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Title DISTRIBUTION OF FORAMINIFERA, NETARTS BAY, OREGON

Abstract approved Gerald A. Fowler
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Netarts Bay is a coastal lagoon on the northern Oregon coast. Four major sedimentary environments are recognized including channel, sand flats, mud flats, and marsh. Fine-grained sediment is carried in by streams and deposited in the marshes and mud flats. Fine sand for the channel and sand flats is derived from the open ocean beaches and turbulent zone. Organic carbon varies from 0.1 to 3.5 percent of the sediment and varies inversely with the sediment size. Carbonate carbon is unimportant.

Fifty-one benthic foraminiferal species were recognized of which 37 formed two percent of the population in one or more samples. Four foraminiferal faunal groups were recognized: the Elphidiella Fauna inhabiting the channel, the Elphidium Fauna reaching greatest abundance on the central bay sand flats, the Ammonia Fauna inhabiting the mud flats and inner bay sand flats, and the Miliammina Fauna characterizing the marsh.

Planktonic foraminiferal populations form less than one percent of the total foraminiferal population. Benthic foraminiferal populations on the order of 80 specimens/cm^2 for the live populations and 200/cm^3 for the dead are found in the dense vegetation of the marsh. Tidal flat populations are approximately an order of magnitude smaller and the channel population is one to two orders of magnitude smaller than for the tidal flat.

Species diversity is greatest on the central bay tidal flats, averaging seven species per sample for live and 15 for dead populations. Values decrease as mud flats, marsh, and channel environments are approached.

The total standing crop and most species inhabiting the innermost part of the bay display simultaneous bimodal population maxima in July and January. These peaks are possibly controlled by the availability of food. *Ammonia* cf. *A. beccarii tepida* and *Elphidium incertum incertum* show strong but independent population maxima in July and October respectively.

Foraminifera-ostracod ratios range from 0.6 to 41.5 with a mean of 13.8. Agglutinated-calcareous foraminiferal ratios vary inversely with sediment size and appear to be related to the pH of the sediments. Thecamoebians are rare in the bay but replace the foraminiferal population as fresh water environments are approached in the inflowing streams. Reworked fossil foraminifera are found only rarely.

DISTRIBUTION OF FORAMINIFERA, NETARTS BAY, OREGON

by

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DISTRIBUTION OF FORAMINIFERA, NETARTS BAY, OREGON

INTRODUCTION

General Statement

Ecologic studies serve to widen our understanding of the world about us and also to provide criteria for recognizing various environments of deposition in the geological record. Recognition of fossil lagoonal environments is especially valuable since these environments represent one of the most important transitional zones between marine and terrestrial areas. Criteria that will help identify these environments in the fossil state will help greatly to elucidate stratigraphic relationships. Because of their small size, variety of form, abundance, and resistance to destruction, foraminifera are especially well suited to provide the criteria necessary to recognize fossil marine and brackish water environments.

Purpose and Scope

This study was undertaken to obtain detailed ecologic information on foraminifera inhabiting brackish water environments along the Oregon Coast. Netarts Bay, located approximately 55 miles (88 kilometers) south of the Columbia River (figure 1), was selected because it is small enough to be worked easily, has an uncomplicated

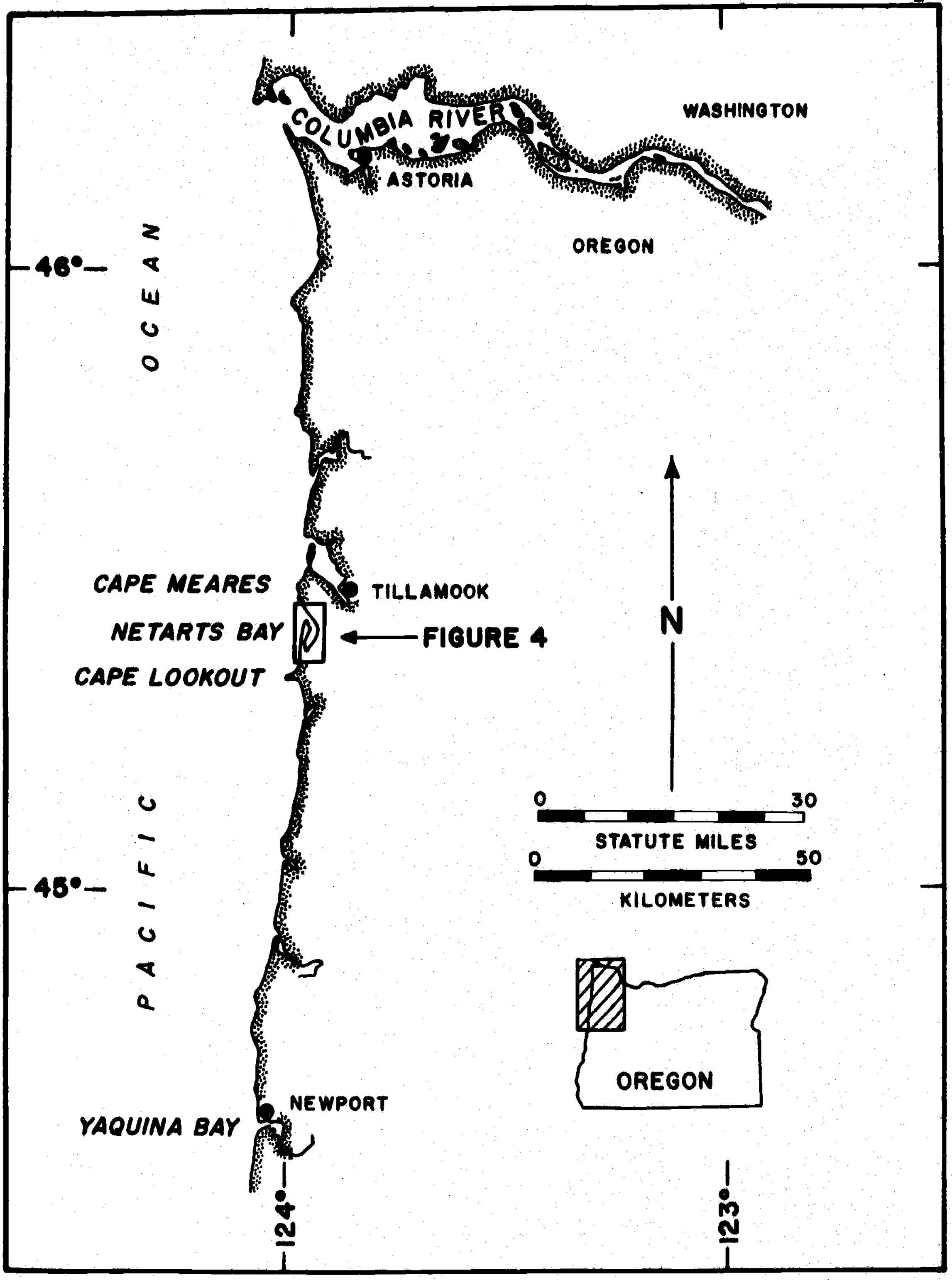

Figure 1. Index map showing the location of the area studied.

hydrography, and is free from contaminating industrial wastes.

Primary objectives of this study are to identify the foraminifera and to outline their distribution with respect to sediment size, organic content, energy of the environment, vegetation, temperature, salinity, and pH. In addition, the standing crop and species populations were examined for seasonal variations.

Previous Work

Natland (1933) was the first to make an ecologic study of foraminiferal faunas of the Pacific Coast of the United States. He identified and zoned by depth and temperature the foraminifera along a traverse between Long Beach and Santa Catalina Island, California. The faunal trends were compared to the succession of fossil faunas in a Tertiary stratigraphic section near Ventura, California. In a similar but expanded ecologic study off southern and central California, Bandy (1953) zoned the foraminiferal faunas and compared them to changes in latitude, salinity, and oxygen content in addition to depth and temperature. Foraminiferal standing crop (live population per unit area) was first investigated on the Pacific Coast by Walton (1955) in his study of Todos Santos Bay, Baja California, Mexico. Many subsequent studies have served to expand knowledge of foraminiferal ecology in the areas of southern California and Central America (see Phleger, 1960 and Smith, 1964). The ecology of foraminifera off Oregon and Washington was studied by Enbysk (1960). Later, Jarman (1962) quantitatively sampled and described both the living and dead foraminiferal populations on the continental shelf between Siletz and Alsea Bays.

On the Pacific Coast most studies of paralic[1] foraminiferal ecology have been made in southern California and northern Mexico. Walton (1955) initiated these studies with his investigation of the marshes, tidal flats, and channels of Estero de Punta Banda, Baja California, Mexico. Phleger and Ewing (1962) investigated the ecology of three lagoons also located in Baja California. The foraminiferal ecology of beaches on the Pacific Coast was first investigated by Reiter (1959). He sampled Santa Monica Beach weekly for a period of seven months and demonstrated a seasonal variation in the standing crop. Cooper (1961) showed the effect of latitudinal variations on foraminiferal populations of beaches and tide-pools from the Mexican Border to the Columbia River. Lankford (1962) made a comprehensive foraminiferal study of the upper sublittoral area from Cabo San Lucus, at the southern end of Baja California, to Cape Flattery, Washington. He showed the existence of foraminiferal zonation controlled by both latitude and depth and modified by the type of substrate. Walton's and Cooper's investigations and a

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[1]Includes marine border environments such as near-shore turbulent zone, beaches, tide pools, bays, lagoons, and salt marshes.

number of unpublished manuscripts were summarized by Bandy (1963). He pointed out the foraminiferal faunal trends to be expected in the various paralic environments of southern California and northern Mexico; most are useful in the interpretation of paralic facies of the geologic past. Due to differences in climate between the Pacific Northwest and southern California not all of Bandy's conclusions may be applied completely to similar environments along the Oregon and Washington Coasts.

Nothing has been published on the foraminifera of the brackish-water environments along the Oregon Coast but several unpublished studies have been made. Jarman (1962) collected two samples from Yaquina Bay and described their foraminiferal populations in some detail. Foraminifera of Yaquina Bay's channel and tidal flats were described by Maloney (n. d.). A number of term papers completed at the Departments of Oceanography and Geology, Oregon State University, discuss foraminiferal ecology of the following areas: Netarts Bay (Hunger, 1964 and 1965), Siletz Bay (Rooth, 1964), Alsea Bay (Manske, 1964), Mc Caffery Slough, Yaquina Bay (Manske, 1965), and Oregon Beach and Tide Pools (Rooth, 1965).

METHOD OF STUDY

Field Procedure

One hundred and nine samples were collected from 73 stations (figure 2) between May 2, 1964 and April 16, 1965 (Appendix A). All samples were preserved with a 20 percent solution of formalin buffered with sodium borate. Sampling was done either from a small boat or on foot. Tidal flats were sampled by forcing a plastic tube, with an inside diameter of 1 3/8 inches (3.4 centimeters) into the substrate. The top one centimeter of each core was removed following the procedure of Walton (1955, p. 959). A Marukawa type grab sampler (figure 3) described by Hopkins (1964, p. 221) was used to collect samples in the deep, swift water of the main channel. The larger surface area obtainable with the grab partially compensated for the normally low foraminiferal population found in the main channel. The entire sample was preserved at each grab station because of the mixing inherent in the sampling process. A small piston corer (figure 3) similar to that described by Reish and Green (1958) was used to sample relatively quiet water of intermediate depth. Samples collected in this manner were handled in the same way as samples collected by the plastic tube.

Surface sediment was collected from 43 randomly distributed

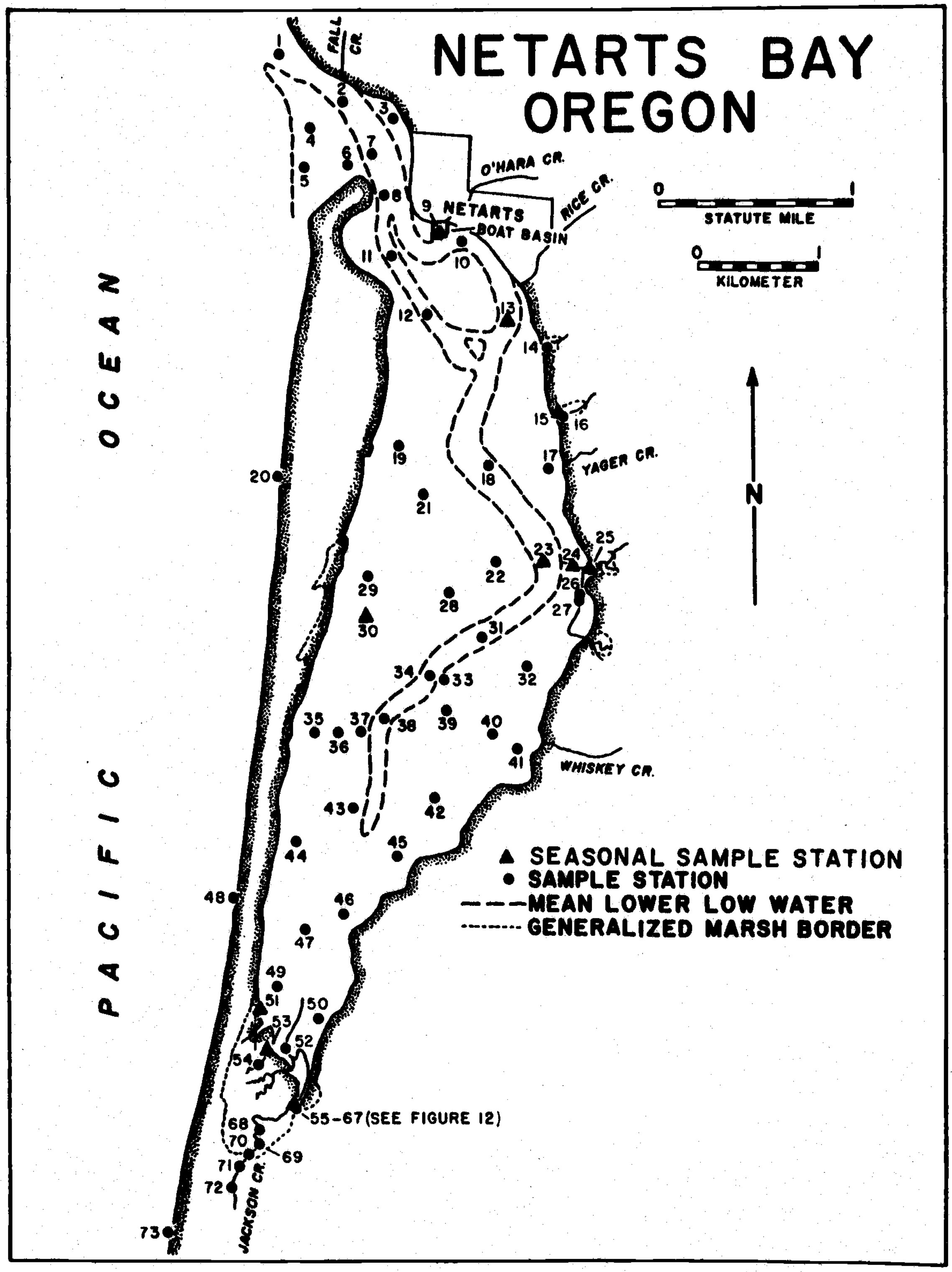
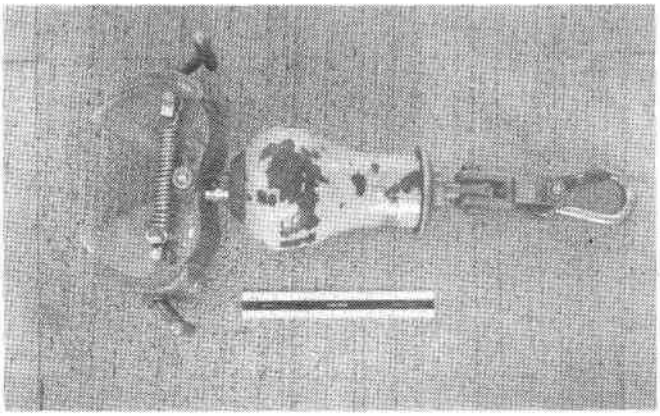
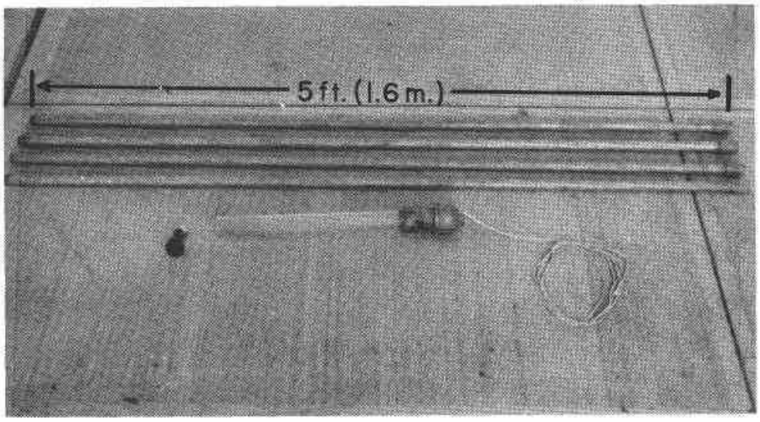


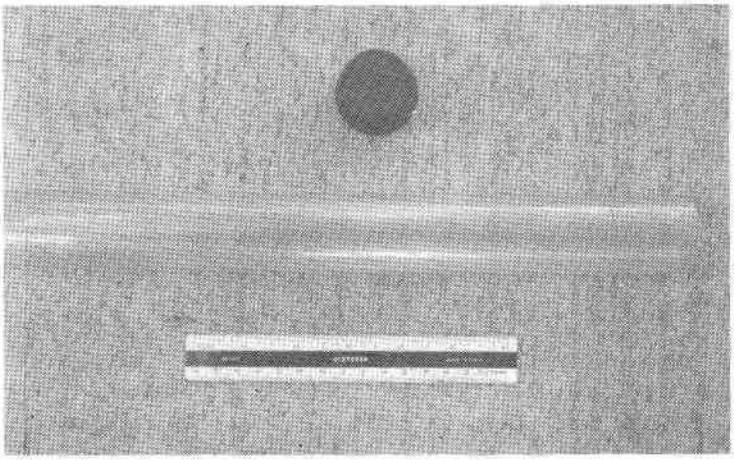
Figure 2. Index map showing sample station locations.



A

B





C

Figure 3. Sampling equipment: A. Marukawa type grab sampler; B. piston corer with detachable lengths of pipe for a handle; C. section of plastic liner and rubber stopper used for sampling in shallow water.

channel, tidal flat, and beach stations. The sediment was placed in small plastic bags and stored at 5° C until processed.

Eleven marsh sediment samples were collected for pH determinations. Jars were completely filled with sediment to exclude as much air as possible. The samples then were chilled immediately with ice to approximately 0° C. Samples were maintained at this temperature until their pH was measured two days later.

Laboratory Procedure

Foraminiferal Analysis

Foraminiferal samples were washed on a screen with 61 micron openings (250 mesh Tyler Series) to free them of silt- and clay-size particles and formalin. The residue was immersed for approximately 30 minutes in a solution of Rose Bengal. This process (Walton, 1952) stains protoplasm red and thus distinguishes foraminifera living at the time of sampling. Samples were again washed on a 61 micron screen to free them of excess stain. They then were oven dried at approximately 80° C. Either tetrachloroethylene or carbon tetrachloride was used to concentrate the foraminifera from the inorganic fraction of the sediments. This was effected by sprinkling the dried sediments on the surface of the liquid and then carefully decanting the floating material. This operation was performed three times for each sample to insure as clean a separation as possible between the foraminifera and non-biogenic fractions of the sediments.

All the specimens were counted in each concentrate unless considerably more than 300 were present in which case a representative split of 300 to 500 specimens was taken from the concentrate and counted. Dryden (1931) has shown that a higher count gives only small increases in reliability of percentage estimates of the fauna. The residues from the floating process were examined to check the efficiency of the concentration. In most cases no foraminifera were found. When foraminifera were found in residues an adjustment was made in the count for that station.

Sediment-size Analysis

An Emery settling tube (Emery 1938) as modified by Poole (1957) was used to make grain-size analysis of sand fractions from the samples. Samples with more than five percent silt- and clay-size material were filtered free of sea water with millipore filters, dispersed in a 0.2 percent solution of Calgon (sodium hexametaphosphate) and analyzed by the soils hydrometer technique described by the American Society for Testing Materials (1964).

Organic Carbon Analysis

The amount of organic carbon in each sample analyzed was determined by subtracting the amount of carbonate carbon from the total carbon. Approximately five grams of material were taken randomly from the sediment samples. This material was dried, powdered, and stored in a desiccator. For each analysis of both total and carbonate carbon 0. 5 grams of the thus prepared sediment were analyzed by the induction method described by Curl (1962). Duplicate samples were run for each station. If the pairs of values showed a significant spread, a third analysis was performed and the two closest values were averaged.

Determinations of pH

Determinations were made with a Beckman pH meter equipped with one calomel and one glass electrode. If the sediment was soft and wet, the electrodes were introduced directly into the sample. If, however, the sample was too dry to make good contact with the electrodes, a portion of the sediment was placed in a paper cup and enough distilled water added to make a slurry. The electrodes then were placed in the slurry. Two readings were taken for each sample. If the pH values differed by 0. 1, the first reading was used. If the values differed by 0. 2, the values were averaged. None of the paired readings differed by more than 0. 2.

PHYSICAL ENVIRONMENT

General Facies

General Description

Netarts Bay is a north-south trending lagoon occupying an indentation in the coast line. The headlands of Cape Lookout to the south of the bay and Cape Meares to the north are both composed of Columbia River Basalt (Baldwin, 1964, p. 16). The rocks underlying the bay are sedimentary and have been referred to the Astoria Formation (Warren, Grivetti and Norbisrath, 1945). Differential rates of erosion of these two types of rock has resulted in the depression which is now occupied by Netarts Bay. A large dune-covered sand spit separates Netarts Bay from the open ocean to the west. A narrow tidal channel approximately 15 feet (3.8 meters) deep breaches the north end of the spit and continues in a semimeandering course for three quarters of the length of the bay. The bay has a total area of 3.8 mi^2 (9.9 km^2); at mean lower low water approximately 2.7 mi^2 (7.1 km^2) of this area is exposed as sand and mud flats. Salt marshes border the southern tip of the bay and portions of the sides of the bay. Beaches and channel, sand flats, mud flats, and salt marsh are the major environments differentiated in Netarts Bay (figure 4).

