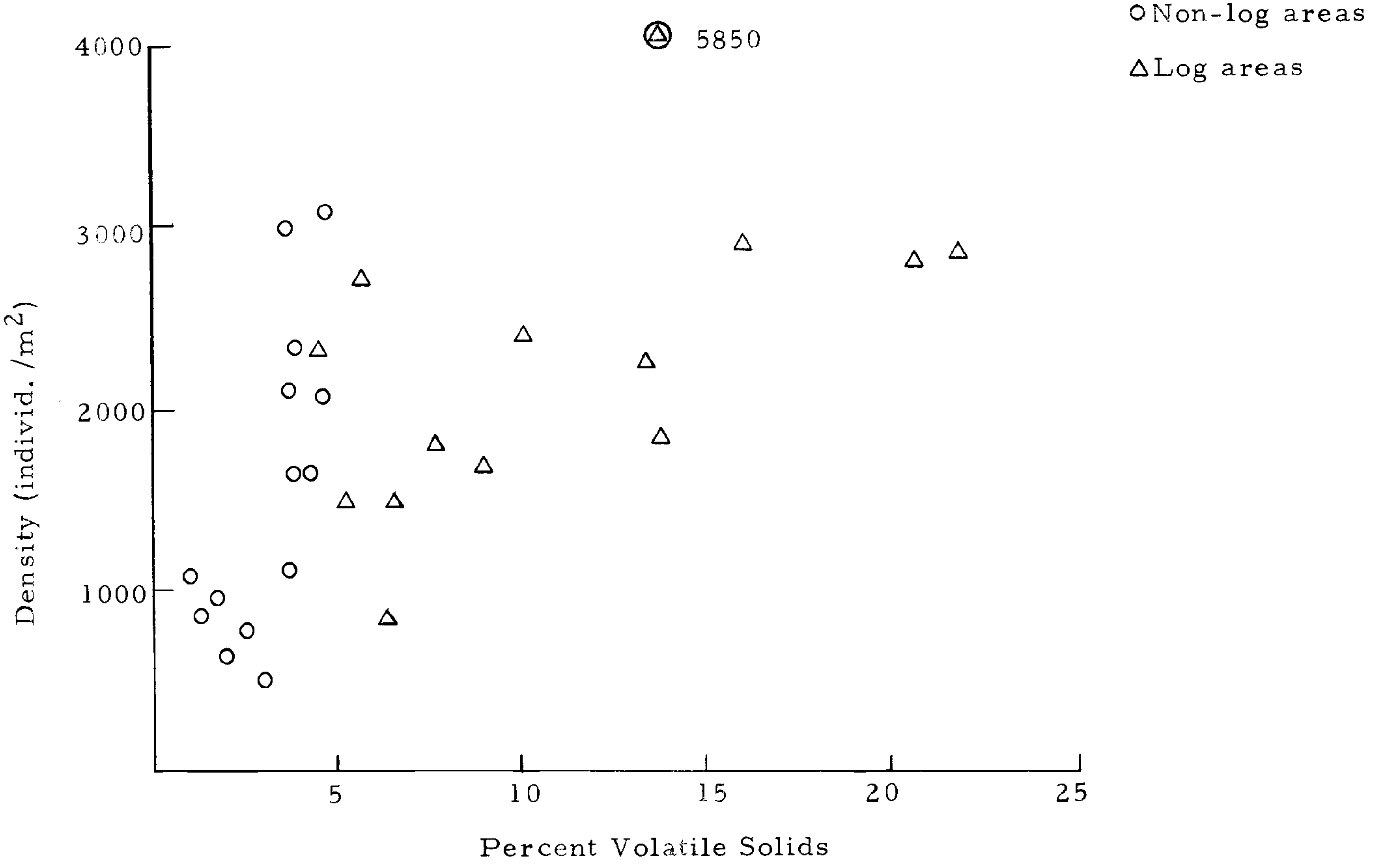

Figure 15. Density of animals collected during the summer in relation to percent volatile solids.

of the sediment.

Winter Diversity

As pointed out in an earlier section, there was a drastic change in the species present in some of the winter collections. There was also a reduction in species diversity within most areas as well as major decreases in density within a few areas.

Although volatile solids decreased in some of the stations, most sediment parameters measured remained fairly constant. Because of these minor changes it was felt that the major variations in diversity and density were the results of other factors not measured.

The analysis of diversity in the winter collection showed insignificant regressions with all variables. Those variables which seemed to have some effect on diversity during this season differed from those affecting the summer diversities (Table 10). The R^2 value of 52.1 percent is misleading; the higher values were due more to the fewer observations in winter than to a meaningful regression equation.

Comparison of diversities from log handling and non-log handling areas is meaningless because of the complexity of the varying environmental factors. Two of the upper areas had so few organisms that their diversities are not validly comparable to the more populated areas.

Table 10. Multiple regression analysis of the relationship between winter diversity and sediment parameters and water depth.

Independent Variable	Variable Number	Trans-formation	Slope (b)	Entering F Value	Entering Step
Mean sediment size (0)	1		-7.5×10^{-1}	1.06	2
Sorting	2		---[a]	---	
Skewness	3		-5.7×10^{-1}	0.03	3
Percent mud	4		---	---	
Sand/mud ratio	5		1.1	1.01	1
Total V.S.	6		---	---	
V.S. < 74 μ	7		---	---	
Depth	8		---	---	
		Log 5	-1.5×10^{1}	2.96	4

Intercept 31.8 Final F 1.36 ($P < 0.50$)

R^2 0.521 (Total d.f. 9)

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[a] Variable added less than 2% to the R^2 value, therefore, not included in the equation.

Winter Density

Density variation in the winter collection was best explained by variation in depth (Table 11). The effect of depth on density was significant at the five percent level. The other variables listed did not add significantly to the regression equation. However, the final R^2 value with four variables was 77.3 percent.

The correlation of density to water depth may have been a result of changing salinity patterns in the winter. The greatest changes in species composition and density occurred in the shallower areas. The salinity pattern changed from a polyhaline, well-mixed salinity pattern in the summer to a stratified system ranging from poly-mesohaline to meso-oligohaline in the winter. Due to the stratification shallower areas were exposed to lower salinities over longer periods probably resulting in a greater decrease in population densities than in the deeper areas.

Spring Diversity

The analysis of the spring diversities showed a significant regression ($P < 0.05$) with sand/mud ratio, the first entering variable (Table 12). The fourth variable, log of sand/mud ratio, added significantly to the existing regression equation increasing the R^2 value to 85.9 percent.

Table 11. Multiple regression analysis of the relationship between winter density and sediment parameters and water depth.