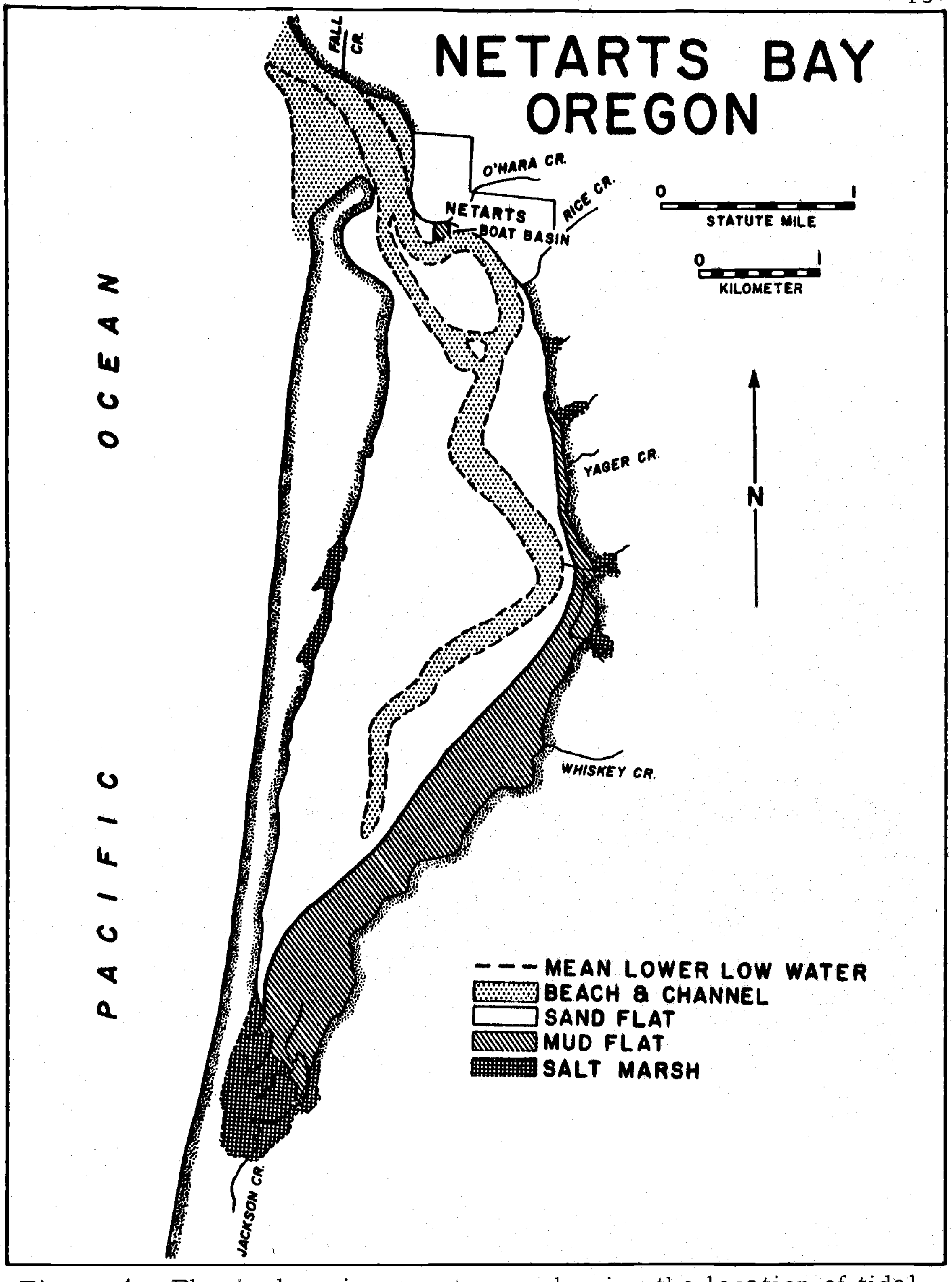


Figure 4. Physical environment map showing the location of tidal channel, sand flats, mud flats, and salt marshes.

Beach and Channel

The tidal channel and beaches near the mouth of the bay represent a fairly uniform, high energy environment characterized by well-sorted sand and gravel and a lack of vegetation. Gravel beds are present in deeper parts of the channel from station 13 oceanward. Rapidly shifting sand caused by waves and tidal currents makes this an especially difficult environment for most organisms to establish themselves in.

Sand Flats

Fine-grained sand similar to that found on the beaches and in the tidal channel forms the sediment substrate over approximately 65 percent of the tidal flats. Most of the sand flats are located in the lower and central bay regions, but a finger of sand extends into the upper bay along the western shore (figure 4). Finer-grained sediment probably is prevented from settling on most of the sand flats by moderately high-energy tidal currents that flow over their surface during much of each tidal cycle. Pelecypods are present and are abundant in areas with a small admixture of silt and organic matter (Marriage 1954). The surfaces of the sand flats are bare except for an occasional bed of *Zostera marina* Linné (eel grass) and more rarely *Sargassum muticum* (Yendo) Fensholt.

Mud Flats

Mud flats are confined to an area beginning approximately midway along the eastern shore of the bay and widening to cover most of the southern end. Low velocity currents found near the edge and back of the bay allow fine-grained sediments to settle out. These flats are inhabited by extensive communities of burrowing and tube-building organisms. Vegetation is absent with the exception of occasional summer colonies of filamentous blue-green algae inhabiting areas continuously covered by water.

The boat basin could be classified with the mud flats if one were to consider only sediment size and energy level. However, the water is up to ten feet (3 meters) deep at low tide and the sediment surface is never exposed. Vegetation is probably absent since bottom samples showed only bare soft mud. The sedimentary environment at this location appears to be unstable. Samples taken in July and October, 1964 and January, 1965 were composed of fine-grained black mud. Samples obtained in April, 1965 were formed of a light-colored sand. Examination of the sand indicates that it is channel sand probably brought in by winter storms.

Salt Marsh

An extensive salt marsh is located at the southern tip of Netarts

Bay. Much smaller patches are present at the mouths of many of the small streams entering the bay along the east side and in depressions between dunes on the spit to the west. Many of the marshes are separated sharply from bordering mud and sand flats by steep erosional banks. Areas of accretion, where the marsh is extending itself over the neighboring tidal flats, are low relative to the older areas of the marsh. This new marsh area, hereafter called the low marsh, is best defined as the area covered by marsh vegetation that is below the elevation reached by the average high tide. The low marsh forms a narrow discontinuous transitional area between the tidal flats and the older marsh. Marsh vegetation is sparse toward the bay but increases in density toward the older and higher marsh areas. Older areas of marsh, hereafter called the high marsh, are above the elevation of the average high tide and comprise most of the marsh. Its surface is covered with a low, dense, meadow-like vegetation with occasional small pools of brackish water.

Marsh sediments vary from moderately soft muds in the low marsh to a peat-like soil in the high marsh. The sediment is dark colored with a pH that is acid and decreases away from the bay (figure 13D). Stevenson and Emery (1958) reported a similar condition in Newport Bay, California.

Most of the marsh is indirectly connected to the bay by means of numerous, small, deep tidal creeks that wind their way into the interior of the marsh. These tidal creeks have little source of fresh water and maintain themselves by ebb and flow of the tide.

Marsh vegetation shows a distinct zonation (see figure 12) that appears to be controlled by the degree of inundation and brackish nature of the ground water. Juncus bolanderi Engelm and Salicornia virginica Linné make up a sparse pioneer vegetation that forms the lowest vegetation zone of the low marsh. Almost pure dense stands of Carex lyngbyei Hornem occur in a sharply defined zone. Its upper limit can usually be taken as the dividing line between the low and high marsh. Distichlis spicata (Linné) Greene (salt grass) and Deschampsia caespitosa (Linné) Beauvois form the lowest zone on the high marsh. It is sharply separated from the next lower zone but grades into the highest zone characterized by Juncus sp. This species populates only the highest area of the marsh usually near the limit of fresh-water vegetation.

Climate

Netarts Bay is located in a marine climate typical of the west coasts of continents between 40° and 60° latitude. Climatological data for Tillamook, six miles to the northeast of Netarts Bay, are available for a 76-year period from a United States Weather Bureau Station located there. The average January and July air temperatures are 41.6°F (5.3°C) and 58.7°F (14.8°C) respectively and average precipitations for the same months are 13.27 inches (34.0 centimeters) and 1.19 inches (3.0 centimeters). The months of November through March are times of heaviest rainfall, all averaging greater than ten inches (25.4 centimeters). Precipitation tapers off toward the summer. Both July and August average less than two inches (5.1 centimeters) of rainfall. The average yearly rainfall is 89.33 inches (226.8 centimeters) (U.S. Weather Bureau, n.d.).

Winds blow dominantly from the southwest during the winter and northwest during the summer. These wind vectors are in direct response to a semipermanent low pressure cell formed near the Aleutian Islands during the winter months and a semipermanent high that migrates north to a position off the Oregon Coast during the summer months (Cooper, 1958). Wind velocities at Newport, Oregon, 55 miles (88 kilometers) to the south of Netarts Bay, average ten to 12 miles/hour (16 to 19 km/hr.) from the north and northwest and southwest during July and January respectively (Cooper, 1958). Wind velocities are generally much higher during afternoons when onshore winds are reinforced by day sea breezes. Very high winds also accompany winter storms.

Hydrography

Salinity, temperature, and degree of mixing of bay and lagoon waters depend on the width and depth of the tidal channel, tidal range, and inflow of fresh water relative to the size of the bay (Pritchard, 1955). In the case of Netarts Bay all of the factors favor a well-mixed water column with temperature and salinity near that of coastal water. Netarts Bay is shallow; approximately 70 percent of the bay bottom is exposed at mean lower low water. Runoff is limited since the ratio of the drainage basin area to the bay area is only 4.9. In comparison, the next smallest ratio for a bay along the Oregon Coast is 40 at Tillamook Bay. The average ratio for bays along the Oregon Coast, whose drainage areas are confined to the Coast Range, is approximately 125.[2]

Tides follow a mixed diurnal pattern with a range of 7.6 feet (2.3 meters) between mean lower low water and mean higher high water (U.S. Coast and Geodetic Survey, 1962). Mixing of the inflowing and outflowing waters is quite intense since most of the water is confined to a narrow tidal channel.

Burt and McAlister (1958) collected temperature and salinity data along a north-south traverse of the bay in January and July, 1958 (Table 1). Surface data showed that, with the exception of one station located near the mouth of a fresh-water creek, salinities during the winter runoff dropped very little toward the head of the bay.

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[2]Bay Areas from Marriage (1954). Drainage basin areas calculated from Oregon State Water Resources Board Drainage Basin Maps of North Coast (1960), Mid Coast (1964) and Coos-Coquille (1961).

TABLE 1 Salinity, temperature, depth, location, and date of collection for water samples taken by Burt and Mc Alister (1958).

Jan. 5, 1958							
Kilometers*	0.3	1.8	4.0	6.3	9.0		
Temp. °C	9.8	--	9.6	8.5	6.8		
Sal. ‰	--	31.6	31.6	29.5	13.9		
Depth in meters	0	0	0	0	0		
July 24, 1958							
Kilometers*	1.8	1.8	1.8	1.8	4.0	5.1	6.3
Temp. °C	10.4	10.4	10.3	10.3	13.5	10.9	12.4
Sal. ‰	34.2	34.2	34.2	34.2	33.7	33.8	33.7
Depth in meters	0	1.5	3.0	3.7[B]	0	0	0

*Distance up the main channel from the mouth of Netarts Bay

[B] Sample taken at the bay bottom

During July the channel close to the boat landing was sampled from top to bottom and the water was found to be completely homogeneous. From this limited amount of data Burt and McAlister (1959) concluded that Netarts Bay is essentially well mixed throughout the year.

Beginning in 1960 and continuing through 1963 a shore station was maintained at Netarts Bay by the Department of Oceanography, Oregon State University to collect surface temperature and salinity data. Samples were taken up to five times a month at the boat landing. Individual values for salinity and temperature ranged from 24.38 to 33.42‰ and 6.3 to 20.3°C respectively. Monthly mean salinity and temperature values ranged from 27.42 to 32.66‰ and 7.9 to 17.0°C respectively (Table 2).

The temperature and salinity of Netarts Bay water are controlled by stream runoff, air temperature over the bay, coastal upwelling and the configuration and strength of the Columbia River Plume. The effect of high runoff was demonstrated on March 7, 1961 when the lowest recorded surface salinity at the boat landing followed a week in which 4.47 inches (11.4 centimeters) of rainfall was measured at Tillamook (U.S. Weather Bureau, 1961). Low salinities of smaller range are caused by effluent from the Columbia River. Denner (1963) demonstrated that Netarts Bay is well within the range of the Columbia River's Plume and Anderson et al. (1961) have shown that the effectiveness of the plume's influence is

TABLE 2 Mean monthly salinity and temperature of Netarts Bay water from January 1960 to December 1963. Compiled from Kujala and Wyatt (1961), Oliphant and Wyatt (1962), Still and Wyatt (1963), and Wyatt, Still and Haag (1965).

Year	Mean monthly salinity in ‰											
	J	F	M	A	M	J	J	A	S	O	N	D
1960	30.93	30.55	29.53	30.11	29.23	31.11	32.66	31.84	32.45	32.19	31.55	--
1961	30.96	29.33	28.74	30.36	30.26	31.96	--	--	32.20	31.90	31.79	31.31
1962	30.16	30.72	29.85	28.11	28.29	31.26	31.66	30.53	32.46	29.86	30.40	30.57
1963	31.25	30.41	31.11	27.42	29.76	28.91	28.60	27.74	31.74	30.54	30.09	30.35

Year	Mean monthly temperature in °C											
	J	F	M	A	M	J	J	A	S	O	N	D
1960	10.0	9.8	9.3	12.1	12.9	13.7	11.9	14.4	11.4	10.6	10.4	--
1961	9.5	10.5	10.2	10.8	14.1	14.8	--	--	13.0	12.4	10.5	8.6
1962	7.9	9.0	8.8	11.5	13.1	12.8	14.4	15.8	12.1	13.5	12.0	10.2
1963	8.2	10.3	8.7	11.2	13.4	15.4	17.0	14.6	15.5	13.9	12.1	11.5

controlled by its areal configuration and salinity which in turn is a reflection of the rate of the river's discharge. Higher than normal salinities such as the 33.42‰ of August 9, 1960 result from upwelling along the coast and are accompanied by lower than normal temperatures (Pattullo and Burt, 1962). This phenomenon is not local but tends to appear at other nearby stations at approximately the same time. Water temperatures of Netarts Bay normally have a yearly range of about 8 to 17°C. Extremes of 6.3 and 20.3°C have been measured but these are exceptional and local. Usually such temperatures can be attributed to extremes in air temperatures over the bay. This was the case when two days of 15 to 38°F (-9.5 to 3.3°C) air temperature (U.S. Weather Bureau, 1963) preceded the 6.3°C water temperature recorded in Netarts Bay on January 12, 1963 (Wyatt, Still and Haag, 1965).

Substrate

Sediment Texture

The phi mean, skewness, and sorting values of sediment grain size were determined for 36 samples. In general the sediment can be divided into two categories. Fine-grained sand (Wentworth scale) forms the substrate of the central regions and mouth of Netarts Bay while muds predominate at the head and along the east shore of the bay. In addition, rounded basaltic pebbles up to approximately three centimeters in diameter were collected by a grab from the main tidal channel near stations 2, 7, and 13 (figure 5).

The sand grains of both the bay and the ocean beaches are polished and angular to subrounded with the majority being subangular. The sands within the two areas are indistinguishable if the presence of organic matter in the bay is overlooked. Mean diameters of both sands are similar (figure 5). There is only a small tendency for reduction in size toward the head of the channel. Both beach and bay sands are well sorted and negatively skewed (Appendix B). The tidal channel and the beaches show especially strong negative skewness values. Skewness values progressively increase toward positive values from the mouth to the head of the bay and from the tidal channel to the sides of the bay.

The characteristics common to both beach and bay sands and the trends exhibited by the bay sands suggest that most of the latter is derived from the former by way of the main tidal channel. Sand in a narrow strip along the southeastern shore of the bay in part may be blown off the relatively barren dunes separating the bay from the ocean by the predominantly on-shore winds. Cooper (1958, p. 18) reported that in recent years storms have broken across this narrow sand spit. The sandy nature of the soil between the dunes and the bay also indicates that sand is being transported from the spit into

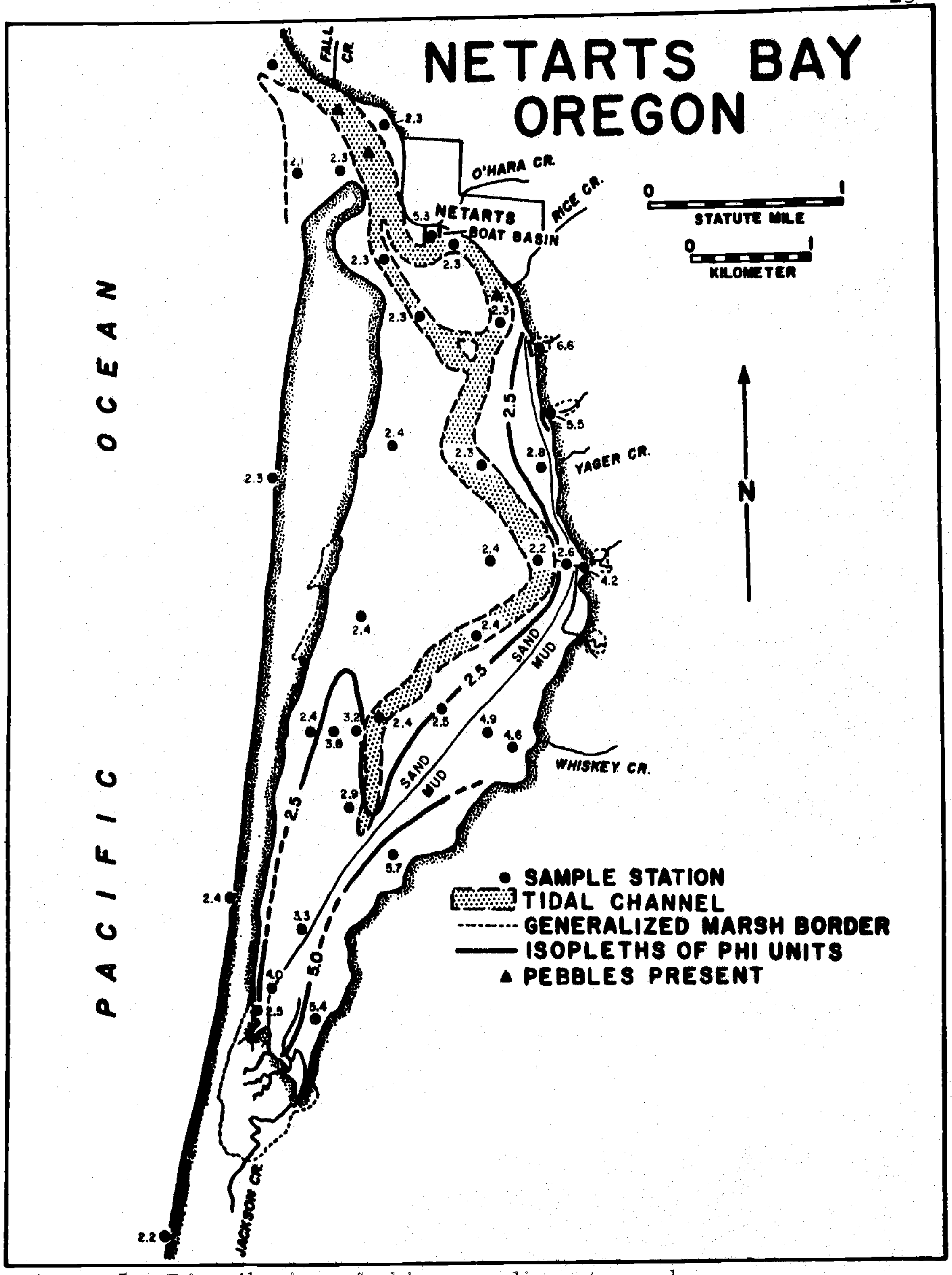

Figure 5. Distribution of phi mean diameter values.

the bay.

The distribution of the very fine-grained sediments of the mud flats is a direct reflection of sediment source and environment energy level. The persistence of a narrow strip of mud along the eastern bay shore indicates that the numerous adjacent small streams are supplying the fine-grained sediment to the area. In addition to the nearby source, quiet environments necessary for the settling of fine-grained sediments (Krumbein, 1939) are found at the head and sides of Netarts Bay. The lack of mud along the western bay shore is probably due to a lack of source rather than to too energetic an environment.

Organic Carbon

Thirty samples, taken for the most part from the tidal flats of Netarts Bay, were analyzed for total and carbonate carbon. Total carbon varied from 0.06 to 3.45 percent (Appendix C). A small amount of carbonate carbon (.05 percent or less), compared to total carbon, indicates the relative unimportance of this form of carbon in the sand-size and finer-grained sediments. The low values, however, may not be truly representative; large abraided shell fragments are particularly abundant in areas of slightly muddy sand where high pelecypod populations normally exist. Erosion, to some extent, may concentrate shell fragments locally by removing the sand-size and finer-grained sediments.

Organic carbon values are lowest in the relatively clean sands of the beaches, main channel, and central-bay tidal flats (figure 6). Carbon content increases progressively toward the finer-grained sediments at the head of the bay. An inverse relationship exists between sediment diameter and organic carbon content (figure 7). The 95 percent confidence interval shows how strongly these parameters are related to each other. Krumbein and Caldwell (1939) and Lidz (1965) also observed this relationship in Barataria Bay, Louisiana and Nantucket Bay, Massachusetts respectively.

Hydrogen ion (pH) Concentration

Hydrogen ion concentration was determined for the surface sediment from 11 marsh stations at the southern end of Netarts Bay (Appendix D). Values range from 7.0 to 5.7 and are consistant with values reported by Stevenson and Emery (1958, p. 28) for Newport Marsh, California. The tendency is for the pH to decrease in value from the muddy sediments of the tidal creek and low marsh to the peat-like sediments of the high marsh (figure 13D). Probably this is a reflection of the denser vegetation supported by the high marsh which in turn tends to increase the organic content of the sediment. The pH of the tidal flat sediments was not measured. However, sediments in the marsh creek (station 55), which are quite similar

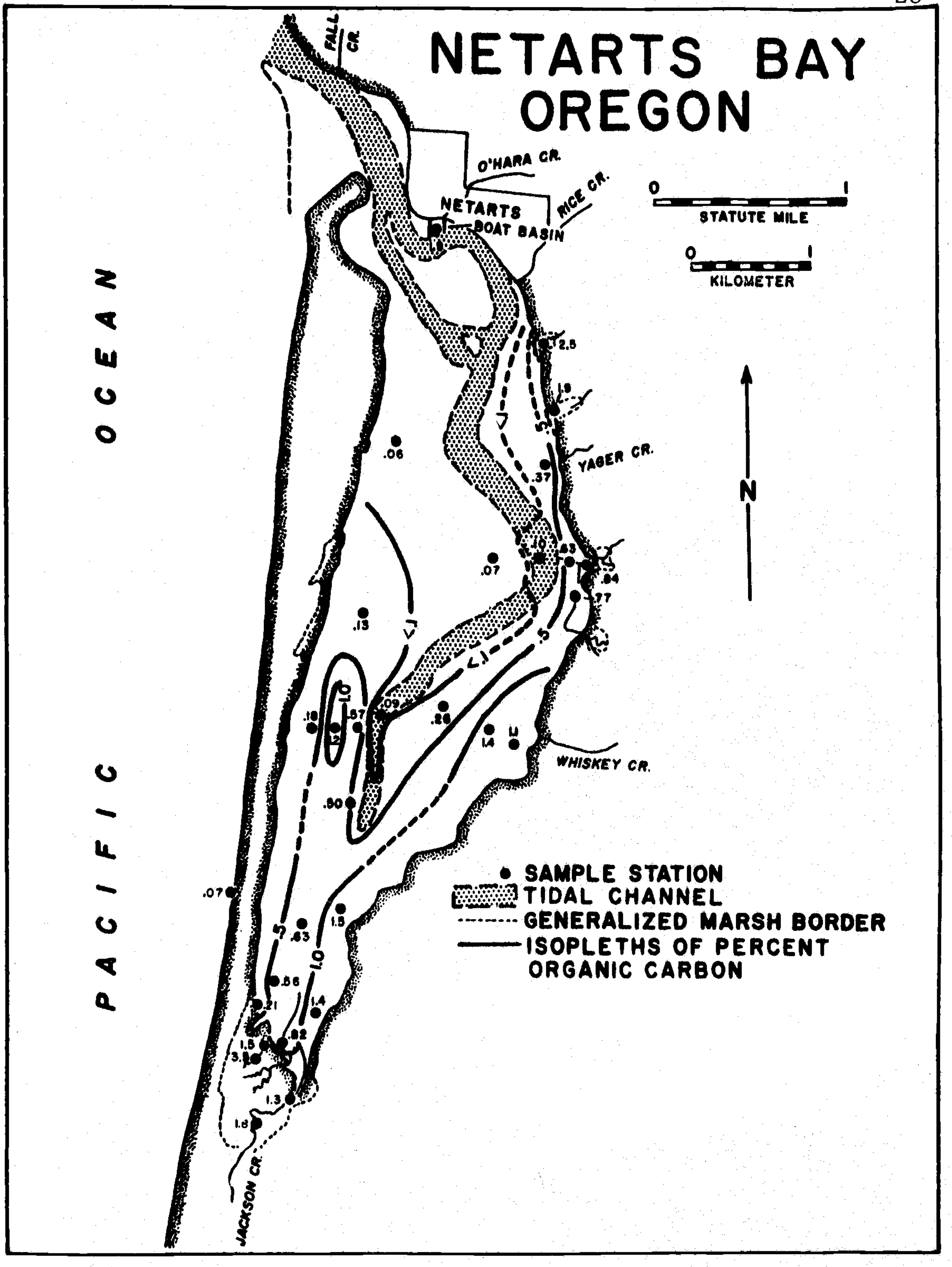

Figure 6. Percent organic carbon in the sediments.

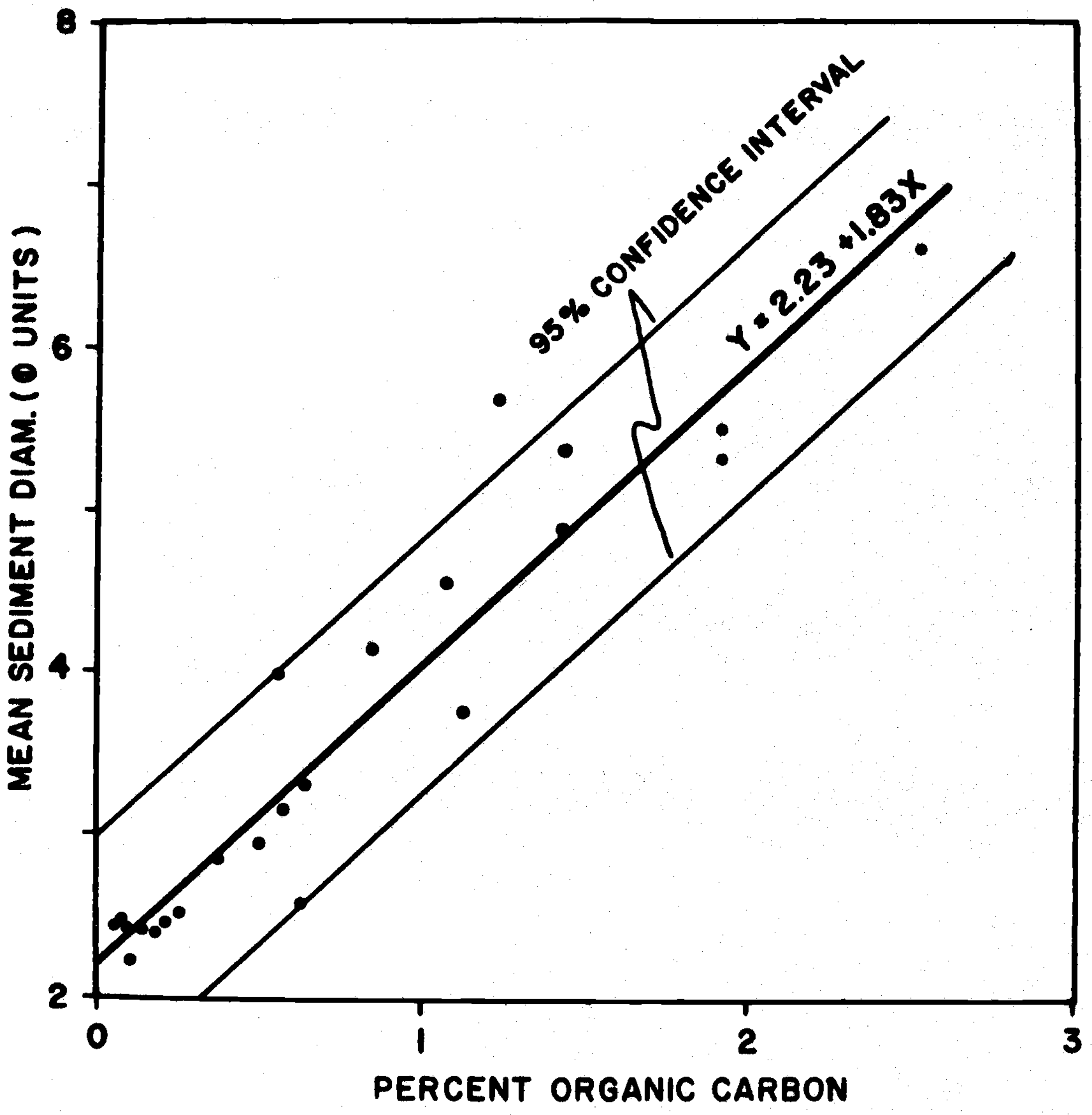

Figure 7. Mean sediment diameter versus the percentage of included organic carbon

to those of the mud flats, registered a pH of 6.6. Stevenson and Emery (1959, p. 28) reported pH values averaging 6.7 from exposed mud flats in Newport Bay, California.

Calcium carbonate starts to dissolve at pH values below 7.8 at 25°C (Krumbein and Garrels, 1952). Since all measured values in the marsh fall well below this value it seems reasonable to assume that organic remains of calcium carbonate have little chance of survival. Partially dissolved calcareous foraminiferal tests in samples originating from the Netarts Bay mud flats also indicate that solution is active in these areas.

FORAMINIFERAL BIOFACIES TRENDS

Species Composition

Introduction

Samples from 73 stations in and near Netarts Bay were examined for their live and dead foraminiferal populations. Fifty-one species were found and of these 49 were identified to the specific level (Tables 3 and 4). Fourteen of the 51 species constitute less than two percent of the total fauna in all samples in which they were found. All species occurring in these samples were tabulated by their preferred name in Appendix E along with their original designation and reference.

It has been demonstrated by previous environmental studies that groups of species which normally live together can be used as units to define biological environments (Bandy and Arnal, 1960; Phleger, 1960). Distributions of single species often fluctuate greatly due to microenvironmental variations (Parker and Athearn, 1959). These fluctuations are to a large extent masked by the averaging effect of the faunal units and therefore the generalized trends are more clearly shown.

Foraminifera from Netarts Bay have been grouped into four

TABLE 3 PERCENTAGE ABUNDANCE OF LIVE BENTHIC SPECIES

SPECIES	1G	2G	3	4	5	6	7G	8G	9	10	11	12	13G	14	15	16	17	18G	19	20	21	22	23G	24	25	26#	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73
AMMOBACULITES EXIGUUS / REOPHAX NANUS																	17									5	17	X	X	4					X	5			6	16	6	X	3		7		22			17	18	3	15	1	7	6	12	7	12		X				X								
AMMONIA cf. A. BECCARII TEPIDA													12	9			33		10		X			65	93	45	60		3	27				40	56	58	56	33	6	26	80	30	26	60	56	78	17		87	50	2	33	29	7																			
AMMOTIUM SALSUM															18										1		6														X					15			2	33	73	39	38	33	7	4	11	6	2		X												
BUCCELLA BLANCOENSIS / BUCCELLA TENERRIMA													6									14												20																																							
BUCCELLA FRIGIDA DEPRESSA																					12	14				3		12	10	31		82	4				22		3				13	2																													
BULIMINELLA ELEGANTISSIMA									10				12				17		2		1	29				X				8	17	5	15			2																																					
CIBICIDES FLETCHERI									2																																																																
CIBICIDES LOBATUS																			2																																																						
DISCORBIS COLUMBIENSIS																																	4																																								
EGGERELLA ADVENA									10																											2			3	5					6																												
ELPHIDIELLA HANNAI		100							2		50		6																		33			20									5																														
ELPHIDIUM INCERTUM INCERTUM						100		100	6				18	30	9	9			21		86		67	12	1	27		86	85	15	17	14	26		24	28	11	33	12		2	45	17	27	6	4	9		5		X	6		9	9		1		59	9													
ELPHIDIUM MAGELLANICUM			100						41		50	100	30	4			17		15			14				10				12			44		X				53	21	1		11				9										2																
ELPHIDIUM MICROGRANULOSUM / ELPHIDIUM SUBARCTICUM									3																										X				3																																		
ELPHIDIUM TRANSLUCENS																										5																																															
EPONIDES COLUMBIENSIS																		100																																																							
HAPLOPHRAGMOIDES HANCOCKI									2																																															X		1			X			1			6						
MILIAMMINA FRIGIDA / MILIAMMINA FUSCA														57	73	91			8		X	14		22	5	4	11						7	20	17	3		33		31	10	24	17	11	19	1	40		3		7	18	17	49	76	60	72	86	27	89	12		6	18	10	1	10	100	100				
NONIONELLA AURICULA																						14																																																			
PATEORIS HAUERINOIDES									10				12																																																											
PATEORIS SUBORBICULARIS																			2																X	2													3																								
QUINQUELOCULINA AKNERIANA BELLATULA																	17		,40								3	1	2	4					2	2	11		12			X	8			1																											
QUINQUELOCULINA LAMARCKIANA																							33																																																		
SPIROPLECTAMMINA BIFORMIS																																									X																																
TEXTULARIA EARLANDI									6												8					X									X						1	X			6																												
TROCHAMMINA CHARLOTTENSIS / TROCHAMMINA SQUAMIFORMIS													6														3				33																1								2																		
TROCHAMMINA INFLATA INFLATA																																																					1			30		X			2		2	59	8								
TROCHAMMINA INFLATA MACRESCENS									8																																												1			X				3	85		92	22	82	99	84						
TOTAL LIVE POPULATION	0	2	2	0	0	1	0	1	63	0	2	1	17	23	11	34	6	1	48	0	907	7	3	40	83	153	35	154	305	26	6	22	27	5	562	64	9	6	32	19	188	313	76	55	68	73	97	0	62	12	492	33	386	69	46	367	88	734	64	79	1340	0	2512	172	2050	1634	390	12	12	0	0	0	0
NUMBER OF SPECIES	0	1	1	0	0	1	0	1	12	0	2	1	8	4	3	2	5	1	7	0	6	6	2	3	4	9	6	4	5	7	4	3	6	4	9	8	4	3	8	5	8	6	8	4	6	5	6	0	5	3	5	5	6	5	5	6	5	5	4	3	6	0	3	4	4	2	3	1	1	0	0	0	0
SPECIMENS/CM²	*	*	*	*	*	*	*	*	6.8	*	*	*	.7	2.3	1.1	3.4	.6	*	4.8	*	91	3.5	.1	4.0	8.3		3.5	15	30	2.6	.2	2.2	2.7	.5	56	6.4	.9	.6	3.2	1.9	19	31	7.6	5.5	6.8	7.3	9.8	*	6.2	1.2	49	3.3	39	6.9	4.6	37	8.8	73	6.4	7.9	134	*	251	17	26	163	39	1.2	1.2	*	*	*	*

G=GRAB SAMPLE
X=<1%
*=<.1
#=EEL GRASS SAMPLE

TABLE 4 PERCENTAGE ABUNDANCE OF DEAD BENTHIC SPECIES

STATION NUMBERS

SPECIES	1G	2G	3	4	5	6	7G	8G	9	10	11	12	13G	14	15	16	17	18G	19	20	21	22	23G	24	25	26#	27	28	29	30	31	32	33	34	35	36	37	38	39	40
AMMOBACULITES EXIGUUS / REOPHAX NANUS							14		X		6		2	5		1	40		5		1	X		16	47	29	42	14	5	26		9			11	24	15	8	7	26
AMMONIA cf. A. BECCARII TEPIDA									1				4	10			3		12		2	3	3	7	7	7	9		8	8	6	2	11	7	45	24	11	8	3	5
AMMOTIUM cf. A. PLANISSIMA														4																					X	2				
AMMOTIUM SALSUM															3									3	1		2			2					1	7	X			
BOLIVINA ADVENA														1																										
BUCCELLA BLANCOENSIS / BUCCELLA TENERRIMA	11	34	20	17	11		14	8		33		11	5					12	3			12	20	1				3	X			1	2	7			X	8	1	
BUCCELLA FRIGIDA DEPRESSA									X				10				3	12	6		5	12	8			2		9	8	8	6	16	27				13		15	2
BULIMINELLA CURTA																														2										
BULIMINELLA ELEGANTISSIMA									29		13		5				1		7		5	3			X	2	2	5	3			8	13				X	8	6	10
CASSIDELLA SP.																											X													
CIBICIDES FLETCHERI		8																				7																	X	
CIBICIDES LOBATUS	5		20	17					X		6		3				1		2			2	5					5					2					8	2	
DISCORBIS COLUMBIENSIS								8	X		6		3									X															X		1	
DISCORBIS ORNATISSIMUS					22	10		8																																
EGGERELLA ADVENA						10			9		6		7	1	2	1	6		6		X	X		5	3	4	8	5	2	18		10	5	7	X	8	12		7	23
ELPHIDIELLA HANNAI	84	50	60	66	34	60	44	76		67	25	45	21					35		100		19	28					2	X	2	28	X		40			X	15	X	
ELPHIDIUM EXCAVATUM																													X											
ELPHIDIUM INCERTUM INCERTUM					11	10	14		13			22	27	3	X		17	18	32		84	26	26	5	X	22	2	52	65	14	39	38	13	33	13	7	14	8	27	X
ELPHIDIUM MAGELLANICUM									30		25		6	5			7		13		X	5		5	X	9	X		4	6			21			2	5		15	3
ELPHIDIUM MICROGRANULOSUM / ELPHIDIUM SUBARCTICUM					11				2		6		2				3		2		2					1		3		2	11	X	2		X		X	8	3	X
ELPHIDIUM TRANSLUCENS																										1													X	
EPONIDES COLUMBIENSIS		8				10												12																						
HAPLOPHRAGMOIDES COLUMBIENSIS EVOLUTUS					11				X										X																					
HAPLOPHRAGMOIDES HANCOCKI									X						4	5									3	2	3													X
LAGENA ACUTICOSTA APIOPLEURA													1																											
LAGENA LAEVIS									X																															
MILIAMMINA FRIGIDA / MILIAMMINA FUSCA									1		6	22	1	57	37	40	1	6	6		X	6	8	44	32	4	20		3	8	11	5	5	7	24	20	2	25	X	7
NONIONELLA AURICULA									1										X									2												
NONIONELLA STELLA									2																														X	
OOLINA MELO									X										X																				X	
PATEORIS HAUERINOIDES									X				2																											
PATEORIS SUBORBICULARIS									X																															
QUINQUELOCULINA AKNERIANA BELLATULA									2										4							X	X		X	2					1				2	
QUINQUELOCULINA LAMARCKIANA									X																															
SPIROPLECTAMMINA BIFORMIS									X																												X		X	X
TEXTULARIA EARLANDI									1					6		X			X								X								1	3	2			X
TROCHAMMINA CHARLOTTENSIS / TROCHAMMINA SQUAMIFORMIS							14		3					1			1	6	1		X		3			9	4	2	X			5			X	3	16		4	18
TROCHAMMINA INFLATA INFLATA									X				1	3	26	27	10					2		12	3	5	4					X							2	X
TROCHAMMINA INFLATA MACRESCENS									X					4	27	25	7		X						3	1	2					2			X		4		X	X
TROCHAMMINA KELLETTAE																																								
UVIGERINA PEREGRINA																			X														2							
TOTAL DEAD POPULATION	19	12	5	6	9	10	7	12	1135	3	16	9	100	79	161	357	72	17	193	3	1011	123	39	73	193	175	201	64	234	49	18	248	63	15	336	59	107	12	291	117
NUMBER OF SPECIES	3	4	3	3	6	5	5	4	26	2	9	4	15	12	7	7	13	7	19	1	10	14	8	9	11	15	15	11	13	12	6	13	11	6	12	10	17	9	22	15
SPECIMENS/CM³	.2	*	.1	.1	.1	.2	*	.1	113	.3	.3	.2	1.0	7.9	16	36	7.2	.2	19	*	101	6.1	.6	2.2	19		20	6.4	23	4.9	.5	25	6.3	1.5	23	5.9	11	1.2	29	12

SPECIES	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73
AMMOBACULITES EXIGUUS / REOPHAX NANUS	36	8	32	23	64	53	48		55	42	48	30	16	5	X	13	9	21	5	4	4			2	X			2	27				
AMMONIA cf. A. BECCARII TEPIDA	28	41	15	27	2	11	14		8	6		2	1	1	1																		
AMMOTIUM cf. A. PLANISSIMA	X		4		1		X																										
AMMOTIUM SALSUM	X	X			X	10	2		4	8	39	9	22	14	1	7	4	12	4	X	X			X	X			2	1				
BOLIVINA ADVENA																																	
BUCCELLA BLANCOENSIS / BUCCELLA TENERRIMA																																	12
BUCCELLA FRIGIDA DEPRESSA			2	X																													
BULIMINELLA CURTA																																	
BULIMINELLA ELEGANTISSIMA	X			X			X									X																	
CASSIDELLA SP.																																	
CIBICIDES FLETCHERI																																	12
CIBICIDES LOBATUS									X																								
DISCORBIS COLUMBIENSIS							X																										
DISCORBIS ORNATISSIMUS																																	
EGGERELLA ADVENA	3		7		10		3		X	X		X			X			X															
ELPHIDIELLA HANNAI			X				X																										37
ELPHIDIUM EXCAVATUM																																	
ELPHIDIUM INCERTUM INCERTUM	3	6	4	13	X		4	100	X	X		X		3	X				X	X													12
ELPHIDIUM MAGELLANICUM	X		X	X	X		X		X					X														X					12
ELPHIDIUM MICROGRANULOSUM / ELPHIDIUM SUBARCTICUM																																	
ELPHIDIUM TRANSLUCENS																																	
EPONIDES COLUMBIENSIS																																	
HAPLOPHRAGMOIDES COLUMBIENSIS EVOLUTUS																																	
HAPLOPHRAGMOIDES HANCOCKI	X					X				X	X	X	3	3	5	2	X	X	X	X	X			X	X		3	18	7	42			
LAGENA ACUTICOSTA APIOPLEURA																																	
LAGENA LAEVIS																																	
MILIAMMINA FRIGIDA / MILIAMMINA FUSCA	24	44	23	35	12	23	21		26	37	9	46	38	58	52	67	80	58	89	94	36	31	10	44	37	4	7	11	30		100		
NONIONELLA AURICULA																																	
NONIONELLA STELLA																																	
OOLINA MELO																																	
PATEORIS HAUERINOIDES																																	
PATEORIS SUBORBICULARIS									X																								
QUINQUELOCULINA AKNERIANA BELLATULA	X	X	1																														
QUINQUELOCULINA LAMARCKIANA																																	
SPIROPLECTAMMINA BIFORMIS					X				X																								
TEXTULARIA EARLANDI	2	X	6	X	5		5		4	3		X		X	1		X	X					X										
TROCHAMMINA CHARLOTTENSIS / TROCHAMMINA SQUAMIFORMIS	2		4		2		3		X	1		X		X			X																
TROCHAMMINA INFLATA INFLATA	X		X		X	X	X		1	1	2	5	9	12	10	9	4	4	X		1	8	X	31	6			25	X	4			12
TROCHAMMINA INFLATA MACRESCENS	X		X	X	X	X			1	1	2	4	11	3	27	2	1	2	X	1	59	61	89	22	56	96	90	40	33	54			
TROCHAMMINA KELLETTAE					X				X																								
UVIGERINA PEREGRINA																																	
TOTAL DEAD POPULATION	600	466	708	287	1172	337	463	1	1548	712	863	210	3544	404	146	697	468	2610	1007	2222	2929	13	2598	439	2801	5093	386	412	240	26	1	0	8
NUMBER OF SPECIES	15	7	14	9	14	7	14	2	15	11	6	11	7	11	10	7	8	8	7	6	6	3	4	6	6	2	3	7	6	3	1	0	6
SPECIMENS/CM³	60	47	25	29	34	34	46	*	137	71	86	21	354	40	15	41	47	261	101	222	293	1.3	260	44	280	509	39	41	24	2.6	.1	*	.2

G=GRAB SAMPLE
X=<1%
*=<.1
#=EEL GRASS SAMPLE

environmentally related faunas named for the dominant[3] or distinctive genus present in each (Table 5). The grouping of the faunas was established by aligning stations according to sediment size and subjectively noting which species are associated. Most species fall into natural groups but several have wide ranges with considerable overlap. The distribution of the faunas coincides in a general way with the major sediment environments of the bay.

Elphidiella Fauna

Elphidiella hannai makes up 70 percent of the live and 68 percent of the dead *Elphidiella* Fauna in the channel environment. In Netarts Bay this species is confined largely to the tidal channel. Off the Oregon Coast, Lankford (1962) has shown that it forms up to 33 percent of the total foraminiferal fauna in the near-shore, sandy, turbulent zone (0 to 15 meters). Detling (1958) reported it as a common tide pool species; Cooper (1961) confirmed Detling's report and found it to be common also in beach sands.

Buccella blancoensis and *B. tenerrima* form 20 percent of the live and 18 percent of the dead *Elphidiella* Fauna in the environment of the channel. Like *Elphidiella hannai*, they are largely confined to the bay's tidal channel. *Buccella tenerrima* occurs in Oregon's near-shore turbulent zone; however, *B. blancoensis* has not been reported from this zone.

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[3]Dominant is here defined to mean greater than 50 percent of the foraminiferal population.

TABLE 5 Foraminiferal biofacies faunas

Elphidiella Fauna - Beach and channel	
Buccella blancoensis	*Discorbis columbiensis*
Buccella tenerrima	*Discorbis ornatissima*
Cibicides fletcheri	*Elphidiella hannai*
Cibicides lobatus	*Eponides columbiensis*
Elphidium Fauna - Central bay sand flats	
Buccella frigida depressa	*Nonionella auricula*
Buliminella elegantissima	*Nonionella stella*
Elphidium incertum incertum	*Quinqueloculina akneriana bellatula*
Elphidium magellanicum	*Trochammina charlottensis*
Elphidium subarcticum	*Trochammina squamiformis*
Ammonia Fauna - Inner bay and central bay mud flats	
Ammobaculites exiguus	*Reophax nanus*
Ammonia cf. *A. beccarii tepida*	*Spiroplectammina biformis*
Ammotium salsum	*Textularia earlandi*
Eggerella advena	
Miliammina Fauna - Salt marsh	
Haplophragmoides hancocki	*Trochammina inflata inflata*
Miliammina frigida	*Trochammina inflata macrescens*
Miliammina fusca	

Most of the Elphidiella Fauna have been reported from the turbulent zone or beaches of the Oregon Coast (Cooper, 1961; Lankford, 1962) and from deeper areas of Oregon's Sublittoral Zone (Enbysk, 1960; Jarman, 1962). Except for Cibicides fletcheri and Buccella blancoensis all species are abundant in the near-shore area. Buccella blancoensis has probably been included with Buccella tenerrima by other authors.