Independent Variable	Variable Number	Trans- formation	Slope (b)	Entering F Value	Entering Step
Mean sediment size (0)	1		-4.9×10^{2}	4.01	3
Sorting	2		2.3×10^{2}	0.77	2
Skewness	3		---[a]	---	
Percent mud	4		---	---	
Sand/mud ratio	5		---	---	
Total V.S.	6		2.5×10^{1}	2.58	4
V.S. < 74 μ	7		---	---	
Depth	8		5.3×10^{1}	6.38	1

Intercept 1.72×10^{3} Final F 4.26 ($P < 0.25$)

R^2 0.773 (Total d.f. 9)

---

[a] Variable added less than 2% to the R^2 value, therefore, not included in the equation.

Table 12. Multiple regression analysis of the relationship between spring diversity and sediment parameters and water depth.

Independent Variable	Variable Number	Transformation	Slope (b)	Entering F Value	Entering Step
Mean sediment size (0)	1		-9.1×10^{-1}	0.36	3
Sorting	2		---[a]	---	
Skewness	3		1.0×10^{-2}	1.33	2
Percent mud	4		---	---	
Sand/mud ratio	5		8.8×10^{-3}	5.92	1
Total V.S.	6		---	---	
V.S. < 74 μ	7		---	---	
Depth	8		---	---	
		Log 5	-6.7×10^{-1}	11.4	4

Intercept 4.73 Final F 7.66 ($P < 0.025$)

R^2 0.859 (Total d.f. 9)

[a] Variable added less than 2% to the R^2 value, therefore, not included in the equation.

The results of the regression analysis were unexpected judging from the results obtained from the summer and winter analyses. A plot of diversity with sand/mud ratio, as shown in Figure 16, shows one data point far from the group. The mean squares line indicates the effect this point had on the regression. Elimination of that point reduced the R^2 value from 42.5 percent to 7.5 percent and would be expected to have a similar effect on the log of sand/mud ratio. Because of the effect this outlyer had on the regression line, it seems inappropriate to place much emphasis on the outcome of the analysis.

Spring Density

The density of animals collected in the spring followed the same pattern as the winter collections. The shallower stations, especially 2, 3 and 4, had low density, with greater densities occurring at the deeper stations. When examined separately, the regression of density with depth was significant ($P < 0.05$) and 45.8 percent of variation was explained. Volatile solids, also regressed separately, explained 69.5 percent of the variation and was highly significant ($P < 0.005$). Because volatile solids and depth were moderately correlated, depth, which entered the multiple regression equation second, did not add significantly to the model (Table 13). The final equation containing four variables was significant ($P < 0.05$) and the R^2 was equal to 80.2 percent.

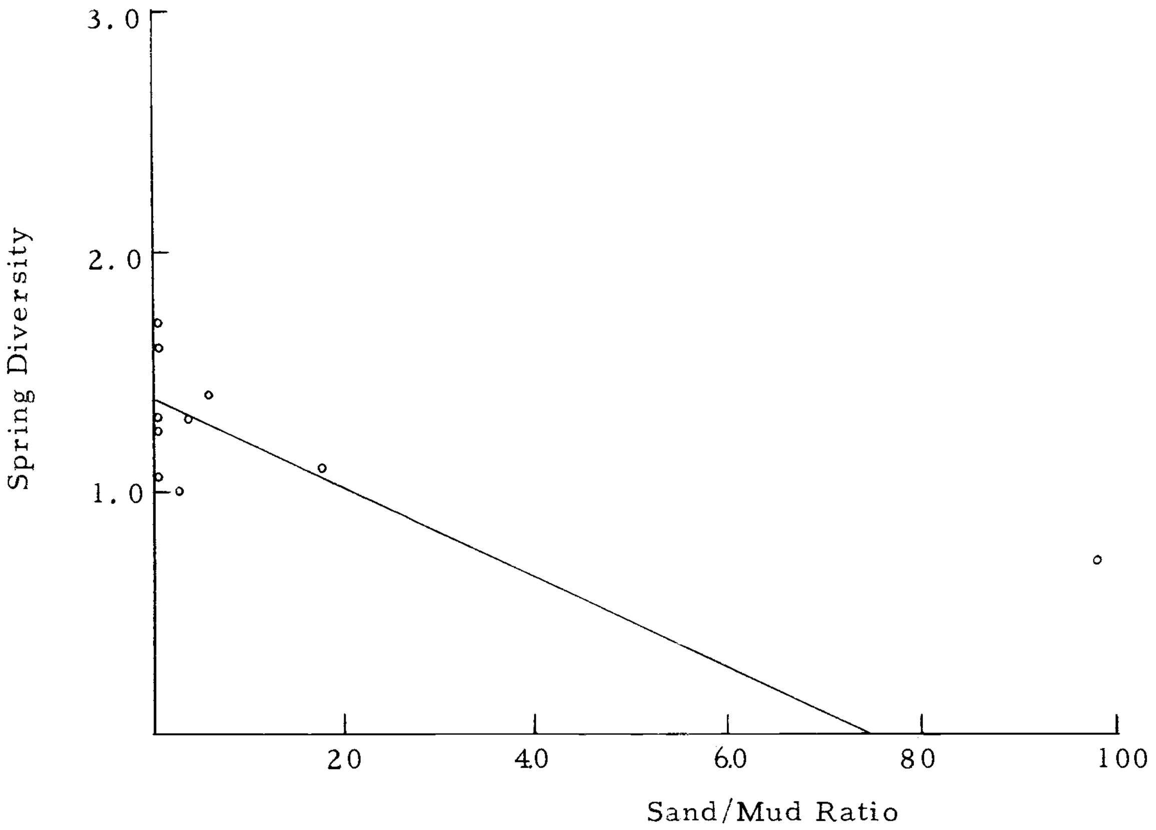


Figure 16. Diversity of spring samples in relation to sand/mud ratios.

Table 13. Multiple regression analysis of the relationship between spring density and sediment parameters and water depth.

Independent Variable	Variable Number	Trans-formation	Slope (b)	Entering F Value	Entering Step
Mean sediment size (0)	1		---[a]	---	
Sorting	2		7.6×10^1	1.70	3
Skewness	3		-1.6	0.63	4
Percent mud	4		---	---	
Sand/mud ratio	5		-7.7×10^{-1}	0.49	5
Total V.S.	6		2.3×10^1	18.20	1
V.S. < 74 μ	7		---	---	
Depth	8		5.2×10^1	4.13	2

Intercept 20.0 Final F 4.97 ($P < 0.10$)

R^2 0.802 (Total d.f. 9)

[a] Variable added less than 2% to the R^2 value, therefore, not included in the equation.