In the area studied, the Elphidiella Fauna is confined largely to the open-ocean beaches and the tidal channel of Netarts Bay. The average live to dead ratio for the Elphidiella Fauna for all channel stations is .06 compared to .25 for all other foraminiferal species. As a consequence of this difference of ratios, the live Elphidiella Faunal population is subordinate to the live Elphidium Fauna in the channel environment while the dead Elphidiella Fauna is the dominant group in most of the lower channel (compare figures 8 and 9, and 10A and 10B).

The dead Elphidiella Fauna tends to decrease in population percentage as the head of the channel is approached (figure 10B). Possibly this is a reflection of an increasingly unfavorable environment for the fauna. Another possible explanation is that the foraminiferal fauna in the channel in part is not indigenous to the environment but represents fauna displaced from the adjoining environments. The Elphidium Fauna is more plentiful toward the head of

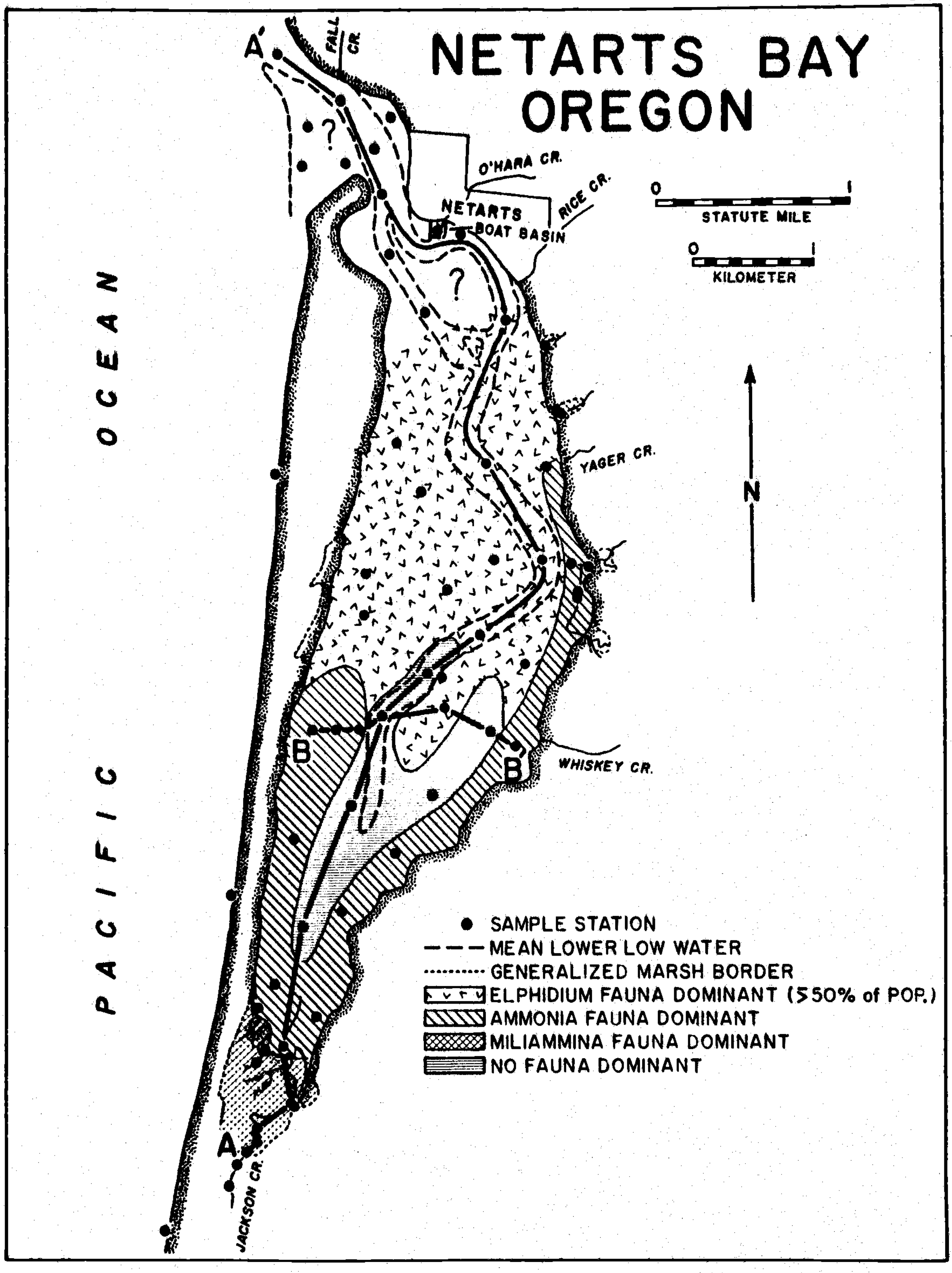

Figure 8. Areal distribution of the live foraminiferal population grouped by species into faunas.

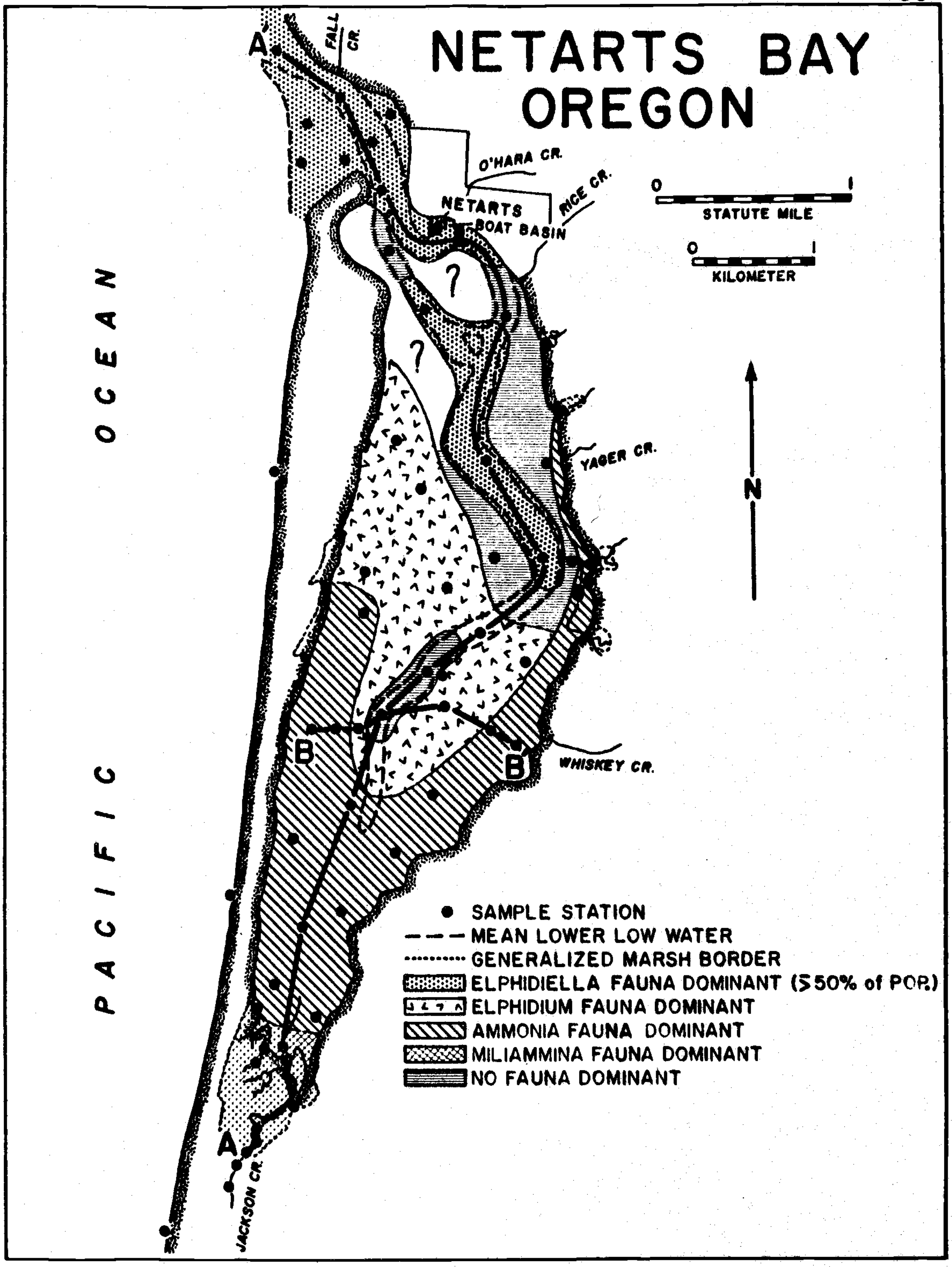

Figure 9. Areal distribution of the dead foraminiferal population grouped by species into faunas.

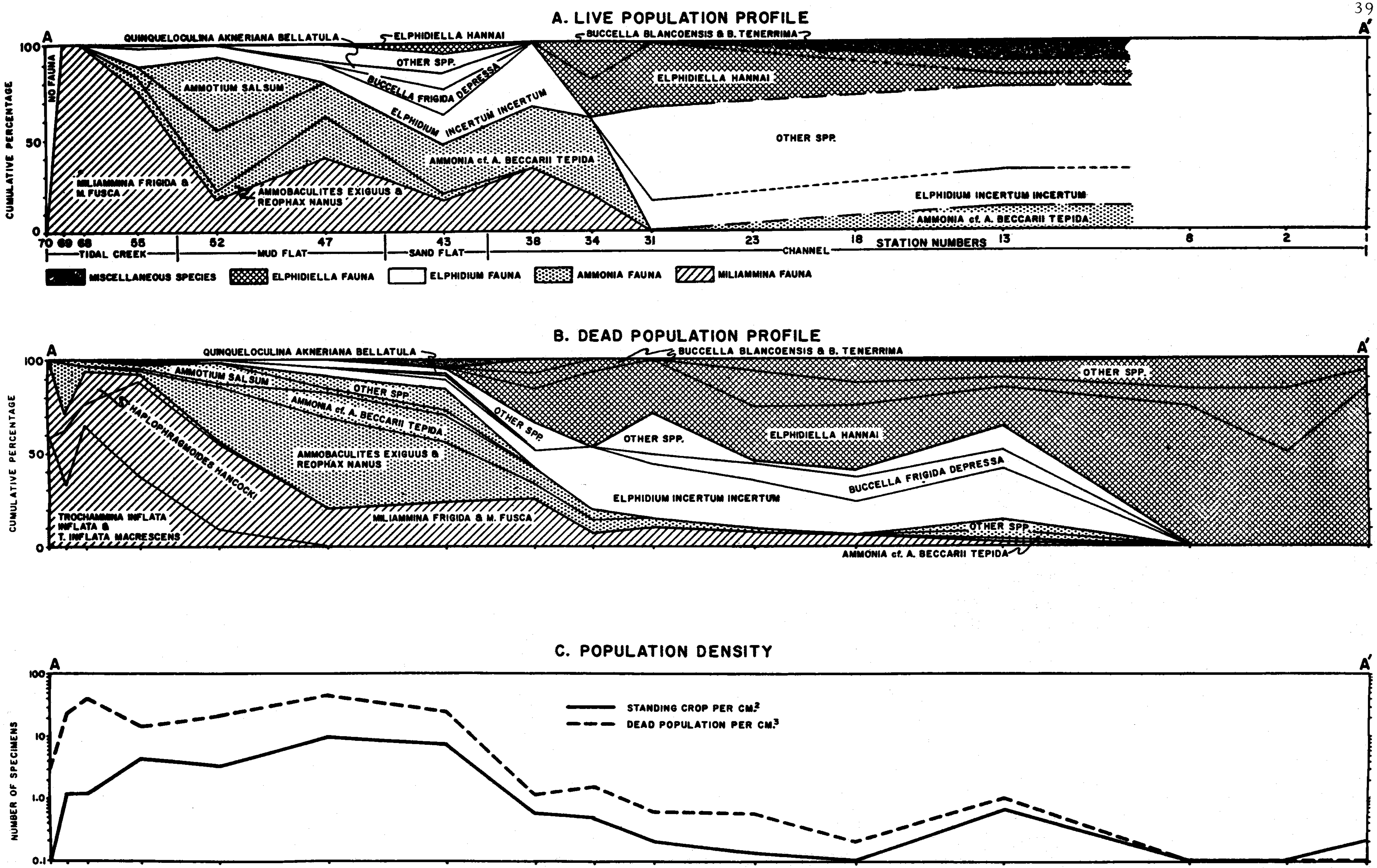

Figure 10. A and B are composite frequency diagrams showing species and faunal distributions of live and dead foraminiferal populations in a north-south profile. C shows variation in population density along the profile (Note semilog scale). Samples with less than ten dead or five live specimens were not plotted on the profile.

the channel where it possibly had been displaced from the surrounding tidal flats and the *Elphidiella* Fauna possibly is swept into the channel from the near-shore turbulent zone. With this in mind the *Elphidiella* Fauna's low live to dead ratio may be due to high mortality caused by transportation up the channel. However, it may also be due to the durable nature of the tests which would tend to increase the dead population with respect to the living population. The dead *Elphidiella* fauna also shows a pronounced tendency to be confined to the channel environment. Along a transverse profile (figure 9) the fauna ranges from 33 percent of the total dead fauna to one percent in a distance of approximately 200 meters on either side of the channel (figure 11B). Since the live *Elphidiella* Fauna is represented by very few specimens per sample, little significance has been attached to their trends in the channel.

Elphidium Fauna

The *Elphidium* Fauna is composed of calcareous species with the exception of *Trochammina chalottensis* and *T. squamiformis*. *Elphidium incertum incertum* is the most abundant and widespread species; it averages approximately 52 percent of the living and dead *Elphidium* Fauna on the central bay sand flats where the fauna is most abundant. The species is present in varying percentages in all parts of the bay except the high marsh (figures 10, 11; see also

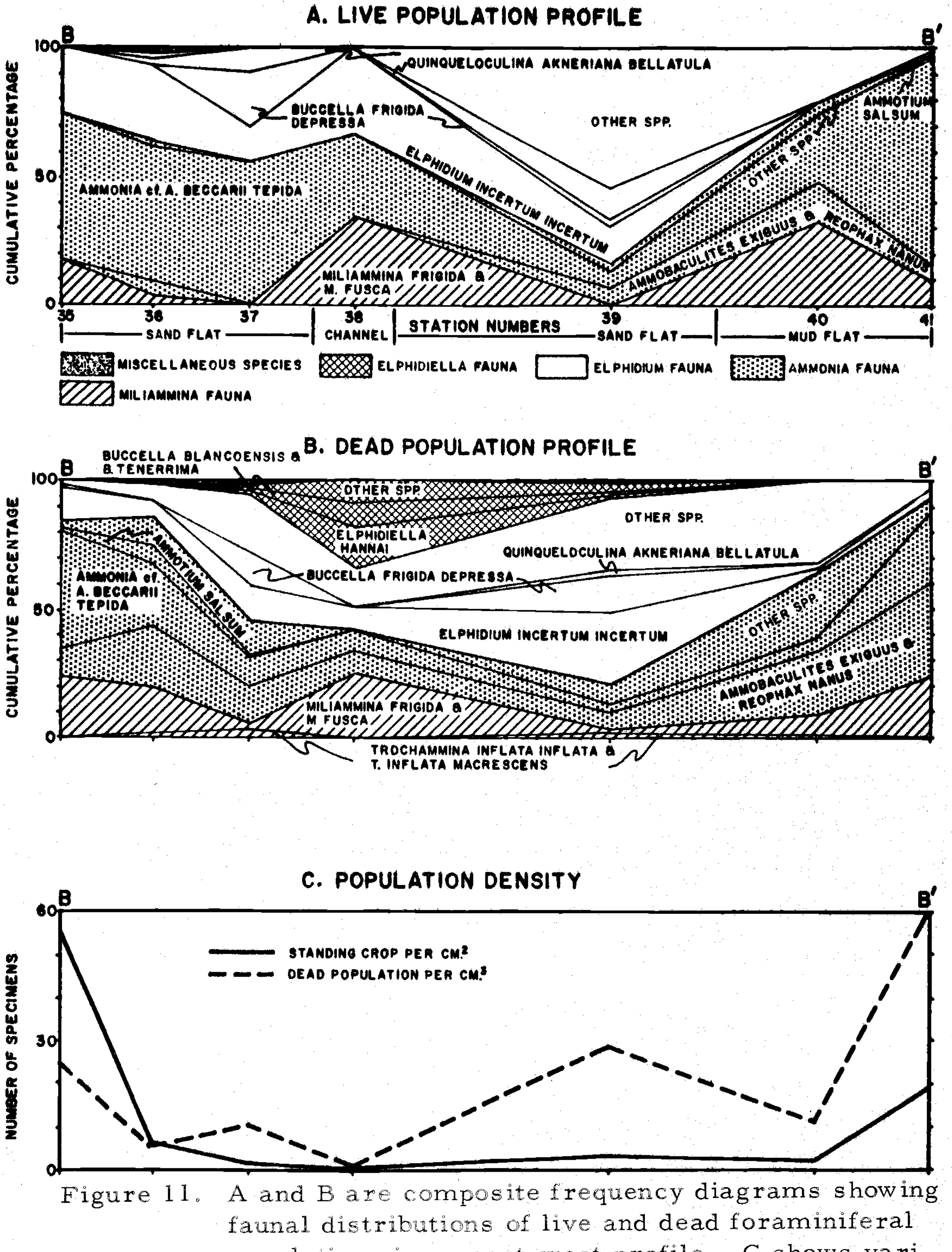

Figure 11. A and B are composite frequency diagrams showing faunal distributions of live and dead foraminiferal populations in an east-west profile. C shows variation in population density along the profile.

figure 13). Maloney (n. d.) found it in Yaquina Bay, Oregon. Both Detling (1958) and Jarman (1962) reported the species in the Oregon littoral and sublittoral zones respectively. Lankford (1962) reports an Elphidium cf. E. clavatum, that appears to be the same species, throughout the upper sublittoral zone (0-50 meters).

Buccella frigida depressa constitutes approximately 12 percent of the live and 17 percent of the dead Elphidium Fauna on the central bay sand flats. This species is largely confined to the clean sand of these tidal flats (figures 10 and 11). Occasionally it is found in the tidal channel where it possibly has been displaced from the surrounding tidal flats. Assuming that what other researchers have called Buccella frigida is the same species as Buccella frigida depressa, the reported occurrence of this species along the Oregon Coast is somewhat conflicting. Maloney (n. d.) found it in Yaquina Bay. Rooth (1965) reported it as common in Oregon tide pools and beaches but Detling (1958) and Cooper (1961) both failed to report it from their beach and tide pool investigations. Boettcher (1965, personal communication) found it throughout the sublittoral zone but Jarman (1962) reported it always deeper than 100 meters and Lankford (1962) sampling the Oregon sublittoral zone out to 120 feet (37 meters) failed to find it.

Quinqueloculina akneriana bellatula is the only porcelaneous species of any significance in Netarts Bay. It forms about five percent of the living and two percent of the dead Elphidium Fauna on the central bay sand flats. The species is most numerous on the sandy tidal flats but living juvenile specimens are occasionally found in muddy surroundings. Along the Oregon Coast it has been reported from beaches and tide pools by Cooper (1961) and to depths of 25 meters by Lankford (1962).

The Elphidium Fauna is dominant on the central bay and flats (figures 8 and 9) where it forms an average of approximately 70 percent of both the living and dead foraminiferal population. In all other areas of Netarts Bay the Elphidium Fauna forms a progressively decreasing percent of the population until near the head and east shore of the bay where it averages approximately five percent of the live population. It is present, however, in all parts of the bay except the high marsh (figure 10, 11 and 13). All members of the Elphidium Fauna except Elphidium magellanicum have been reported from off the Oregon Coast (Enbysk, 1960; Cooper, 1961; Jarman, 1962; Lankford, 1962).

Ammonia Fauna

The Ammonia Fauna is composed of six agglutinated and one calcareous species. However, the calcareous species, Ammonia cf. A. beccarii tepida forms approximately 73 percent of the living fauna on the inner bay tidal flats. High individual living populations of this species are associated with muddy to muddy-sand environments located at the sides and head of the bay (figures 10A and 11A). In the central bay area and the marsh creeks it forms a much smaller part of the foraminiferal fauna. On the tidal flats of the inner bay *Ammonia* cf. *A. beccarii tepida* comprises only approximately 25 percent of the dead *Ammonia* Fauna in comparison to 73 percent of the living fauna (compare figures 10A and 10B). Partially dissolved calcareous tests common in much of the inner bay area indicate that dissolution is probably the agent responsible for this difference. Wide salinity and temperature tolerances (Bradshaw 1957, 1961) make *Ammonia* cf. *A. beccarii tepida* well adapted to subaerial exposure and the resultant temperature and salinity variations associated with shallow lagoonal environments. Along the Pacific Coast this species has been reported as far north as Gray's Harbor, Washington by Andrews (1965) who reported it as *Ammonia beccarii*. Bandy and Arnal (1957) have reported it, under the name of *Streblus tepidus* as far south as the west coast of Panama where it occurs in the upper sublittoral zone. Further sampling to the south of Panama would probably extend its range. It has not been reported from Oregon's sublittoral zone. Undoubtedly this is because Oregon's sublittoral water is always well below the lower temperature value demonstrated by Bradshaw (1961) to be necessary for the species to reproduce itself.

Ammobaculites exiguus and Reophax nanus form approximately ten percent of the live Ammonia Fauna on the inner bay tidal flats. Of the two species Ammobaculites exiguus is by far the more important. Ammobaculites exiguus and Reophax nanus are approximately five times more abundant in the dead than live fauna. This is probably due to the immunity of their agglutinated tests to solution. In addition, there is a tendency for the long, uniserial portion of the test to break into several parts which then might be counted as separate individuals. An inspection of species collected by Maloney (n. d.) indicated that his Ammobaculites sp., common in the upper reaches of Yaquina Bay, is identical to Ammobaculites exiguus. Reophax nanus is reported in small numbers off the Oregon Coast by Lankford (1962) and Boettcher (1965, personal communication).

Ammotium salsum averages approximately 12 percent of the Ammonia Fauna over the inner bay. In most of this area it forms only two to six percent of the Ammonia Fauna. However, in a rather narrow belt of tidal flats bordering the salt marsh at the southern end of the bay it forms approximately 40 percent of the living Ammonia Fauna and at station 51 it forms 89 percent. This narrow belt is composed of muddy sand to soft mud and is subaerially exposed more than half of the tidal cycle. A comparison of the populations of seasonally collected samples obtained from the bottoms of two marsh creeks in the same area (see figure 21, stations 53 and 55) shows that Ammotium salsum forms the largest part of station 53's population while being nearly absent from the population of station 55. These two marsh creeks are similar to each other with the exception that the marsh creek in which station 55 is located has a source of fresh water which can be expected at low tide to replace most of the brackish bay water in the creek. Apparently the periodic influence of low salinity water adversely effects Ammotium salsum by altering some necessary element of its environment. To the author's knowledge this species has not been reported elsewhere on the Pacific Coast.

The Ammonia Fauna is present in the central and upper bay areas and in the low marshes. It, however, is the dominant fauna only in a roughly "V"-shaped area with its vertex at the head of the bay and its arms extended along the sides of the bay (figure 8). The live Ammonia Fauna dominates only 80 percent of the area dominated by the dead fauna (compare figures 8 and 9). Of the Ammonia Fauna, Eggerella advena, Reophax nanus, Spiroplectammina biformis, and Textularia earlandi are reported also from off the Oregon Coast by Enbysk (1960), Jarman (1962), and Lankford (1962).

Miliammina Fauna

Miliammina fusca and M. frigida are the only species of the

Miliammina Fauna that occur in significant numbers outside of the salt marsh. On the mud flats they form approximately 15 percent of the live and 25 percent of the dead populations (figure 10A and 10B). In the marsh area studied (figure 12) these two species average approximately 68 percent of the live and 77 percent of the dead populations of the lower marsh (figure 13A and B). In the high marsh their population decreases to eight percent of the live population and 24 percent of the dead.

Miliamina fusca is quite tolerant of low-salinity water. Hedberg (1934) observed it living in water of 0.5 ‰ salinity. It, however, is not restricted to a low salinity environment as it is found to some extent throughout Netarts Bay and its empty tests have been reported in low numbers from off the Oregon Coast by Jarman (1962) and Boettcher (1965, personal communication).

Trochammina inflata inflata and T. inflata macrescens are especially characteristic of the high marsh where together they form 90 percent of the live and 75 percent of the dead populations (figure 13A and B). Both of these subspecies rapidly decrease in percent toward areas covered by normally high tides. Only small numbers are found on the tidal flats and the specimens are seldom living. Of the two, T. inflata macrescens is associated with the subaerial environment and T. inflata inflata with marsh pools (figures 13A and B). The association of these two subspecies in the

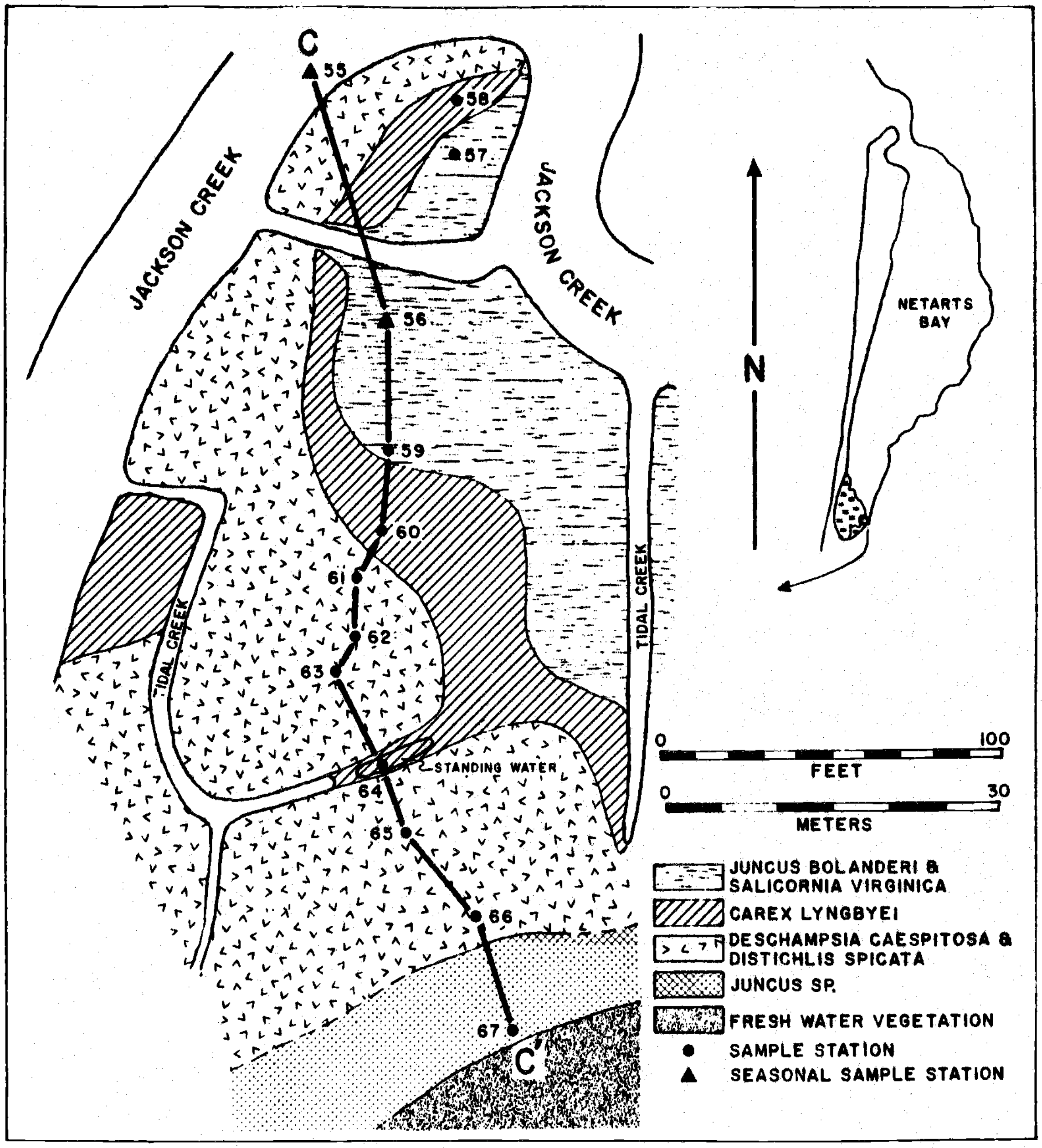

Figure 12. Index map showing marsh stations, vegetation types, and location of profile C.

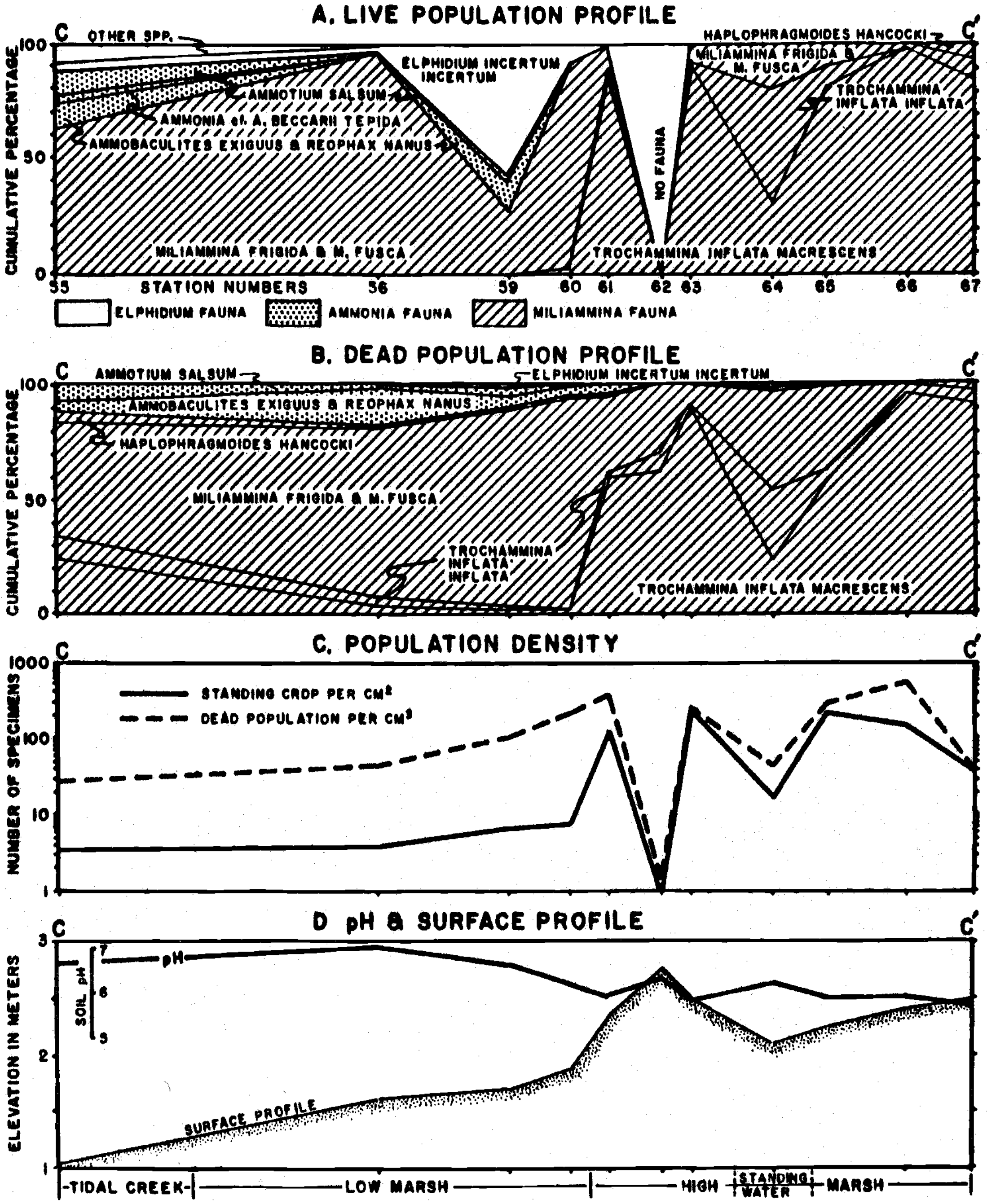

Figure 13. A and B are composite frequency diagrams showing faunal distributions of live and dead foraminiferal populations along the marsh profile shown in figure 12. C shows variation in population density along the profile (Note semi-log scale). D is a plot of pH values and surface elevations along profile C.

marsh separated by only minor differences of environment tends to confirm Brady's theory (1870) that T. inflata macrescens represents a form of T. inflata inflata growing under adverse conditions. On the other hand lack of gradational adult forms casts doubt on the above theory.

Haplophragmoides hancocki is only locally abundant in the marsh and marsh channels. Its percentage of the total population increases markedly as salinities approach those of freshwater both in the tidal creeks and the subaerial marsh environment. In the high marsh the species usually forms one percent or less of the population. However, as fresh water conditions are approached near the marsh border the species increases to six percent of the live population and three percent of the dead population (figures 13A and B). In the Jackson Creek tidal channel a similar but larger peak (42 percent) occurred in the dead population just before the foraminiferal population was replaced by the thecamoebian population (figure 10B). Parker and Athearn (1959) also observed the correlation between high frequencies of this species and low salinities in Poponesset Bay, Massachusetts.

The entirely agglutinated character of the Miliammina Fauna is probably in response to the characteristic low pH of the environment. However, low pH does not absolutely exclude calcareous foraminifera. This fact is demonstrated by the presence of Elphidium incertum incertum which forms up to 59 percent of the live population at station 59 in the low marsh despite a pH of 6.6 (figure 13A and D). A dead Elphidium incertum incertum population of less than one percent indicates that a low pH does destroy the empty calcareous tests (figure 13B).

The Miliammina Fauna can be divided into subfaunas. Miliammina frigida and M. fusca are characteristic of the low marsh. Between the low marsh and high marsh a rather sharp faunal break occurs (figure 13A and B). Trochammina inflata inflata macrescens, and Haplophragmoides hancocki make up the second subfauna. These species are largely confined to the high marsh where they form approximately 91 percent of the live population and 75 percent of the dead population. The environment inhabited by the second subgroup is seldom covered by the tides and the fauna apparently receives most of the moisture necessary from brackish water in the soil.

Foraminiferal faunas reported from other salt marshes bordering the Atlantic, Pacific, and Gulf Coasts are surprisingly similar to those inhabiting the same environments in Netarts Bay. Miliammina fusca and Trochammina inflata (-T. inflata inflata) have been reported from marshes bordering the Atlantic Ocean by Phleger and Walton (1950) and Parker and Athearn (1959); the Gulf Coast by Parker, Phleger, and Peirson (1953); and Pacific Ocean by Walton

(1955). Other species usually found in the salt marshes of these areas are Ammonia cf. A. beccarii tepida (=Rotalia beccarii Streblus tepidus, and Ammonia tepidus), Ammotium salsum (=Ammobaculites salsus), Ammobaculites exiguus, Elphidium incertum incertum (=E. incertum), and Trochammina inflata macrescens (=T. macrescens).

Species Diversity

Introduction

In problems dealing with recognition and differentiation of the various paralic environments, trends of species abundance are highly useful to the paleoecologist. A similar number of specimens should be counted in samples compared for species abundance (Bandy, 1954) since the larger the count the more likely it is to include rare species. Where possible, 300-400 specimens were counted in Netarts Bay samples. However, approximately half of the samples contained less than 300 specimens. Samples which contained considerably less than 300 specimens, such as those obtained from the tidal channel and ocean beaches, tend to exhibit abnormally low numbers of species.

Live Fauna

Species abundance trends are most reliably displayed by live foraminifera since, with the exception of the lower channel and ocean beaches, they can be assumed to have been in place at the collecting site. Foraminifera found alive in the lower channel and ocean beaches may, at least in part, be displaced from the adjacent tidal flats and open ocean turbulent zone. It is important that the fauna be in place since only one specimen of a species need be transported to the sample site for that species to be included in the count.

Aside from the 11 living species in the somewhat artificially created environment of the boat basin (station 9) the highest number of live species occurs along the sides of the central bay area (figure 14). Samples in this central bay area average approximately seven live species per sample with a maximum of nine at station 35. Toward the head of the bay the number of live species decreases to around five per station on the mud flats and four in the high marsh. The channel-beach environment averages only two live species per station.

By grouping the samples according to the sedimentary environment they fall into, it can be seen that a rough trend exists from low numbers of live species in the marsh to higher numbers in the sand flats (figure 15A). This trend almost certainly is a reflection of the

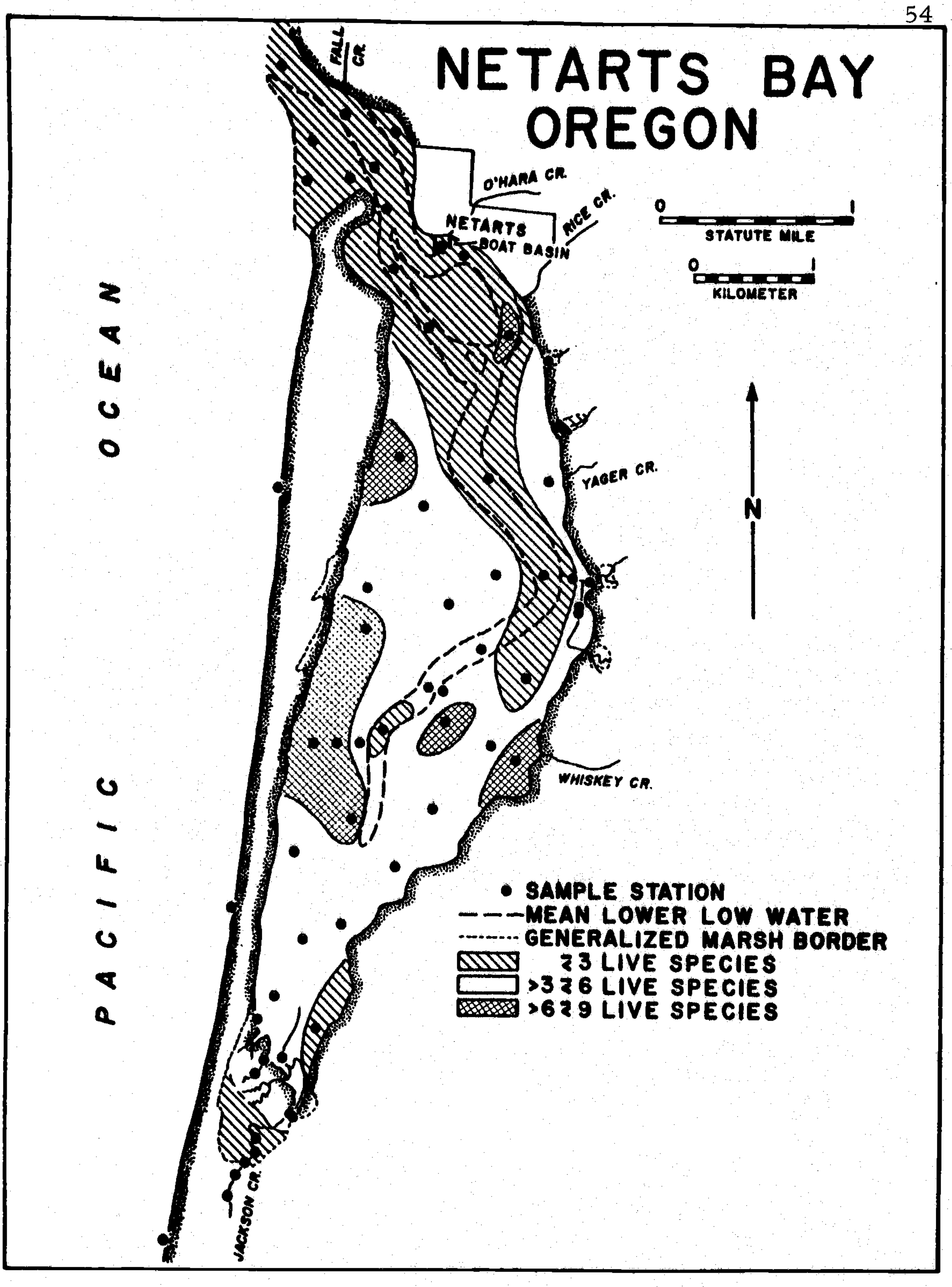

Figure 14. Areal distribution of the abundance of live foraminiferal species per sample.

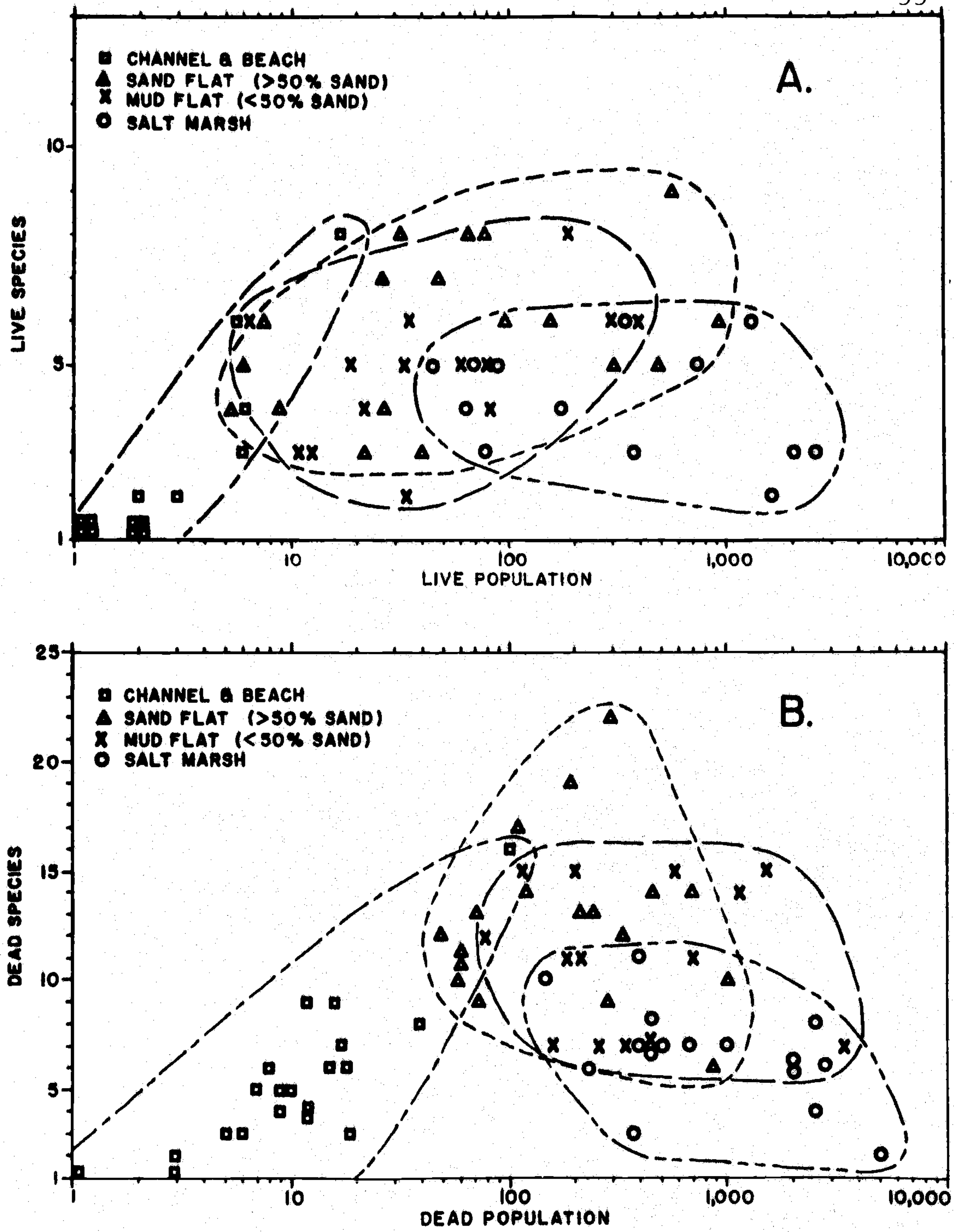

Figure 15. Sample populations grouped according to their sedimentary environments on a plot of species and population (Note semi-log scale).

more rigorous nature of the environments at the head of the bay and in the salt marshes. Low pH, long periods of subaerial exposure, and large ranges of salinity and temperature are all factors which limit the number of species which are able to establish themselves in the environments.

A similar trend exists from high numbers of species at the sides of the bay to low numbers in the channel and toward the mouth of the bay (figure 14). This trend is subject to question because of the low population density found in the channel-beach environment (figure 15A). However, summation of the number of living species observed in all samples in each of the four sedimentary environments gives values of 11, 18, 14 and 10 for the channel-beach, sand flat, mud flat, and marsh environments respectively. These figures attest to the validity of the trend.

Dead Fauna

Fossil faunas compare more closely to dead population trends than to those for only live species. Therefore, for paleoecologic work, dead species abundance is the preferred parameter. In most of Netarts Bay, trends in the abundance of dead species at each station are similar to those for the live species (see figures 15A and B).

The trend of higher numbers of species from the marsh to the central bay sand flats is consistent with what Bandy (1963) reported for similar environments in southern California and northwestern Mexico. However, the tendency for a decrease in species abundance as the channel or head of the bay is approached has not been reported elsewhere to the author's knowledge. The marshes of Netarts Bay are populated by fewer species than have been reported from other marshes. If all the marsh stations in Netarts Bay are considered, only eight species form one percent or more of the total population of any one station. A similar comparison shows that the marshes of Estero de Punta Banda, Baja California (Walton, 1955) San Antonio Bay, Texas (Parker, Phleger, and Peirson, 1953), and Barnstable Bay, Massachusetts (Phleger and Walton, 1950) are populated by 12, 11, and 11 species respectively.

Standing Crop

Foraminiferal standing crop is an expression of the number of individuals living in an area at any given time. For quantitative measurements, samples with undisturbed surfaces of known area are needed. In Netarts Bay most samples represent a relatively undisturbed 10 cm^2 area. However, at the seven stations sampled using the grab an undisturbed surface could not be obtained. Destruction of the sample surface and mixing of the sediment resulted from the closing and opening of the sampler's jaws. The standing crops for these samples were calculated using 23 cm^2 as the standard area sampled by the grab. This figure was determined empirically by sampling three stations with the corer and the grab simultaneously and comparing the living populations. The apparent area sampled by the grab varied from 8 cm^2 to 45 cm^2 and averaged 23 cm^2. In all but two of the seven grab samples the standing crop measured less than 0.1/cm^2. Stations 15 and 23 showed significant living populations. An average of seasonal samples from these stations gives standing crops of 0.5/cm^2 and 0.1/cm^2 respectively. These are quite close to the 0.7/cm^2 and 0.1/cm^2 values reported for July, 1964 and used for the standing crop map (figure 16).