It was assumed that the decrease in species abundance and density with the onset of the rainy season was a naturally occurring phenomenon which operates on an annual cycle. It was expected that the spring collection taken in May would show at least a partial return to the densities and species composition of the previous summer. However, as seen in Figure 17, spring densities in most cases remained comparable to winter levels which were usually lower than summer densities. Apparently the return to summer population densities occurs later in the season. This is plausible since division of the previous summer's samples into early and late summer showed a marked difference in densities of some populations. For example, stations 5, 8, 9 and 10 were sampled in July and again in late August-early September. The combined total in July for the four stations of *C. salmonis* was 12; *Amphisamytha bioculata*, 29; *Polydora socialis*, 10 and *Pseudopolydora kempi*, 18. In late summer the same areas had 101 *C. salmonis*, 51 *A. bioculata*, 82 *P. socialis*, and 185 *P. kempi*. These four species are among those most markedly reduced in the winter and spring samples. The three polychaetes listed are sedentary and must be assumed to have increased their numbers in that period by larval recruitment rather than by migration from other regions. Although *C. salmonis* is somewhat mobile, it seems unlikely that the increase in population size of this species could be caused by recruitment of adults alone. Instead, introduction

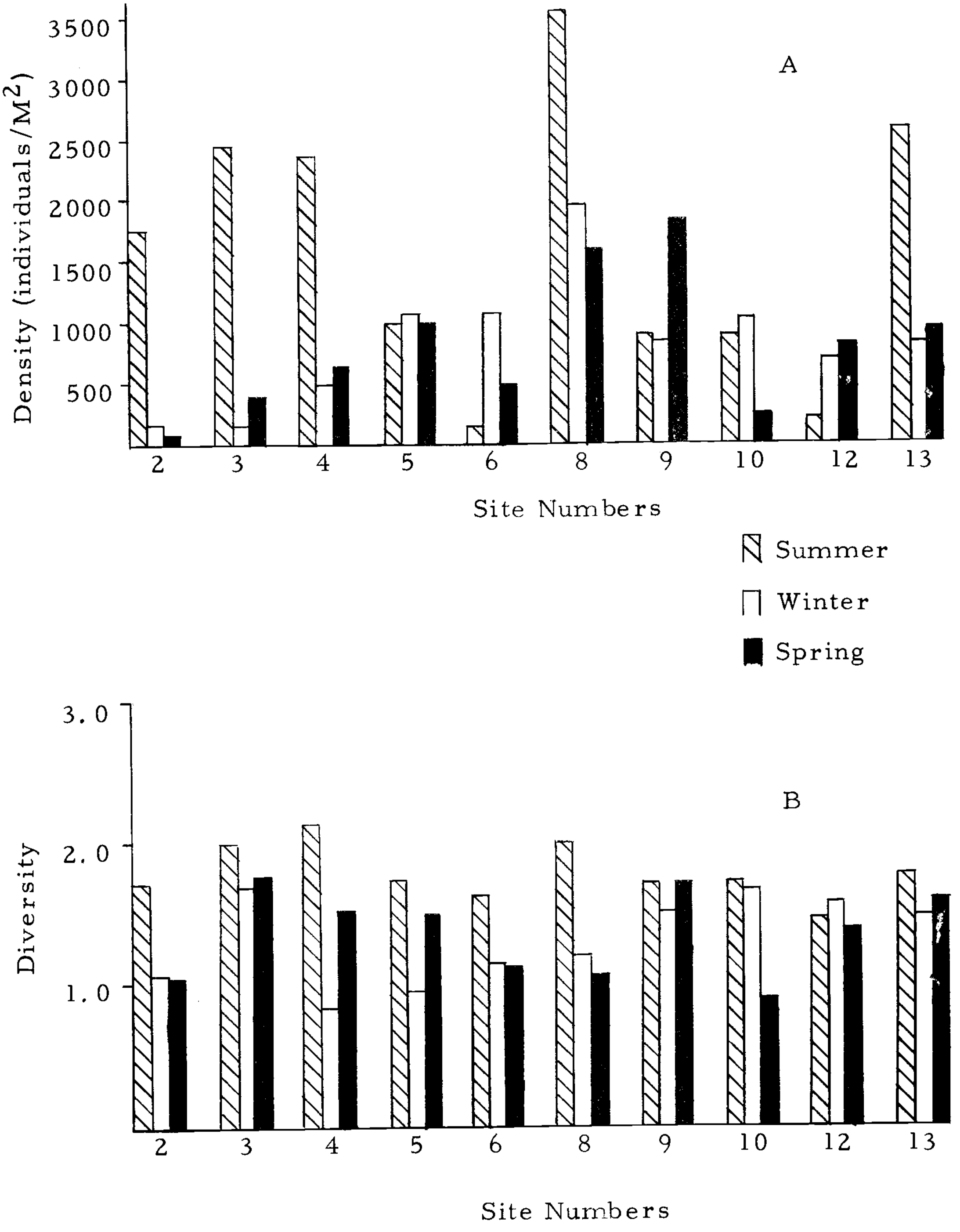


Figure 17. Density and diversity of animals collected in the ten stations sampled throughout the year 1971-1972.

of new individuals by existing females is probably responsible for the greatest increase.

Similarity of Benthic Communities

Although diversity indices take into account species richness and equitability of species, they are insensitive to the type of species in the collection. The similarity index, unlike diversity, measures the degree of similarity in two samples by comparing the abundance of similar species in two collections. The use of the similarity index in water quality studies has been based on the assumption that areas exposed to comparable pollution stress will have similar species compositions (Burlington, 1962; Pearson, Storrs and Selleck, 1967).

Some problems inherent with this index are discussed by MacFadyen (1954). One problem existing in this study was the ubiquitous, sometimes dominant, bivalve *Macoma inconspicua*. If one or a few such species exist in a study no meaningful similarities can be drawn between collections. Because of *M. inconspicua*, similarity indices were ignored on the winter and spring collections. Although the clam was also present in all summer collections it usually was not dominant and, therefore, not a major problem.

Because the similarity index is a comparison of two collections, analysis is not easily handled with conventional statistical methods. Instead a list was made for each station which included all other stations having 50 percent or greater similarity to it. The stations were then arranged in subgroups based on recurrence of stations in common and the subgroups were subsequently arranged in a trellis diagram (Figure 18). This method is a variation of the standard method of MacFadyen (1963) and involved several trials and a certain amount of subjectivity. The results show rather clearly, however, four highly similar groups of stations and a few stations that are transitional between groups.

The 50 percent cutoff level for highly significant stations was an arbitrary choice based on the similarities of 12 replicate grabs taken from each of six areas. The mean similarity for most areas was between 55 and 65 percent with 10' the only area greater than 65 percent (Figure 19). It was felt, from these results, that 50 percent was a conservative estimate for highly similar stations. The 50 percent figure was also the lower level chosen by Day and Pearcy (1968) for highly similar collections.