The principal collection of 56 samples used for the standing crop distribution was obtained in July, 1964. One sample was collected in May, 1964 as part of a pilot study. Seven samples were collected in October, 1964 and nine in January, 1965 as the necessity for more control became apparent (Appendix A). Samples collected at different times and different seasons must be compared with care. Walton (1955) demonstrated that standing crops can vary 500 percent over a period of one year. High standing crops at stations 21, 28, 29, and 42 in the central part of Netarts Bay (Table 3) may be due to a large seasonal increase in the living population of Elphidium incertum incertum that occurred in October (see figure 21). Examination of figure 16 shows that the large area of high standing crop (>10/cm^2) in the central bay is defined by three of these October

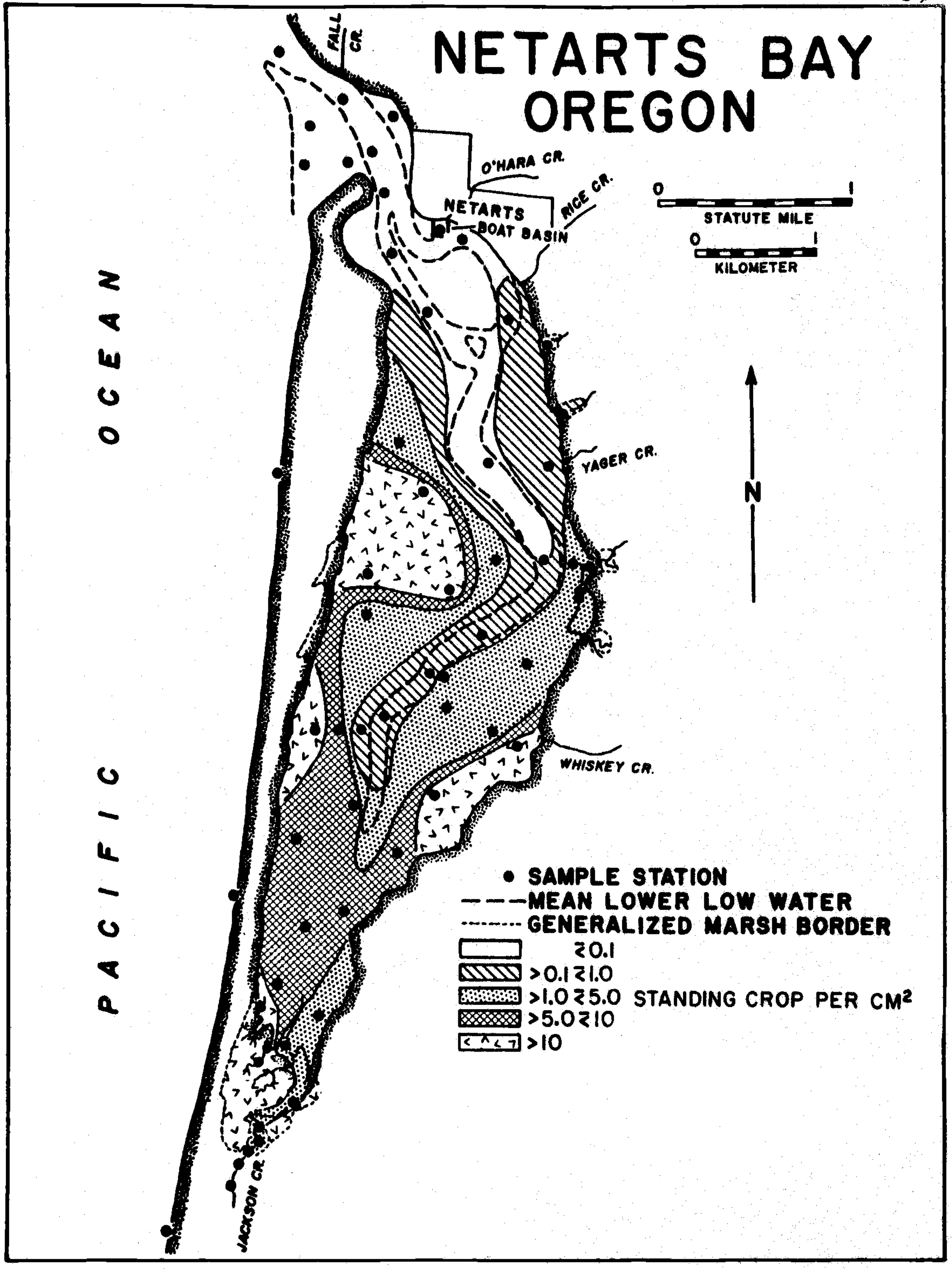

Figure 16. Areal distribution of foraminiferal standing crop.

samples (21, 28, and 29). In July it is possible that these stations supported a standing crop of between 1.0 and 5.0/cm^2 as displayed by the surrounding stations (19, 22, and 30). Conversely, in October, stations 19 and 22 may have supported a standing crop comparable to stations 21, 28, and 29. However, at that time a seasonal sample taken at station 30 displayed a standing crop of only 2.6 cm^2.

The beaches adjacent to Netarts Bay and the main channel display the lowest standing crop values. The values range from <0.1 cm^2 for the beaches and outer channel to 0.7 cm^2 in the inner channel. These low standing crops are probably due to the high energy and unstable substrate of the environment. In addition, large, diurnal temperature changes, evaporation, and water seepage on the beach also contribute to low values there. Standing crops in the tidal channel, with the exception of that at station 13, tend to increase with distance up the channel from the bay mouth. Assuming a reduction in intensity of the tidal currents away from the bay mouth, it can be said that as environmental energy decreases population density increases.

Seasonal samples collected at station 13 show consistently higher standing crop values than do adjoining channel stations which were sampled in July (figures 10C and 16). Standing crops varied from 1.0 to 0.1/cm^2 with an average value of 0.5/cm^2. Adjoining stations in the channel display values of less than 0.1/cm^2. The higher standing crop at station 13 may be due to a slackening of the tidal current in the channel at this point. However, the author has no confirming evidence.

Standing crops increase from values less than $1.0/cm^2$ in the channel to values often greater than $10/cm^2$ at the sides of the bay (figure 16). Highest standing crops in these areas are associated with stands of eel grass or blue-green algae usually found near the edges of the bay on the sand and mud flats. The vegetation provides a degree of protection from the currents and probably serves as a direct or indirect source of food for the foraminifera. Furthermore, the matted roots of eel grass act to stabilize the substrate (Ricketts and Calvin 1939, p. 247). The standing crops on the tidal flats of Netarts Bay range from 0.6 to $90/cm^2$ with an average value of approximately $8/cm^2$. In comparison, Phleger and Lankford (1957) obtained values of $19\text{-}35/cm^2$ for upper San Antonio Bay, Texas and $5.3\text{-}11/cm^2$ for the lower portion of the bay. In Todos Santos Bay, Baja California, Walton (1955) found an average standing crop of $3.7/cm^2$ for the area of the bay shallower than ten fathoms (18 meters). However, Lankford (1959) working in the shallow water off the Mississippi Delta reported rather high standing crops which ranged from 20 to $800/cm^2$ and averaged $250/cm^2$. The reasons for the high productivity in the area are not known. Several possible factors are the nutrients, trace elements, bacterial populations, and organic solids introduced into the area by the river effluent.

In Netarts Bay, the highest standing crops occur in the salt marshes. Values there average approximately $80/cm^2$ with a range of from zero at the highest elevation to $251/cm^2$ (figure 17). High foraminiferal populations in the marshes of Barnstable Bay, Massachusetts have been attributed by Phleger and Walton (1950) to an abundant food supply and protection supplied by matted and tangled vegetation. It is thought that these factors also contribute to the high standing crop of the marshes of Netarts Bay. In comparison to Netarts Bay other reported standing crop values from marshes are quite low. From Baja California Walton (1955) reported values ranging from 0 to $11/cm^2$ on the salt marshes of Estero de Punta Banda. Phleger and Ewing (1962) reported values that ranged from 0 to $7.5/cm^2$ from marshes of Laguna Ojo de Liebra, Baja California. Lankford (1959) reported a standing crop of $16/cm^2$ from a marsh station on the Mississippi Delta. Parker and Athearn reported standing crops that ranged from approximately 10 to $40/cm^2$ from the marshes of Poponesset Bay, Massachusetts. The much lower standing crop values reported from other marshes compared to Netarts Bay marsh values are probably due to the location of the other marshes in areas where climates are either more tropical or experience greater temperature extremes. In such climates marsh temperatures and salinities can be expected to vary through greater

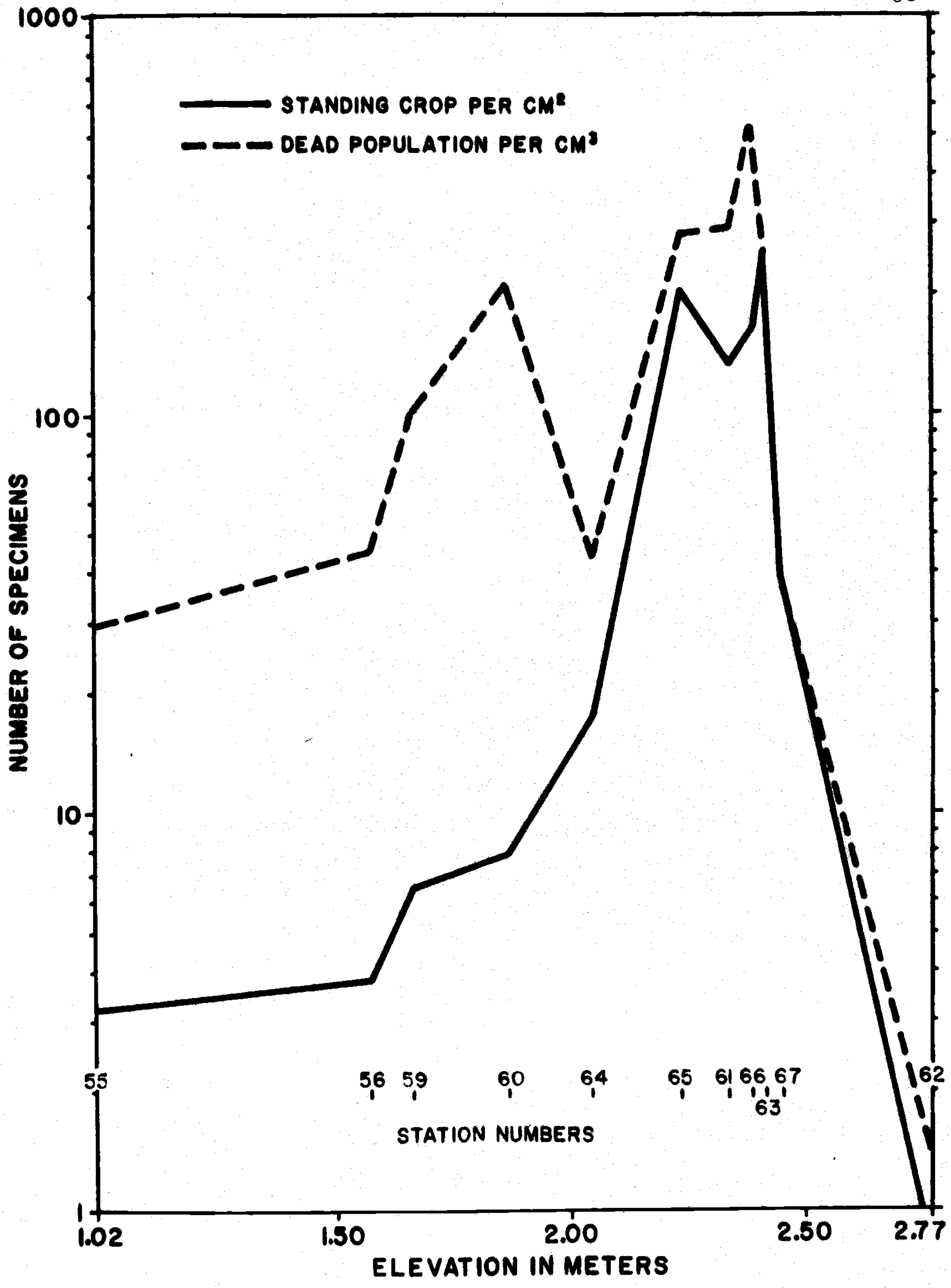

Figure 17. Live and dead marsh populations from stations along profile C plotted against their elevations above mean lower low water.

ranges, thus making the environment more difficult for foraminifera to adjust to.

Dead Population Density

Barring destruction after burial and during diagenesis the distribution of dead foraminifera in surface sediments is essentially what stratigraphers and paleoecologists find in fossil form. There are two methods in general use by which samples are compared quantitatively. One method compares samples by their dry weight and the other compares wet volume. The former method is preferred by paleoecologists and some modern ecologists who are not concerned with surface area. The latter is used for most modern ecological studies which consider surface area and living populations. Phleger (1960, p. 36) discusses the merits of the two forms of sample measurement. Wet volume comparisons were used for Netarts Bay samples because standing crop measurements were desired.

The samples taken from Netarts Bay fall into two classes. In 46 the volume was measured directly and in 26 the volume was estimated (figure 18). Of the latter seven were taken with the grab and 19 were obtained with the corer. All volumes were estimated by weight. The procedure was to weigh the sand fraction of the sediment after it was washed free of silt and dried. The original weight

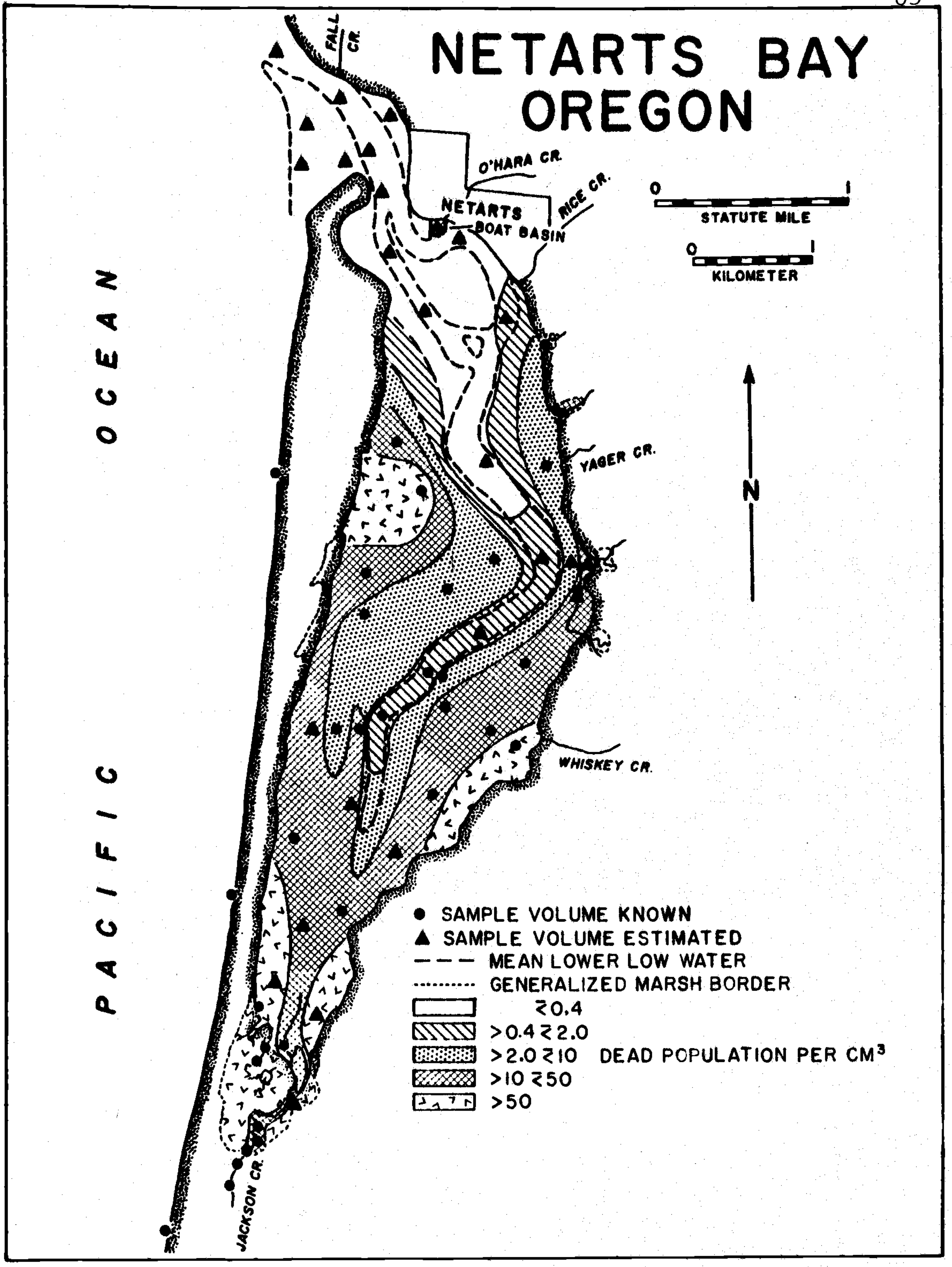

Figure 18. Abundance of the dead foraminiferal population.

of the sediment was then computed from the sand/silt-clay ratio taken from the sediment size analysis. The volume of the sediment was estimated by comparing the derived weights to the known volume and weight of a portion of the unprocessed original sample.

The distribution of dead foraminifera is similar to that shown by the standing crop (compare figures 16 and 18). The dead population, however, tends to define the channel more closely and to show a more consistently large abundance near the sides of the bay. Probably the somewhat clearer trend definition shown by the dead population is a reflection of the larger populations available to study. However, in evaluating the dead population it must be kept in mind that there may be some loss of empty tests after deposition due to solution, abrasion, reworking, and transport.

Live : Dead Population Ratios

In areas where foraminifera are preserved in place after death, the living population to the dead population ratio (L/D × 100 values given in Table 6) can be used to indicate relative rates of deposition (Phleger 1951, p. 65). Low ratios suggest slow deposition, and high ratios suggest rapid deposition of detrital sediment. In Netarts Bay values range from 1.7 to 250 and show considerable variation. The highest values, averaging 67, are on the central bay sand flats, but high average values of 48 and 39, also occur in the channel and

TABLE 6 Live/dead population ratios for Netarts Bay with samples grouped by sedimentary environment.

Channel		Sand flats		Mud flats		Salt marsh	
Station number	L/D	Station number	L/D	Station number	L/D	Station number	L/D
2	50	17	8.3	9	5.5	53	11
3	52	19	25	14	31	54	17
6	12	21	90	15	6.8	55	31
8	150	22	5.7	16	9.5	56	53
11	20	24	54	25	43	57	19
12	17	28	240	27	17	58	28
13	68	29	130	32	8.9	59	6.4
18	30	30	52	40	16	60	3.5
23	29	33	43	41	31	61	46
31	33	35	250	42	67	63	97
34	33	36	108	45	20	64	39
38	50	37	8.2	46	22	65	73
		39	11	49	4.5	66	32
		43	30	50	1.7	67	101
		44	19	52	56		
		47	21				
		51	56				

Stations with no live population have been excluded.

Ratios are expressed as percent (Live/dead x 100).

marsh environments respectively. A low average value of 23 occurs on the mud flats. These data suggest that the most rapid deposition is on the central bay sand flats and to a lesser extent in the channel and marsh, and that the lowest rate of sedimentation occurs on the mud flats. Similar high rates of deposition are reported for the sand flats of the lower lagoon in Laguna Guerrero Negro, Baja California (Phleger and Ewing, 1962).

In the shallow water environments care must be used in evaluating L/D ratios since, in such environments, processes which are not important in deep marine water often act to transport or destroy foraminiferal tests. Also sediment in shallow water environments is seldom deposited only once. It usually is reworked many times by waves and the ebb and flow of tidal currents before it finds its place of final deposition. In general, reworking of sediment by erosion and benthic organisms or destruction of tests by dissolution tends to alter the L/D value. These variations then will be reflected in the estimated rate of sedimentation.

It seems doubtful that the relatively high rate of sedimentation indicated for the channel by L/D values is real. A channel cut in soft sediment usually has a balanced rate of erosion and deposition which is maintained by the twice daily intake and discharge of the tidal prism (Emery and Stevenson 1957, p. 676). A high rate of deposition would upset this balance and reduce the size of the channel. This would in turn increase the current which would then increase the rate of erosion until the balance was regained. The high L/D values may be due to either abrasion or displacement of the empty foraminiferal tests. The hollow nature of the tests gives them a low density and they therefore are more easily moved by currents than equal volume sand grains.

The highest L/D values for Netarts Bay are associated with the central bay sand flats. Values for this area are extremely variable and are due to a few stations that display extremely high values (Table 6). These high values are probably due to two factors: local short term increases in production and local rapid rates of deposition. These stations (21, 28, 29, 35, and 36) all are located near beds of eel grass where rapid deposition can be expected at the expense of erosion elsewhere on the sand flats. Foraminiferal populations at these stations appear to be composed of high numbers of living specimens of one or sometimes two species (Table 3). Deposition in these areas probably does not occur over an extended period since high areas of the tidal flats are subjected to destruction by winter storm waves. Tidal flat elevations were not measured but lack of extensive marsh development bordering the central bay sand flats indicates that this area is not shoaling more rapidly than tidal flats elsewhere in the bay.

The average L/D value of 23 for mud flats is low in comparison to the rest of Netarts Bay, especially to the sand flats' value of 67. If, however, the five samples with abnormally high values of the latter area are disregarded, an average L/D value of 26 is obtained for the sand flats. This value compares quite closely with that for the mud flats indicating possibly that sedimentation rates are approximately the same for the entire tidal flat area of Netarts Bay.

The average L/D value of 39 for the marsh is appreciably higher than the average for the mud flats. This is to be expected as the marsh vegetation will tend to trap and retain a greater amount of detrital material than the bare mud flats. Stations 59 and 60 show very low values (Table 6). These samples were collected in January when the vegetation surrounding these stations had died off, thus probably reducing food supply of the foraminifera either directly or indirectly. In the marsh only the agglutinated foraminiferal population can be expected to survive burial to any extent. The small calcareous population that is present in the lower marsh will, however, be dissolved by the acid soil.

Agglutinated-Calcareous Ratio

The ratio of agglutinated to calcareous benthic foraminifera (Appendix F) tends to increase from the mouth to the head of Netarts Bay and west to east across the bay (figure 19). One reversal of this trend is evident at station 41 on the east side of the bay. An

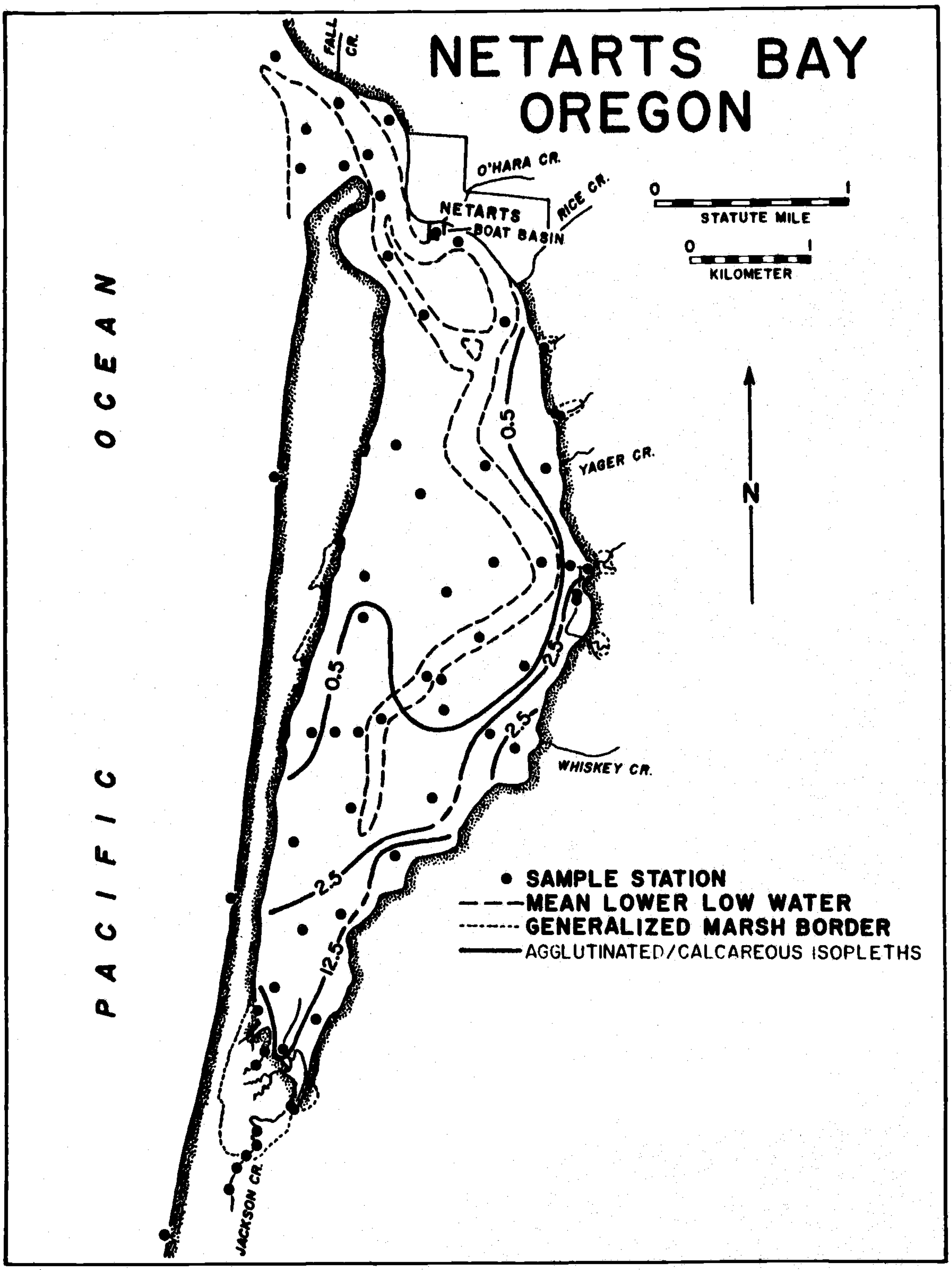

Figure 19. Areal distribution of the ratios formed by agglutinated and calcareous total foraminiferal population.

exceptionally large living and dead population of Ammonia cf. A. beccarii tepida is apparently the responsible factor. Agglutinated species reach a maximum in the high marsh where they form the entire foraminiferal population. This distribution pattern seems to be related inversely to the sediment size distribution (compare figures 5 and 19). Cockbain (1963) found a somewhat similar trend for the foraminifera and sediments of the Juan de Fuca and Georgia Straits. However, this trend is not universal. In Nantucket Bay, Massachusetts, Lidz (1965) reported that agglutinated species dominate the foraminiferal fauna on sandy bottoms. They, however, give way to hyaline forms in the silt-size sediments.

Emery and Stevenson (1957, p. 733) state that sediments of salt marshes and mud flats located in estuaries and lagoons usually have a low pH, if the sediments are deficient in calcareous material. A sediment only needs a pH below 7.8 to start to dissolve the included calcareous material (Krumbein and Garrels, 1952). Low pH values effect the calcareous population in a second way. If the low readings extend to the sediment water interface, the low pH values put calcareous species at a competitive disadvantage since they must expend energy to maintain their tests against the dissolving potential of the surrounding water (Parker and Athearn, 1959). Apparently the trends of the agglutinated-calcareous ratio in Netarts Bay are a response to the pH of the sediments since calcareous material is virtually absent (Appendix C). In addition, the living calcareous foraminifera form a much smaller percentage of the population on the marshes and mud flats than on the sand flats (figures 10A and 11A).

In Nantucket Bay the percentage of calcareous material in the sediment increases with decreasing sediment size. This included calcareous material (up to ten percent) acts as a buffer to prevent the formation of an acid condition which would destroy the calcareous portion of the foraminiferal population. The similarity in trends between Netarts Bay and the Juan de Fuca and Georgia Straits may also be a reflection of sediment pH. However, conditions in environments of the Straits more closely approximate open ocean conditions rather than those of a lagoon or estuary. Hence trends in the Straits may well be due to some other unknown environmental factor.

Planktonic Population

The planktonic population was not speciated in this study since it generally forms only a fraction of a percent of the total foraminiferal population. In addition, species of this population seldom represent a particular benthic environment since they normally occur in the water column and are not associated with the bottom. However, the number of live and dead specimens was recorded.

In Netarts Bay, planktonic foraminifera were found at only 13 of the 73 stations sampled (Table 7). In 12 of the 13, planktonic

TABLE 7 Planktonic foraminiferal populations of Netarts Bay, Oregon.

Station number	Number dead	Percent dead	Number live	Percent live
9	112	10	6	9
13	1	X	0	--
19	4	2	0	--
24	1	1	0	--
37	2	2	0	--
39	2	1	0	--
43	2	67	0	1
47	0	--	1	--
54	1	X	0	--
55	1	X	0	--
65	1	X	0	--
69	2	X	0	--
71	1	50	0	--

X = < 1 percent

populations ranged from one to four specimens. Station 9, in the boat basin, was found to have a planktonic population of six live and 112 dead specimens which represents nine and ten percent of the respective populations. Planktonic foraminifera possibly are able to survive and reproduce in the relatively deep, quiet water of the boat basin.

Planktonic species are rather limited off the Oregon Coast. Lankford (1962) observed that Globigerina bulloides and G. eggeri are common and that G. quinqueloba, G. pachyderma, and G. uvula (= Globigerinoides minutus) are common to rare. In general, planktonic foraminifera form only a very small percentage of the paralic foraminiferal population. On the Pacific Coast, Lankford (1962) and Cooper (1961) reported that planktonic foraminifera seldom formed greater than one or two percent of the foraminiferal population in the inner sublittoral and beach-tide pool environments respectively. Walton (1955) demonstrated that planktonic foraminifera formed only approximately 0.25 percent of the total foraminiferal population in the channel environment of Estero de Punta Banda, Baja California. Bandy (1961) in the Gulf of California; Parker, Phleger, and Peirson (1953) on the Gulf Coast of Texas; and Wilcoxon (1964) on the Atlantic Coast all reported similarly low planktonic foraminiferal populations in the paralic zone. In the water column, Phleger (1951, p. 67) reports that planktonic foraminifera are characteristic of offshore water masses and are seldom found in planktonic tows in shoal water.

Seasonal Trends

A seasonal study was designed to determine the ranges and patterns of standing crops and species populations in the various environments occurring in Netarts Bay. Seasonal studies from somewhat comparable environments have been reported by Phleger and Lankford (1957) from San Antonio Bay, Texas, and Parker and Athearn (1959) from marshes of Poponesset Bay, Massachusetts. Other important seasonal studies have been conducted by Walton (1955) and Reiter (1959).

In Netarts Bay 11 stations were chosen to represent the various environments (figures 2 and 12). These stations were sampled approximately every three months (Appendix G) and species populations and standing crop were determined (Table 8). Seasonal stations tend to fall into two natural areal groups on the basis of their fauna and population patterns. Stations 51, 53, 55, and 56 represent the innermost part of the bay and stations 9, 13, 15, 23, 24, 25, and 30 represent the environments from the central and outer bay areas.

The aggregate population of the inner bay stations is approximately five times that found for the stations representing the central

TABLE 8 PERCENTAGE ABUNDANCE OF LIVE FORAMINIFERA AND THECAMOEBIANS AT SEASONAL STATIONS

SPECIES — **STATION NUMBERS & DATES OF COLLECTION**

BENTHIC SPECIES	9					13					15				
	MAY 64 (NO SAMPLE COLLECTED)	JULY 64	OCT. 64	JAN. 65	APR. 65	MAY 64	JULY 64	OCT. 64	FEB. 65	APR. 65	MAY 64	JULY 64	OCT. 64	JAN. 65	APR. 65
HYALINE SPP.															
AMMONIA cf. A. BECCARII TEPIDA							12			20					
BUCCELLA FRIGIDA DEPRESSA				2				40							
BUCCELLA BLANCOENSIS / BUCCELLA TENERRIMA							6								
BULIMINELLA ELEGANTISSIMA		9		29		6	12	20			6				
CASSIDULINA LIMBATA										20					
CIBICIDES FLETCHERI		1													
CIBICIDES LOBATUS								20							
DISCORBIS COLUMBIENSIS									20						
ELPHIDIELLA HANNAI		1	6			2	6								
ELPHIDIUM INCERTUM INCERTUM		6		5	50	21	17		60	20	34	9	100		
ELPHIDIUM MAGELLANICUM		38	94	49		70	29				22			2	
ELPHIDIUM MICROGRANULOSUM / ELPHIDIUM SUBARCTICUM		3													
ELPHIDIUM TRANSLUCENS															
PORCELANEOUS SPP.															
PATEORIS HAUERINOIDES		9					12								
QUINQUELOCULINA AKNERIANA BELLATULA								20							
AGGLUTINATED SPP.															
AMMOBACULITES EXIGUUS / REOPHAX NANUS											3				
AMMOTIUM SALSUM												18		5	
EGGERELLA ADVENA		9		2							3				
HAPLOPHRAGMOIDES HANCOCKI		1													
MILIAMMINA FRIGIDA / MILIAMMINA FUSCA				5							25	73		84	100
TEXTULARIA EARLANDI		6													
TROCHAMMINA CHARLOTTENSIS / TROCHAMMINA SQUAMIFORMIS							6			40				2	
TROCHAMMINA INFLATA INFLATA		7		7										7	
TROCHAMMINA INFLATA MACRESCENS					50						6				
TROCHAMMINA KELLETAE									20						
PLANKTONIC SPP.		9													
TOTAL FORAMINIFERAL POPULATION		68	18	41	2	24	17	5	5	5	32	11	4	43	25
TOTAL THECAMOEBIAN POPULATION															

BENTHIC SPECIES	23					24					25				
	MAY 64 (NO SAMPLE COLLECTED)	JULY 64	OCT. 64	FEB. 65	APR. 65	MAY 64 (NO SAMPLE COLLECTED)	JULY 64	OCT. 64	JAN. 65	APR. 65	MAY 64 (NO SAMPLE COLLECTED)	JULY 64	OCT. 64	JAN. 65	APR. 65
HYALINE SPP.															
AMMONIA cf. A. BECCARII TEPIDA							65	7	16	8		93	58	23	
BUCCELLA FRIGIDA DEPRESSA								5		16					
BUCCELLA BLANCOENSIS / BUCCELLA TENERRIMA			33		17										
BULIMINELLA ELEGANTISSIMA								3	4						
CASSIDULINA LIMBATA															
CIBICIDES FLETCHERI															
CIBICIDES LOBATUS															
DISCORBIS COLUMBIENSIS								X							
ELPHIDIELLA HANNAI															
ELPHIDIUM INCERTUM INCERTUM		67	33				12	63	66	45		1	16	31	10
ELPHIDIUM MAGELLANICUM				50	17			21	6	32					14
ELPHIDIUM MICROGRANULOSUM / ELPHIDIUM SUBARCTICUM															
ELPHIDIUM TRANSLUCENS														8	
PORCELANEOUS SPP.															
PATEORIS HAUERINOIDES															
QUINQUELOCULINA AKNERIANA BELLATULA		33						X	X						
AGGLUTINATED SPP.															
AMMOBACULITES EXIGUUS / REOPHAX NANUS															57
AMMOTIUM SALSUM			33						X			1			
EGGERELLA ADVENA															
HAPLOPHRAGMOIDES HANCOCKI															
MILIAMMINA FRIGIDA / MILIAMMINA FUSCA				50			22		7			5	26	31	19
TEXTULARIA EARLANDI								X							
TROCHAMMINA CHARLOTTENSIS / TROCHAMMINA SQUAMIFORMIS					66										
TROCHAMMINA INFLATA INFLATA															
TROCHAMMINA INFLATA MACRESCENS														8	
TROCHAMMINA KELLETAE															
PLANKTONIC SPP.															
TOTAL FORAMINIFERAL POPULATION		3	3	2	6		40	168	112	38		83	31	13	21
TOTAL THECAMOEBIAN POPULATION							2		3					1	1

BENTHIC SPECIES	30					51					53				
	MAY 64 (NO SAMPLE COLLECTED)	JULY 64	OCT. 64	FEB. 65	APR. 65	MAY 64 (NO SAMPLE COLLECTED)	JULY 64	OCT. 64	JAN. 65	APR. 65	MAY 64 (NO SAMPLE COLLECTED)	JULY 64	OCT. 64	JAN. 65	APR. 65
HYALINE SPP.															
AMMONIA cf. A. BECCARII TEPIDA		27	8				2	15	X	46		29	89	2	26
BUCCELLA FRIGIDA DEPRESSA		31	19	11	81										
BUCCELLA BLANCOENSIS / BUCCELLA TENERRIMA															
BULIMINELLA ELEGANTISSIMA		8													
CASSIDULINA LIMBATA															
CIBICIDES FLETCHERI															
CIBICIDES LOBATUS															
DISCORBIS COLUMBIENSIS								1							
ELPHIDIELLA HANNAI															
ELPHIDIUM INCERTUM INCERTUM		15	73	78			X	65	X	4			7	2	15
ELPHIDIUM MAGELLANICUM		12			12										
ELPHIDIUM MICROGRANULOSUM / ELPHIDIUM SUBARCTICUM															
ELPHIDIUM TRANSLUCENS														2	
PORCELANEOUS SPP.															
PATEORIS HAUERINOIDES															
QUINQUELOCULINA AKNERIANA BELLATULA		4											2		
AGGLUTINATED SPP.															
AMMOBACULITES EXIGUUS / REOPHAX NANUS		4		11			18		14	4		14		1	32
AMMOTIUM SALSUM							73	15	69	42		38		35	
EGGERELLA ADVENA															
HAPLOPHRAGMOIDES HANCOCKI							7			4				1	2
MILIAMMINA FRIGIDA / MILIAMMINA FUSCA									16			17	2	48	21
TEXTULARIA EARLANDI															
TROCHAMMINA CHARLOTTENSIS / TROCHAMMINA SQUAMIFORMIS															
TROCHAMMINA INFLATA INFLATA					6				X			1		5	4
TROCHAMMINA INFLATA MACRESCENS								3	X			1		2	
TROCHAMMINA KELLETAE															
PLANKTONIC SPP.															
TOTAL FORAMINIFERAL POPULATION		26	26	9	16		492	34	701	48		386	44	81	47
TOTAL THECAMOEBIAN POPULATION															

BENTHIC SPECIES	55					56				
	MAY 64	JULY 64	OCT. 64 (NO SAMPLE COLLECTED)	JAN. 65	APR. 65	MAY 64	JULY 64	OCT. 64	JAN. 65	APR. 65
HYALINE SPP.										
AMMONIA cf. A. BECCARII TEPIDA	19			3		36				
BUCCELLA FRIGIDA DEPRESSA										
BUCCELLA BLANCOENSIS / BUCCELLA TENERRIMA										
BULIMINELLA ELEGANTISSIMA										
CASSIDULINA LIMBATA										
CIBICIDES FLETCHERI										
CIBICIDES LOBATUS										
DISCORBIS COLUMBIENSIS										
ELPHIDIELLA HANNAI										
ELPHIDIUM INCERTUM INCERTUM	12	9		3	21	14			3	11
ELPHIDIUM MAGELLANICUM				9		4				
ELPHIDIUM MICROGRANULOSUM / ELPHIDIUM SUBARCTICUM										
ELPHIDIUM TRANSLUCENS										
PORCELANEOUS SPP.										
PATEORIS HAUERINOIDES										
QUINQUELOCULINA AKNERIANA BELLATULA						1				
AGGLUTINATED SPP.										
AMMOBACULITES EXIGUUS / REOPHAX NANUS	12	7		9		12	6			
AMMOTIUM SALSUM	4	7		9		6	4			
EGGERELLA ADVENA										
HAPLOPHRAGMOIDES HANCOCKI							X			
MILIAMMINA FRIGIDA / MILIAMMINA FUSCA	38	76		63	79	19	60	98	97	22
TEXTULARIA EARLANDI						7				
TROCHAMMINA CHARLOTTENSIS / TROCHAMMINA SQUAMIFORMIS		2								
TROCHAMMINA INFLATA INFLATA	15			3		1	30	2		11
TROCHAMMINA INFLATA MACRESCENS							X	X		56
TROCHAMMINA KELLETAE										
PLANKTONIC SPP.										
TOTAL FORAMINIFERAL POPULATION	26	46		32	19	67	367	442	38	9
TOTAL THECAMOEBIAN POPULATION										

G=GRAB SAMPLE
X= 1%

and outer bay tidal flats (figure 20). In the inner bay, the population is composed principally of Ammotium salsum and Miliammina fusca-M. frigida with lesser numbers of Ammobaculites exiguus-Reophax nanus and Ammonia cf. A. beccarii tepida. With the exception of station 56, which will be discussed separately, the seasonal stations in the inner bay and many of their included species show simultaneous population maxima which are distinctly bimodal. These maxima occur in January and July (figure 20). A somewhat similar pattern of species and standing crop maxima was observed by Phleger and Lankford (1957) in upper San Antonia Bay, Texas. The simultaneous population peaks shown by inner bay species tend to indicate that the same influence is controlling their populations. Whatever the factor or factors are that control these maxima, it appears to significantly influence only the inner bay population. Temperature and salinity probably are not the controlling factors. This is indicated by the presence of a population peak both in winter and summer when the opposite extremes of temperature and salinity would be expected to occur. Probably the foraminiferal population in the inner bay varies with the availability of food as was shown to be the case for Elphidium crispum (Linné) off Plymouth, England (Myers, 1942). The source of this food can only be surmised. Possibly the summer population maxima is associated with the greater availability of plant material usually present during the warmer months of the year. The winter

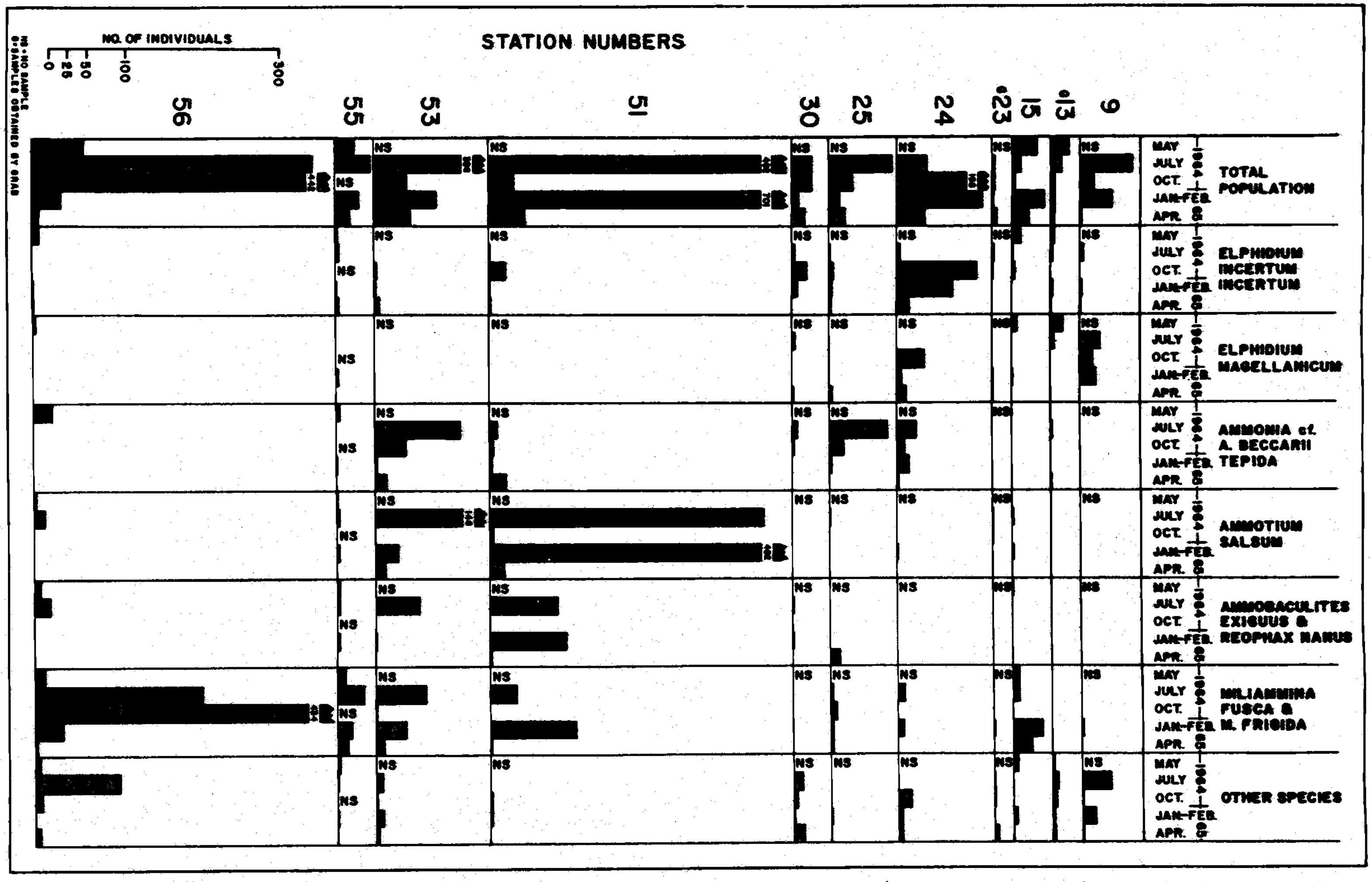

Figure 20. Seasonal variations in the total living population (standing crop) and living species populations at each seasonal station.

population peak may be associated with increased runoff due to increased precipitation. The resulting greater influx of freshwater can be expected to carry nutrients conducive to plant growth and particulate food, all of which serve as food for foraminifera.

At station 56, Miliammina frigida and M. fusca form the majority of the population. The standing crop reaches maximum abundance during October but it does not seem to be related to the standing crop patterns of the other seasonal stations in the inner bay area. Probably this is due to the station's location amid perennial phanograms that grow and flower during the warm months of the year and die down during the winter. These plants undoubtedly offer much in the way of protection and direct and indirect sources of food.