Table 14 lists the stations contained within each group and partial sediment characteristic corresponding to each station. Group I contained seven stations with several features in common. The sediments in this group, with the exception of station 9, were sandy, ranging in mean particle size from 1.90 Ø to 2.78 Ø. All the stations in this group were located in the lower half of the study area. Station 9, an abandoned log dumping site, had higher volatile solids in the sediment

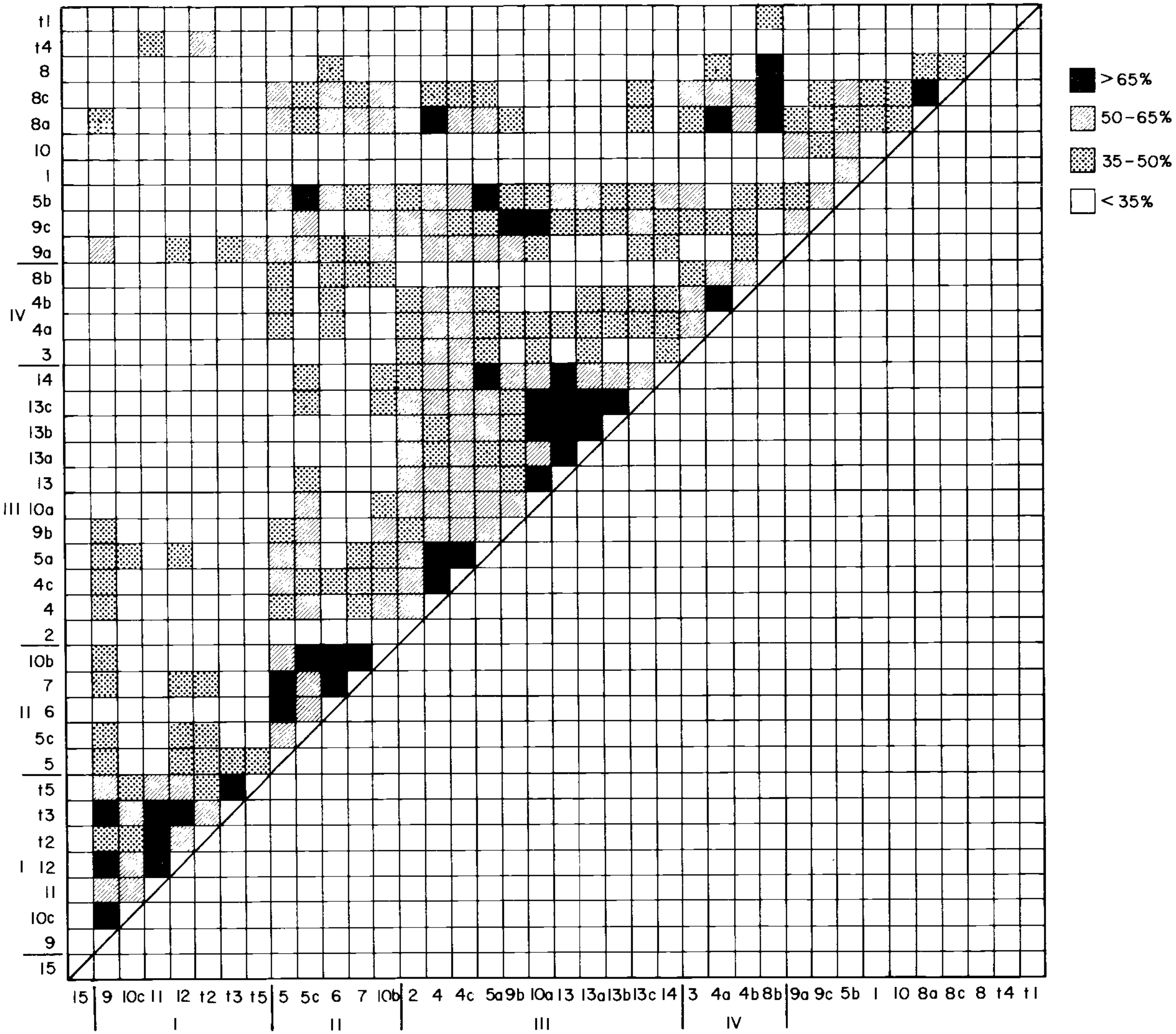


Figure 18. Trellis diagram of similarity values for all summer samples.

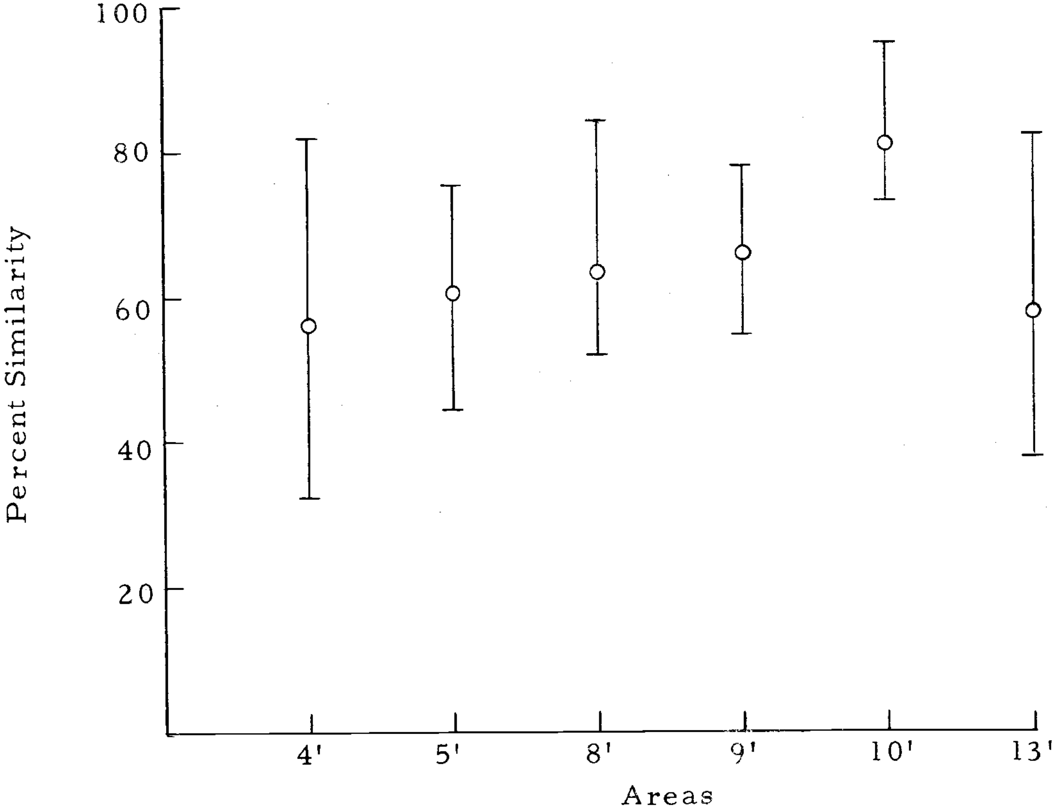


Figure 19. Mean similarity and range of 12 samples collected from six areas within the study region.

Table 14. Summer stations that comprise the highly similar groups. The mean Ø sediment particle size, volatile solid and diversity of macrofauna associated with each station is listed.

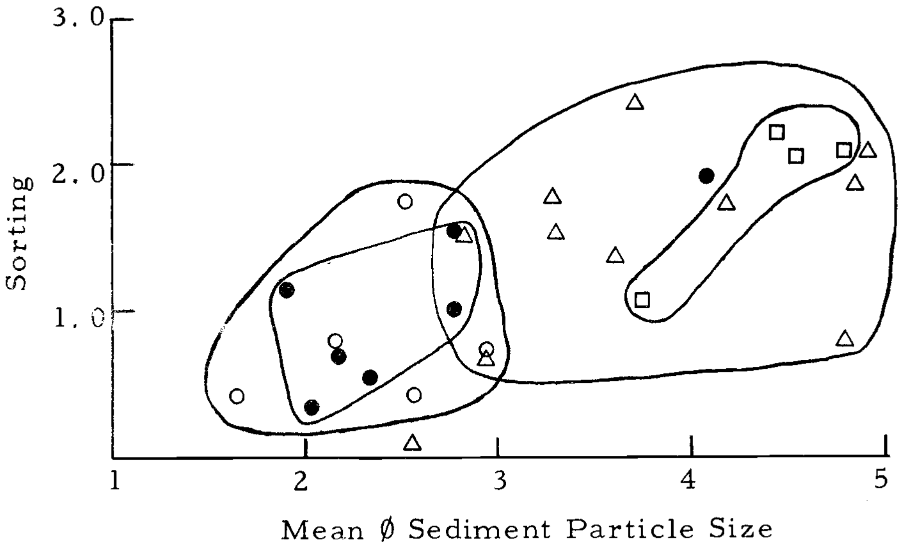
Group	Station	Mean Sediment Size	Volatile Solids	Non-Log	Log	Diversity
I	9	4.05	9.46		X	1.56
	10'c	2.32	1.70	X		1.70
	11	2.78	1.85	X		1.33
	12	2.00	1.45	X		1.30
	t-2	1.90	3.68	X		1.05
	t-3	2.75	1.58	X		1.33
	t-5	2.17	1.87	X		0.69
II	5	2.89	5.39	X		1.73
	5'c	1.63	1.13	X		1.82
	6	2.15	2.98	X		1.46
	7	2.53	4.74	X		1.43
	10'b	2.57	2.09	X		1.70
III	2	4.75	12.75		X	1.63
	4	4.15	9.01		X	2.19
	4'c	4.78	4.81		X	2.04
	5'a	3.28	2.86	X		1.90
	9'b	4.82	6.34		X	1.70
	10'a	3.58	3.60	X		1.63
	13	2.52	4.85	X		1.68
	13'a	3.67	4.10	X		1.80
	13'b	3.28	3.53	X		1.56
	13'c	2.78	3.68	X		1.74
	14	2.85	3.17	X		2.21
IV	3	3.70	10.09		X	1.98
	4'a	4.38	5.23		X	2.14
	4'b	---	2.58		X	2.10
	8'b	4.77	21.59		X	2.00

than the other stations. Group II contained five stations, all with sandy substrates similar to Group I. The stations in Group II were located between the active log dump and Toledo public boat dock except 10'c which was below the log dump. All of these sites were low in volatile solids. Groups I and II could not be separated on the basis of plots which compared four sediment parameters in three combinations of two (Figures 20, 21, and 22).

Group III was classified as a fine sediment group. It contained 11 stations most of which had fine sediment characteristics and was easily distinguishable from Groups I and II (Figures 20 and 22). The stations in this group were well distributed throughout the study region. Four of the 11 stations were located in log storage areas and in the abandoned log dump. The volatile solids in the group ranged from moderate to high.

The fourth group contained only four stations, all of which were located in the vicinity of log storage or dumping activities. The volatile solids in the four stations were not uniformly high but the sediments were very fine as shown in Figure 22.

Not all stations fit into one of the four groupings but appeared instead to be partially aligned with two or more groups. Stations 9'a, 9'c and 5'b had high similarity with some stations in Groups II and III while station 10 had high similarity between stations in Groups I and II. In a similar way, station 1 might be considered transitional between



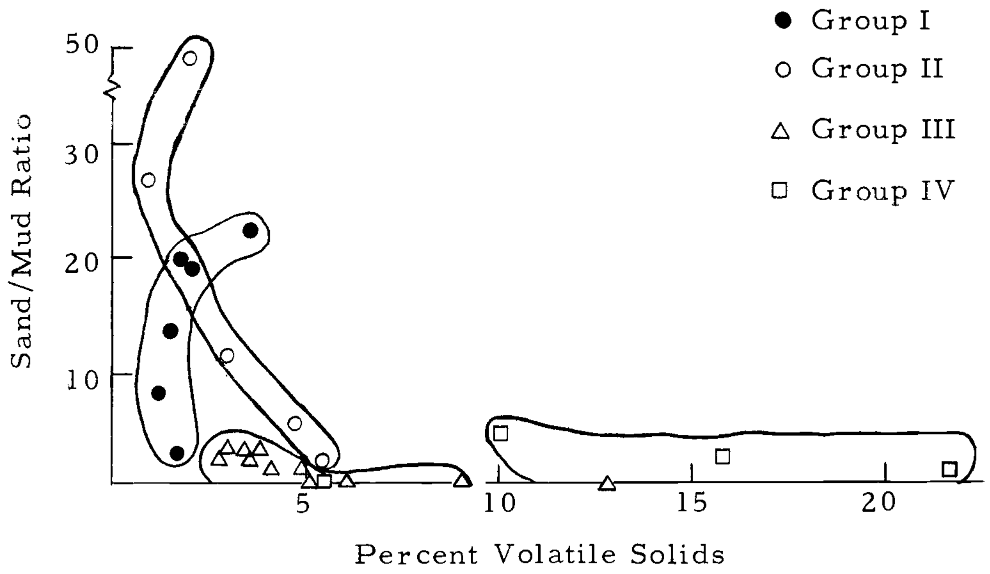


Figure 20. Position of summer samples with respect to sediment sorting and mean ∅ sediment particle size. Samples which are highly similar with respect to species composition are designated by the same symbols.

Figure 21. Position of summer samples with respect to sand/mud ratio and percent volatile solids. Samples which are highly similar with respect to species composition are designated by the same symbols.

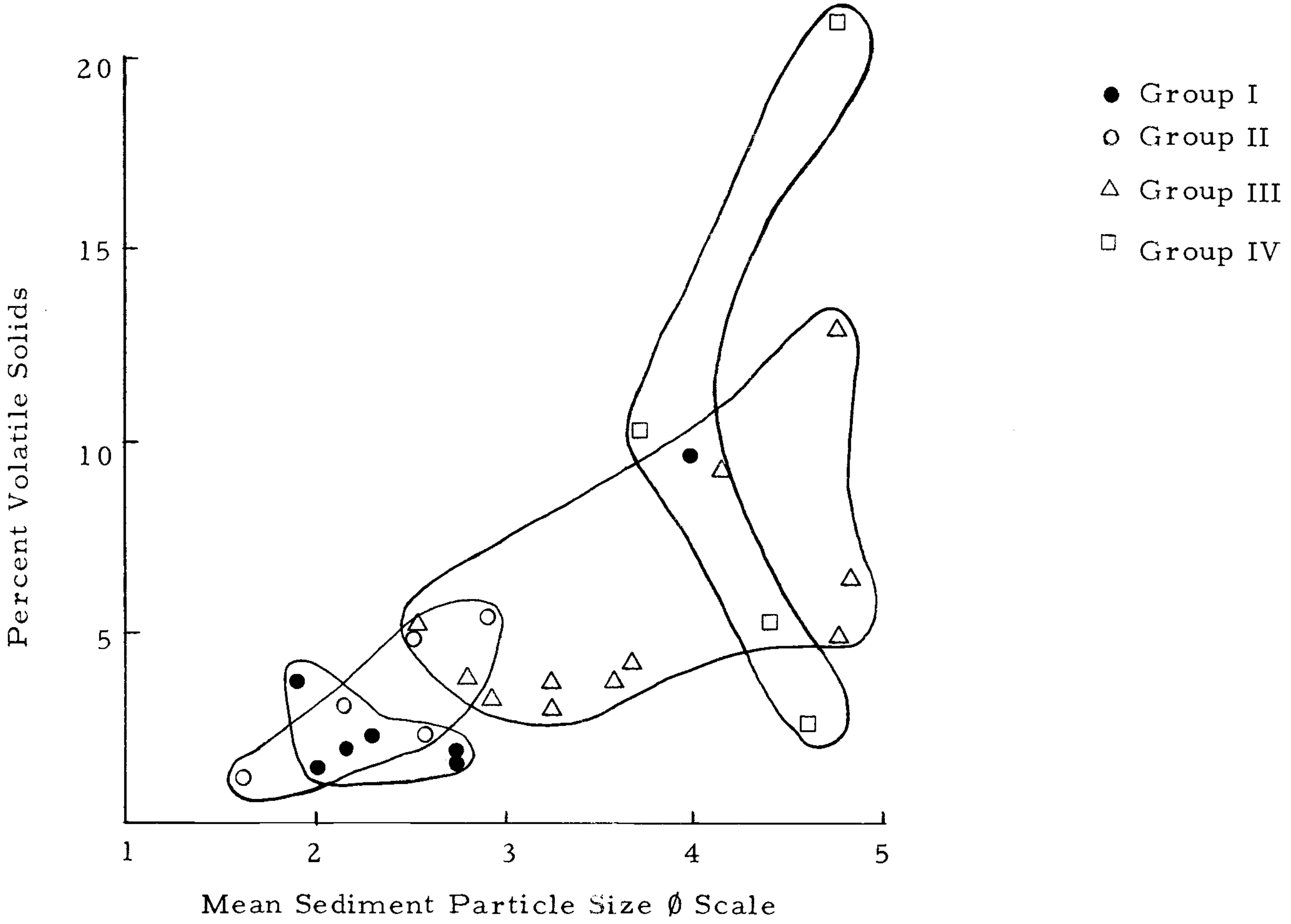


Figure 22. Position of summer samples with respect to percent volatile solids and mean ∅ sediment particle size.

Groups III and IV and station 8'c transitional to Groups II and IV. Station 8'a, unlike the others, had high similarity with stations in Group II, III and IV while stations 8, 15, t-1 and t-4 show no relationship with any of the groups.

A shortcoming of the similarity index is the possibility that some stations may be improperly grouped because of a similar highly dominant species. To avoid such a misalignment it is important to examine the species collections within a grouping to check for a dominant species and obvious differences between the remaining species.

Group I was dominated by M. inconspicua and E. estuarius. Stations 11 and 12, t-2, t-3 and t-5 had low densities of organisms and five or fewer species, of which M. inconspicua and E. estuarius never represented below 50 percent and as high as 80 percent. The other two stations in this group, 9 and 10'c, had 9 and 11 species, respectively. Station 9 was dominated by M. inconspicua (59. 5 percent) while 10'c was dominated by M. inconspicua and E. estuarius (50 percent). Therefore, 10'c and 9 could be considered artificially aligned with this group. The sediment differences at station 9 reinforce this conclusion.

Group II is dominated by the bivalves M. inconspicua and M. arenaria. Although together they account for at least 57 percent of the organisms in any one sample, there are other less dominant species that the sites have in common, indicating a truer similarity. Group III differed from Groups I and II in having no single species which was dominant throughout. Of the 11 stations in this grouping at least eight species were common to any one pair, increasing to 15 common species in one pair. The dominant species in this grouping, as calculated by Boesch (1971) and listed in descending order, were: *C. salmonis*, *P. socialis*, *P. kempi*, *M. inconspicua*, *N. tenuis* and *A. bioculata*.

In Group IV as in Group III there was no clearly dominant species throughout. In addition, the dominant organisms in this group were not as clear-cut as were the dominants in Group III. In estimating dominance in this group, ten species achieved a score and *C. spinicorne* was the only species with a score for each station. In most instances, however, the dominance scores were low supporting the conclusion that there were no truly dominant species in this group. Those species with the highest scores in descending order were: *C. spinicorne*, *C. salmonis*, *A. bioculata*, *B. glandula*, *N. tenuis* and *M. arenaria.*

Figures 20, 21, and 22 show a good separation of the coarse sediment groups (I and II) and the fine sediment groups (III and IV). However, there is poor separation, in all three figures, of Group I from Group II and Group III from Group IV.

All the coarse sediment stations within Group I contain the haustorid amphipod, *Eohaustorius estuarius* while this species was absent from Group II samples. Haustorid amphipods are generally considered inhabitants of coarse, unstable sediments (Boesch, 1972) often common on sandy, wave exposed beaches. Although the sediment parameters do not separate the two groups it seems likely that the environment associated with Group I is more rigorous than Group II. Unstable sediments caused by greater current velocities may have been the causative factor for their dissimilarity and the significantly lower diversity in Group I.

Comparing the two fine sediment groups, III and IV, with respect to diversity of specific phylogenetic groups, the greatest difference was found in the crustaceans. Group IV had a mean crustacean diversity of 1.062 while Group III was much lower at 0.223. Polychaete diversity and total macroinvertebrate diversity, however, showed no distinct differences between the two groups. The crustaceans were the dominant species in Group IV while the polychaete species dominated Group III.

Another difference between Groups III and IV is the occurrence of the barnacle *Balanus glandula* and *Corophium spinicorne* in Group IV and their absence from Group III. The occurrence of *Balanus* is a good indication of large debris composed of bark, branches, and other materials. In examining these two species in all samples, it is obvious that their occurrence is highly correlated (Figure 23).

Other more subtle differences exist between Groups III and IV. Three rare crustaceans found in the study, Gnorimosphaeroma lutea, Tanis sp. and Achelia nudiuscula, were associated predominantly with Group IV stations. The isopod Gnorimosphaeroma was found by Erikson (1966) associated with submerged logs while Tanais and Achelia were reported to be common inhabitants of bryozoan and hydrozoan colonies encrusted on bell buoys (Light et al., 1961; Miller, 1968). Therefore, like C. spinicorne, these species can be linked with the submerged bark and wood debris. Another more common amphipod Anisogammarus confervicolus often found clinging to mats of Enteromorpha may also be associated with the sunken bark. It seems reasonable to conclude that the differences in biota between Groups III and IV are the result of increased habitat provided by the sunken bark and wood debris rather than any differences in the other sediment parameters measured.

Further evidence supporting the bark habitat assumption can be found at station 9, 9'a, 9'b and 9'c. These stations, located at an abandoned log dumping site, had sediment characteristics very similar to the active log handling areas, except that the bark debris had presumably silted over. The fauna found at these stations was remarkably different than the other log handling areas. Besides a lower relative density and diversity found in these samples, the

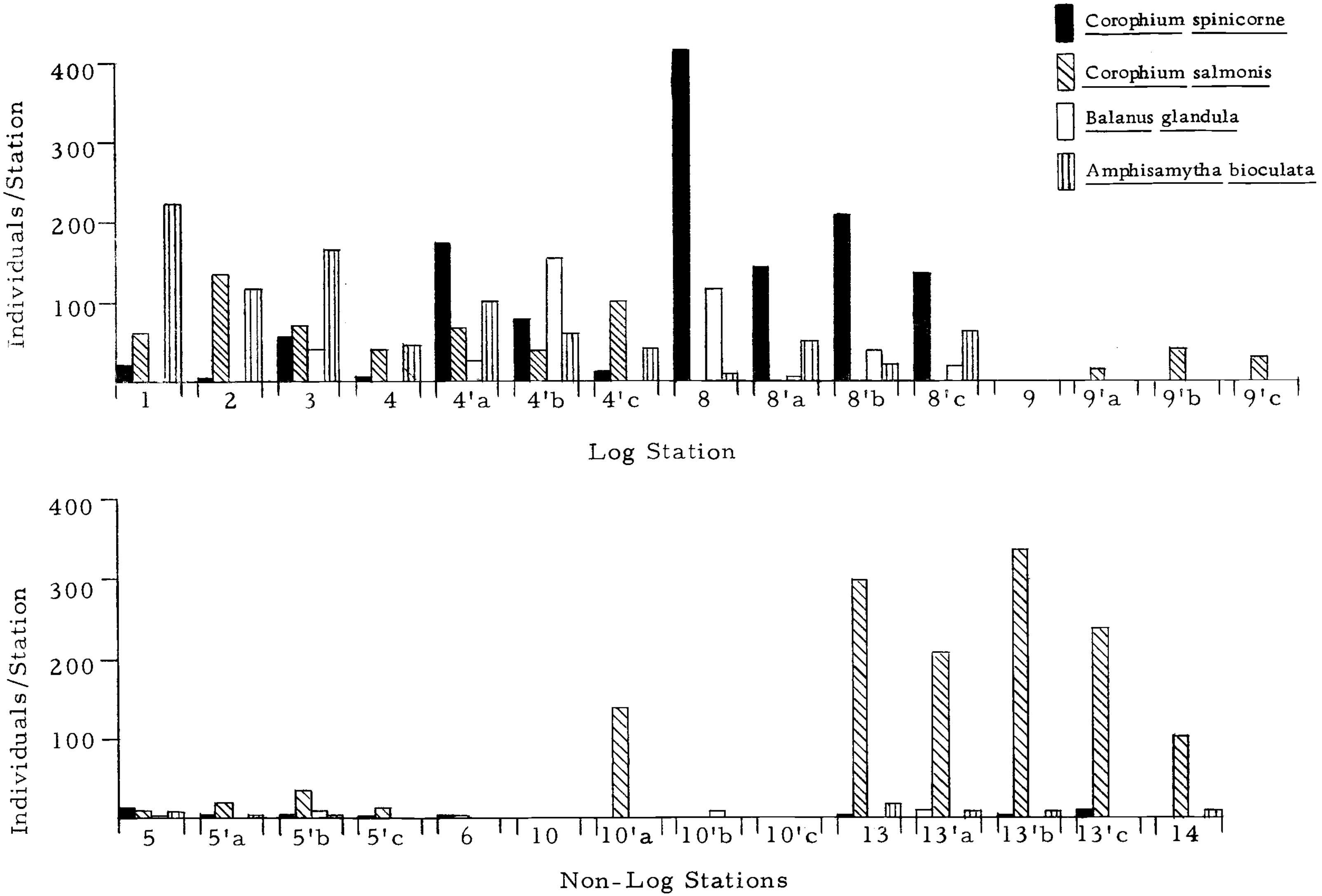


Figure 23. Numbers of four species in log and non-log summer samples.

polychaete A. bioculata was nearly absent. The occurrence of this species was quite common in the other log handling areas and quite rare in areas where there was no log handling (Figure 23). Corophium spinicorne and B. glandula were also absent in samples from the abandoned log site and the occurrence of C. salmonis was very sparse.

VI. SUMMARY AND CONCLUSION

From the data collected it seems rather conclusive that the bark deposits, although they do result in a heavy organic load in the sediments, have little discernable effect on species diversity and may increase density of the benthic macroinvertebrates. In many cases the log sites also seem to result in a different species composition. Whether this difference is the result of differences in physiological tolerances of the species or the varied habitat provided by the bark debris is difficult to say with certainty. However, the data collected in the study suggests that the latter hypothesis is likely.

Although the macrobenthic invertebrates are only a subsystem of the total ecosystem in the estuary they have been used extensively in the past as indicators of polluted regions because of their sessile nature. A healthy benthos is interpreted as a healthy region for other metazoans, microorganisms, algae and vascular plants. Therefore, in Yaquina Estuary where an apparently healthy benthos exists within the bark deposits it may also be reasonable to expect a healthy nektonic and planktonic component of the ecosystem.

Although the potential for severely reduced water quality exists in areas of bark deposits, physical conditions in the region apparently keep the deterioration minimal. In other areas where current velocity is low or tidal flushing absent, results could be very different. Caution should be practiced, therefore, in extrapolating the results obtained in Yaquina Estuary to other areas.

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APPENDICES

Appendix I. Sediment characteristics of each sampling area. Sampling areas are divided into those within log handling areas and those not within log handling areas.

Sampling Area	Depth M	% Sand	% Silt	% Clay	Mean Ø	V. S.	Classification
Log							
1	1.0	42	52	6	4.50	11.77	Sandy silt
2	0.5	31	62	7	4.75	12.75	Sandy silt
W-2	0.5	84	16	0	3.25	6.20	Sand
S-2	0.5	75	25	0	3.67	5.46	Silty sand
3	0.5	81	19	0	3.70	10.09	Sand
W-3	0.5	71	29	0	3.88	6.10	Silty sand
S-3	0.5	71	29	0	3.65	3.33	Silty sand
4	0.5	67	23	10	4.15	9.10	Silty sand
4'-a	0.5	63	31	6	4.38	5.23	Silty sand
4'-c	0.5	42	55	3	4.78	4.81	Sandy silt
W-4	0.5	61	39	0	4.23	4.30	Silty sand
S-4	0.5	54	43	3	4.35	6.18	Silty sand
8	5.0	50	38	12	4.89	12.48	Silty sand
8'-a	5.0	66	31	3	3.97	15.63	Silty sand
8'-b	5.0	44	48	8	4.77	21.59	Sandy silt
8'-c	5.0	49	38	13	4.90	20.61	Silty sand
W-8	5.0	70	30	0	3.65	7.90	Silty sand
S-8	5.0	57	43	0	4.22	9.90	Silty sand
9	4.0	67	31	2	4.05	9.46	Silty sand
9'-a	4.0	51	35	14	4.92	6.67	Silty sand
9'-b	4.0	50	42	8	4.82	6.34	Silty sand
W-9	4.0	43	53	4	4.42	6.00	Sandy silt
S-9	4.0	38	60	2	4.63	18.85	Sandy silt
Non-Log							
5	1.0	85	15	0	2.89	5.39	Sand
5'-a	1.0	79	20	1	3.28	2.86	Sand
5'-b	1.0	94	6	0	0.87	1.00	Sand

Appendix I. (Continued)

Sampling Area	Depth M	% Sand	% Silt	% Clay	Mean Ø	V. S.	Classification
5'-c	1.0	97	3	0	1.63	1.13	Sand
W-5	1.0	89	11	0	3.80	2.60	Sand
S-5	1.0	89	11	0	2.05	5.71	Sand
6	2.0	98	2	0	2.15	2.98	Sand
W-6	2.0	71	27	2	3.80	2.60	Silty sand
S-6	2.0	95	5	0	2.05	5.71	Sand
7	2.0	97	3	0	2.53	4.74	Sand
t-1	5.0	86	14	0	2.36	4.18	Sand
t-2	5.0	94	6	0	1.90	3.68	Sand
t-3	4.5	99	1	0	2.75	1.58	Sand
t-4	4.0	100	0	0	1.99	1.52	Sand
t-5	3.0	98	2	0	2.17	1.87	Sand
10	4.0	81	19	0	3.46	3.75	Sand
10'-a	4.0	77	21	2	3.58	3.60	Sand
10'-b	4.0	98	2	0	2.57	2.09	Sand
10'-c	4.0	95	5	0	2.32	2.18	Sand
W-10	4.0	71	27	2	3.55	4.05	Silty sand
S-10	4.0	100	0	0	1.97	4.29	Sand
11	1.0	95	5	0	2.15	2.71	Sand
12	0.5	93	7	0	2.00	1.45	Sand
W-12	0.5	71	29	0	4.03	2.80	Silty sand
S-12	0.5	38	62	0	4.23	4.80	Sandy silt
13	0.5	91	9	0	2.52	4.85	Sand
13'-a	0.5	57	37	6	3.67	4.10	Silty sand
13'-b	0.5	75	23	2	3.28	3.53	Silty sand
13'-c	0.5	77	23	0	2.78	3.68	Sand
W-13	0.5	84	16	0	2.67	3.36	Sand
S-13	0.5	92	8	0	2.83	10.39	Sand
14	1.0	94	6	0	2.91	3.17	Sand
15	0.5	98	2	0	2.75	4.60	Sand

APPENDIX II. PHYLOGENETIC OUTLINE OF ANIMALS COLLECTED IN ALL SAMPLES

Phylum: Arthropoda

Class: Crustacea

Order: Amphipoda

Family: Corophiidae

Corophium salmonis
Corophium spinicorne
Corophium brevis

Gammaridae

Anisogammarus confervicolus

Haustoriidae

Eohaustorius estuarius

Ampithoidae

Ampithoë sp.

Order: Isopoda

Family: Sphaeromidae

Gnorimosphaeroma lutea

Order: Thoracica

Family: Balanidae

Balanus glandula

Order: Tanaidacea

Family: Tanaidae

Tanais sp.

Order: Cumacea

Family: Diastylidae

Order: Harpacticoida

Order: Decapoda

Family: Caridea

Crago franciscorum

Class: Pycnogonida

Family: Ammotheidae

Achelia nudiuscula

Class: Insecta

Order: Diptera

Phylum: Mollusca

Class: Bivalvia

Order: Eulamellibranchia

Family: Tellinidae

Macoma inconspicua
Macoma balthica

Family: Myidae

Cryptomya californica
Mya arenaria

Phylum: Nemertinea

Class: Anopla

Order: Heteronemertini

Cerebratulus sp.

Phylum: Annelida

Class: Polychaeta

Order: The Sedentaria

Family: Ampharetidae

Amphisamytha bioculata

Family: Arenicolidae

Arenicola marina

Family: Capitellidae

Notomastus (*Clistomastus*) *tenuis*
Capitella capitata

Family: Spionidae

Polydora socialis
Pseudopolydora kempi
Streblospio benedicti

Family: Cossuridae

The Errantia

Family: Goniadidae

Goniada brunneata

Family: Nephtyidae

Nephtys sp.

Family: Nereidae

Neanthes (*Nereis*) *diversicolor*

Family: Phylodocidae

Eteone lighti