Seasonal standing crop maxima for stations located in the central and outer bay areas show a rather random pattern. This lack of a consistent pattern is due largely to the independent population maxima produced by the area's two most numerous species, Ammonia cf. A. beccarii tepida and Elphidium incertum incertum (figure 20). The season of highest total population at any one station depends largely on which species forms the bulk of the population. Ammonia cf. A. beccarii tepida has its population peak in July. This population maxima shows up at stations 13, 24, 25, and 30 in the central and outer bay and at two stations (51 and 53) in the inner bay (figure 20). Two nonseasonal central bay samples (35 and 41) collected during

July show extremely large populations of Ammonia cf. A. beccarii tepida (Table 3). The reproduction of this species is probably temperature controlled since it is near its northern limit. It has been reported only as far north as Grays Harbor, Washington (Andrews, 1965). Bradshaw (1961) has shown that it is unable to reproduce below 18° to 20°C. Water temperatures measured in the tidal channel of Netarts Bay seldom reach these values (Tables 1 and 2). Reproduction temperatures, however, probably are achieved locally in the bay during warm summer days when the tidal flats are either exposed or covered by shallow water.

Elphidium incertum incertum develops its maximum population in October. Population peaks were observed at stations 24, 25, and 30 in the central and outer bay and station 51 in the inner bay. Non-seasonal stations 21, 28, and 29, collected from the central bay area in October, also show very high populations of E. incertum incertum. The factors responsible for the bloom of this species in October are not known since information is not available on its reproduction and survival limits. Food does not seem to be the factor since other species do not show parallel population increases. However, food can not be ruled out since it is possible that E. incertum incertum can use food in some form not usable or available to other species. The somewhat smaller populations found in January and February may indicate that the species is relatively long lived or is able to reproduce in the winter months in response to an increased food supply brought in by high winter runoff.

In addition to the species reported in tables 4, 5, and 9 empty tests of Bolivina compacta, Cyclogyra sp., Lagena filicosta, and Nonionella japonica were found in the seasonal samples.

Reworked Foraminifera

The presence of Bolivina advena, Uvigerina peregrina, Buliminella curta and Cassidella sp. in Netarts Bay is considered to be the result of reworking. Reworked specimens are normally distinguishable by their relatively poor state of preservation and their yellow limonitic stain. The four species are represented by few specimens and no living members in Netarts Bay. Fowler (personal communication) has noted their occurrence in Tertiary sediments of Oregon. These fossil foraminifera almost certainly came from the Miocene Astoria Formation. All sedimentary rocks cropping out in the Netarts Bay watershed are referred to this Formation (Warren, Grivetti, and Norbisrath, 1945). The specimens were introduced into the bay through tributary creeks and/or the tidal channel.

Cooper (1961) in sampling the beaches and tide pools of Oregon and California observed no fossil foraminifera from Oregon but an abundance of them from southern California. In Oregon, deep weathering caused by humid climatic conditions probably destroys much fossil material before it is exposed by erosion. The relatively dry climate of southern California makes deep weathering much less likely.

Foraminifera-Ostracod Ratio

Bandy (1963) in summarizing data from many papers on the paralic environment of southern California and the Gulf of California has shown that foraminifera/ostracod values of 12 or less characterize lagoonal facies whereas ratios of 100 or more characterize beach and sublittoral facies. Sixteen samples, distributed randomly throughout Netarts Bay were checked for ostracods in order to test this parameter.

Ratios were found to vary from 41.5 to 0.6 with a mean of 13.8 (Table 9). Assuming that the values varied in a random fashion, a 95 percent confidence interval gives a student's t distribution range of 6.1 to 20.0. This range compares well with the value of 12 given by Bandy for the southern California area and tends to establish the usefulness of this parameter for temperate to cool-temperate climates.

Average values of the foraminifera-ostracod ratio for the different sedimentary environments in the bay tend to show an increase from 11 for the channel and sand flats to 28 for the mud flats,

TABLE 9 A comparison of foraminifera and ostracod populations for selected stations in Netarts Bay.

Station number	Total ostracods	Total foraminifera	Foram/ ostracod
9	120	1314	11.0
13	9	118	13.1
17	7	78	11.1
19	34	224	6.6
24	22	172	7.8
30	132	76	0.6
31	2	24	12.0
36	57	123	2.2
40	19	788	41.5
44	29	342	11.8
45	54	1240	23.0
47	17	561	33.0
50	29	114	3.9
51	35	90	2.6
60	78	2301	29.5
67	19	777	40.9

and 35 for the marsh. Lidz (1965) observed a similar sediment size to foraminifera/ostacod trend in Nantucket Bay, Massachusetts.

Foraminiferal-Thecamoebian Relationship

According to Loeblich and Tappan (1964, C16) other authors have included some members of the orders Arcellinida, Gromida, and part of the suborder Allegromiina in a category called thecaomebians. These organisms are characterized by an agglutinated or chitinous, sack-like chamber and nonreticulate pseudopodia. They are primarily indigenous to freshwater environments but are occasionally found in marine environments. In the present study specimens that appear to fit the description of the genus *Saccammina* have been called thecamoebians because they are found near or associated with freshwater environments.

In this study all thecamoebians were counted together without reference to species. Distinction was made only between living and dead specimens. Thecamoebians are uncommon in Netarts Bay. They were found at only 23 of the 73 sample stations. Most of these stations are located in or near tidal creek channels through which fresh water flows at some time during the tidal cycle.

Samples 9 and 68 to 72 are not considered as typical bay samples. Station 9 (the boat basin) is anomalous and will be discussed later. Stations 68 to 72 were taken in Jackson Creek near the limit of salt water penetration and consequently do not represent conditions typical of the bay. With the exception of these stations, the live thecamoebian population is nearly nonexistent. In the three samples containing live specimens, thecamoebians are only 0.01 times as numerous as living foraminifera. A similar comparison for the dead thecamoebians shows them to be up to 0.05 times as numerous as the dead foraminifera in some samples but to average approximately 0.02 times (Table 10).

Station 9 is anomalous in that both the live and dead thecamoebian populations are much greater than those occurring at other stations excepting those in Jackson Creek (Table 10). The source of this high population is probably O'Hara Creek which empties into the boat basin within approximately 50 meters of where the sample was obtained. In O'Hara Creek there is no transition zone between fresh water and bay environments. The creek enters the boat basin through a culvert that is high enough to prevent bay waters from backing up more than a few meters at high tide. Thus organisms displaced from upstream find no quiet, brackish-water, transition zone to settle out in as is usually the case with other streams. They are, instead, swept directly into the boat basin.

In tidal creeks with a source of fresh water, foraminiferal populations are replaced by thecamoebian populations as brackish-water conditions approach those of fresh water (figure 21). The dead

TABLE 10 Thecamoebian population in Netarts Bay with comparisons to the foraminiferal population.

	Dead		Live			Dead		Live	
Station no.	No.	Thecamoebian/ Benthic Forams	No.	Thecamoebian/ Benthic Forams	Station no.	No.	Thecamoebian/ Benthic Forams	No.	Thecamoebian/ Benthic Forams
9	180	0.14	10	0.16	50	3	X	0	--
13	2	0.02	1	0.06	52	2	X	0	--
14	4	0.05	0	--	57	3	X	1	0.01
15	4	0.02	0	--	58	58	0.02	0	--
16	16	0.04	0	--	59	1	X	0	--
25	6	0.03	0	--	64	4	X	0	--
27	4	0.02	0	--	68	3	X	0	--
37	2	0.02	0	--	69	137	0.57	0	--
40	1	X	0	--	70	209	80.	5	*
41	23	0.04	1	--	71	234	*	32	*
45	3	X	0	--	72	1174	*	55	*
47	2	X	0	--					

X = <.01   * => 100

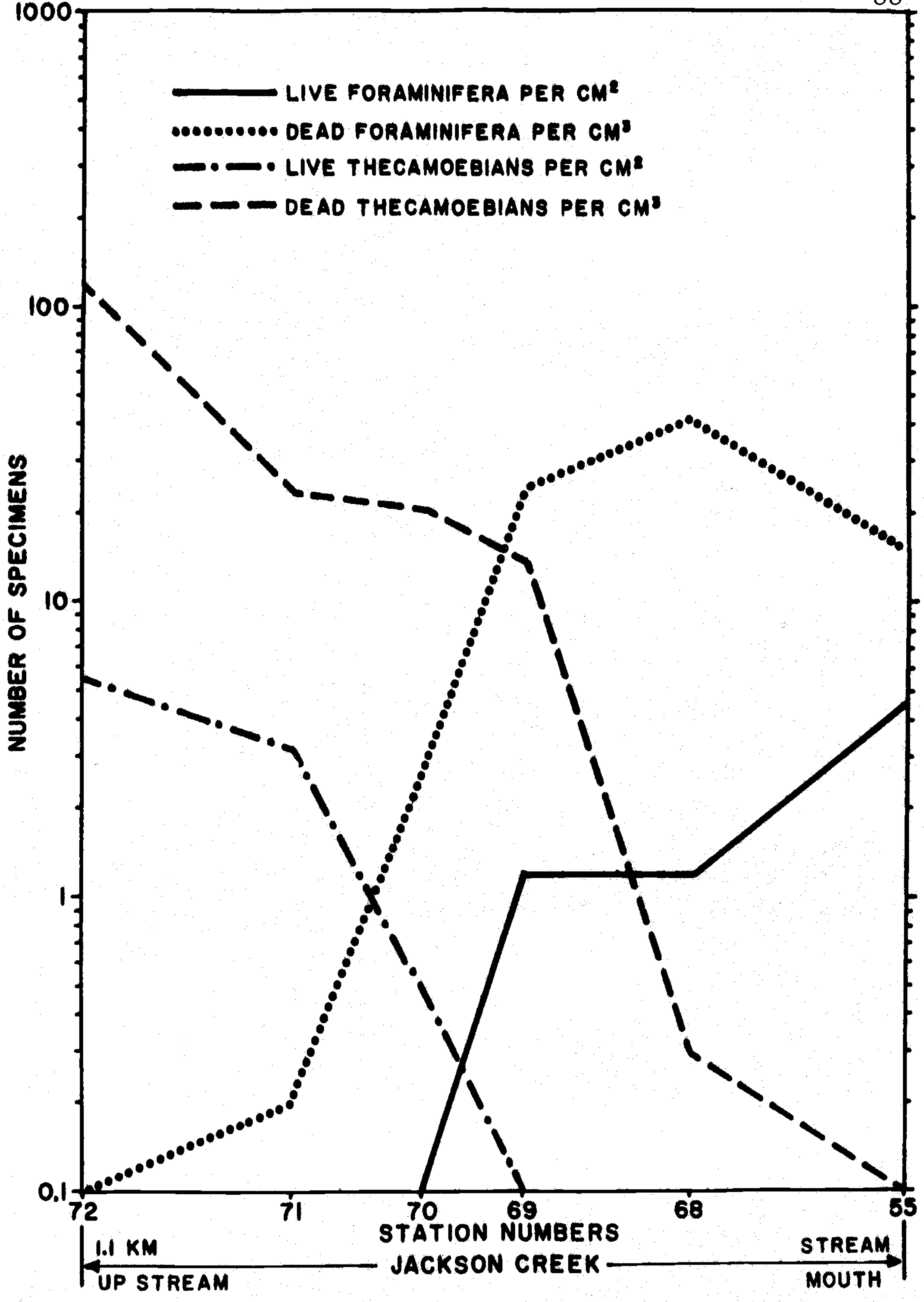

Figure 21. Live and dead populations of both foraminifera and thecamoebians for stations located in the tidal channel of Jackson Creek.

thecamoebian and foraminiferal populations extend farther downstream and upstream respectively than do their live populations. This tends to indicate that the tidal creek environment varies over a period of time thus allowing either the thecamoebians or foraminifera to temporarily extend their range.

SUMMARY AND CONCLUSIONS

Sediments of Netarts Bay essentially are composed of fine sand derived from the adjacent beaches and turbulent zone, and muds from inflowing streams. Sandy sediments cover the outer and central bay area while mud predominates at the head and east side of the bay. The distribution of mud and sand is a reflection of the proximity of source areas and the energy of the environment. Organic carbon content of the bay sediments shows a strong inverse relationship to the sediment size. Carbonate material is an unimportant constituent of the bay sediments. Hydrogen ion concentrations for the marsh sediments range from 7.0 to 5.7. Generally the values reduce away from the tidal flat-marsh border.

Fifty-one species of foraminifera have been identified from Netarts Bay: of these 38 are thought to be indigenous, four reworked, and nine displaced into the bay by way of the tidal channel. The bay fauna can be roughly divided into four groups which tend to inhabit areas with specific sedimentary, physical, and chemical characteristics. An Elphidiella Fauna is confined to the tidal channel which is directly connected to the fauna's normal environment, the near-shore turbulent zone. The Elphidium Fauna inhabits the sand flats and is found also in the sublittoral zone off the Oregon Coast. Mud flats and salt marshes are populated by the Ammonia Fauna and the

Miliammina Fauna respectively. Ammonia cf. A. beccarii tepida, Ammobaculites exiguus, and Ammotium salsum are the principal species of the Ammonia Fauna and Miliammina fusca, Trochammina inflata inflata, and Trochammina inflata macrescens are the principal species of the Miliamminia Fauna. Various combinations of these species are found in most of the brackish water environments along the Pacific, Atlantic and Gulf Coasts of North America. Probably Trochammina inflata inflata and Miliammina fusca have a world wide distribution.

An average of seven species per sample occurs on the central bay tidal flats near the sides of the bay. The species number decreases toward the head of the bay and marsh, and toward the channel and the mouth of the bay. In Netarts Bay the number of species per sample is somewhat less than that reported from other similar environments.

Salt marshes fringing Netarts Bay support average standing crops of approximately 80 specimens/cm^2. Standing crops occurring on the tidal flats are close to an order of magnitude smaller than the marsh's and the tidal channel values are one to two orders smaller than those on the tidal flats. Mud and sand flats have comparable standing crops; however, values for the sand flats show greater variation than those of the mud flats. On the tidal flats standing crops are roughly inversely proportional to the energy of the environment and directly proportional to the amount of vegetation present usually in the form of eel grass or blue-green algae. These areas of vegetation are almost always located near the sides of the bay away from the turbulent water of the main channel. Tidal flats standing crops in Netarts Bay are comparable to values reported by other workers from similar environments. Netarts Bay marsh populations are, for the most part, much larger than those observed in comparable environments elsewhere.

Dead foraminiferal populations tend to be two to ten times more numerous than the standing crop. Their relative population values generally parallel trends of the standing crop.

Live-dead foraminiferal population ratios are quite variable. However, on the average, these ratios indicate that the central bay sand flats are rapidly building up, that the sedimentation rate for the channel and marsh are somewhat less, and that the mud flats are receiving the least sediment. Since reworking of sediments, and transportation and destruction of tests after burial, tend to locally modify the live-dead ratios, the latter may not indicate general sedimentation conditions.

The agglutinated-calcareous ratio for the total population tends to increase toward the head and east side of Netarts Bay. The high marsh population is entirely agglutinated. The agglutinated-calcareous ratio tends to vary inversely with sediment size. This relationship is probably governed by the pH of the sediment. Trends delineated in Netarts Bay are not general for all brackish-water environments. Agglutinated-calcareous ratio trends in lagoons where sediments contain an appreciable amount of calcareous material show no similarity to the agglutinated-calcareous ratio trends occurring in Netarts Bay.

Planktonic foraminifera, with the exception of the boat basin, are very rare in Netarts Bay. Other near-shore and brackish water studies indicate that low planktonic populations are normal for paralic areas.

Seasonal populations on the innermost tidal flats at the head of Netarts Bay show strong bimodal peaks occurring in July and January. The populations are composed principally of Ammotium salsum but most other species present in appreciable numbers show identical population maxima. Availability of food is thought to control this seasonal pattern. The marsh shows one peak formed almost wholly of Miliammina fusca and M. frigida during the summer and fall. This peak correlates with the growth and flowering of associated perennial phanerograms. The central and outer bay areas show no consistent relationship between size of population and season. The two major species of the central tidal flats, Ammonia cf. A. becarii tepida and Elphidium incertum incertum, both show definite population maxima in July and October respectively. The increase of Ammonia cf. A. beccarii tedpida probably is related to the warmer bay waters during the summer.

Foraminifera-ostracod ratios for the bay have a mean value of 13.8. This value compares closely with what other researchers have reported from southern California and northwestern Mexico.

Thecamoebian populations are extremely low in Netarts Bay compared to the foraminiferal populations. However, thecamoebians rapidly displace the foraminifera as fresh water conditions are approached.

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APPENDICES

APPENDIX A SAMPLING DATA

Station number	Date	Sampler	Location	Station number	Date	Sampler	Location
1	7/15/64	G	C&B	38	7/23/64	C	C&B
2	7/15/64	G	C&B	39	7/23/64	C	S
3	7/15/64	C	C&B	40	7/23/64	C	Mu
4	7/14/64	C	C&B	41	7/22/64	C	Mu
5	7/14/64	C	C&B	42	10/10/64	C	Mu
6	7/14/64	C	C&B	43	7/15/64	C	S
7	7/14/64	G	C&B	44	10/10/64	C	S
8	7/15/64	G	C&B	45	7/15/64	C	Mu
9	7/14/64	C	Bb	46	10/10/64	C	Mu
10	7/14/64	C	C&B	47	7/15/64	C	S
11	7/15/64	C	C&B	48	7/23/64	C	C&B
12	7/15/64	G	C&B	49	7/15/64	C	Mu
13	7/15/64	G	C&B	50	7/15/64	C	Mu
14	7/22/64	C	Mu	51	7/23/64	C	S
15	7/22/64	C	Mu	52	7/23/64	C	Mu
16	7/22/64	C	Mu	53	7/23/64	C	Mu
17	7/22/64	C	S	54	7/23/64	C	Ma
18	7/15/64	G	C&B	55	7/15/64	C	Ma
19	7/23/64	C	S	56	7/15/64	C	Ma
20	7/23/64	C	C&B	57	7/15/64	C	Ma
21	10/10/64	C	S	58	7/15/64	C	Ma
22	7/23/64	C	S	59	1/23/65	C	Ma
23	7/15/64	G	C&B	60	1/23/65	C	Ma
24	7/15/64	C	S	61	1/23/65	C	Ma
25	7/15/64	C	Mu	62	1/23/65	C	Ma
26	7/15/64	Hand	Mu	63	1/23/65	C	Ma
27	7/15/64	C	Mu	64	1/23/65	C	Ma
28	10/10/64	C	S	65	1/23/65	C	Ma
29	10/10/64	C	S	66	1/23/65	C	Ma
30	7/23/64	C	S	67	1/23/65	C	Ma
31	7/15/64	C	C&B	68	7/23/64	C	Ma
32	10/10/64	C	S	69	7/23/64	C	Ma
33	5/2/64	C	S	70	7/23/64	C	Ma
34	7/23/64	C	C&B	71	10/10/64	C	Ma
35	7/15/64	C	S	72	10/10/64	C	Ma
36	7/23/64	C	S	73	7/23/64	C	C&B
37	7/23/64	C	S				

C = Core sample, G = Grab sample, S = Sand flat, Mu = Mud flat, C&B = Channel and Beach, Ma = Marsh, Bb = Boat basin.

APPENDIX B - TEXTURAL SEDIMENT PARAMETERS*

Station number	Mean	Sorting	Skewness	Station number	Mean	Sorting	Skewness
1	2.074	.255	-.196	25	4.158	1.971	+.623
3	2.318	.206	-.144	30	2.410	.296	-.033
5	2.144	.235	-.144	31	2.413	.238	-.033
6	2.243	.214	-.189	35	2.398	.245	-.149
9	5.305	2.429	+.316	36	3.780	1.738	+.794
10	2.302	.224	-.114	37	3.162	.898	+.512
11	2.334	.242	-.135	38	2.426	.256	-.063
12	2.320	.210	-.111	39	2.532	.295	+.010
13	2.311	.238	-.129	40	4.863	2.532	+.522
14	6.588	3.445	+.292	41	4.569	1.588	+.446
15	5.483	3.266	+.349	43	2.946	.817	+.520
17	2.839	.741	+.509	45	5.657	3.225	+.408
18	2.314	.214	-.156	47	3.282	1.088	+.675
19	2.444	.230	-.051	48	2.346	.187	-.139
20	2.281	.183	-.214	49	4.007	1.845	+.766
22	2.454	.254	-.057	50	5.374	2.346	+.245
23	2.226	.305	-.014	51	2.489	.230	-.029
24	2.566	.488	+.120	73	2.214	.249	-.253

*Parameters are in phi units after Inman (1952).

APPENDIX C WEIGHT PERCENTAGES OF CARBON IN NETARTS BAY SEDIMENTS

Station number	Total carbon	Carbonate carbon	Organic carbon
9	1.96	.05	1.91
14	2.51	.00	2.51
15	1.93	.02	1.91
17	.37	.00	.37
19	.06	.00	.06
22	.10	.03	.07
23	.11	.01	.10
24	.66	.03	.63
25	.84	.00	.84
27	.81	.04	.77
30	.13	.00	.13
35	.18	.00	.18
36	1.12	.00	1.12
37	.57	.00	.57
38	.09	.00	.09
39	.27	.01	.26
40	1.42	.00	1.42
41	1.09	.03	1.06
43	.52	.02	.50
45	1.47	.00	1.47
47	.63	.00	.63
48	.09	.02	.07
49	.56	.00	.56
50	1.42	.00	1.42
51	.21	.00	.21
52	.83	.01	.82
53	1.47	.00	1.47
54	3.45	.00	3.45
55	1.27	.00	1.27
68	1.84	.00	1.84

APPENDIX D - HYDROGEN-ION CONCENTRATION

Station	pH	Station	pH	Station	pH
55	6.6	61	5.9	65	5.9
56	7.0	62	6.3	66	5.9
59	6.6	63	5.8	67	5.7
60	6.2	64	6.2		

APPENDIX E - ANNOTATED FAUNAL REFERENCE LIST

Trinomials represent genus, species, and subspecies. The preferred modern name is followed by the original name and reference for ease of location in the Catalogue of Foraminifera (Ellis and Messina, 1940-1966).

Ammobaculites exiguus Cushman and Bronnimann, 1948, Contr. Cushman Lab. Foram. Research, vol. 24, pt. 2, p. 38, pl. 7, figs. 7, 8.

Ammonia beccarii tepida (Cushman) = Rotalia beccarii tepida Cushman, 1926, Carnegie Inst. Washington, Pub. no. 344, p. 79, pl. 1.

Ammotium planissimum (Cushman) = Haplophragmoides planissima Cushman, 1927, Bull. Scripps Inst. Oceanog., Tech. ser., vol. 1, no. 10, p. 135, pl. 1, fig. 6.

Ammotium salsum (Cushman and Bronnimann) = Ammobaculites salsus Cushman and Bronnimann, 1948, Contr. Cushman Lab. Foram. Research, vol. 24, pt. 1, p. 16, pl. 3, figs. 7-9.

Bolivina advena Cushman, 1925, Contr. Cushman Lab. Foram. Research, vol. 1, pt. 2, p. 29, pl. 5, fig. 1.

Bolivina compacta Sidebottom = Bolivina robusta compacta Sidebottom, 1905, Manchester Lit. Philos. Soc., Mem. Proc., Vol. 49, no. 5, p. 15, pl. 3, fig. 7.

Buccella blancoensis (Bandy) = Eponides blancoensis Bandy, 1940, Jour. Paleontology, vol. 24, no. 3, p. 277, pl. 42, fig. 1. This species was not distinguished from B. tenerrima in the population counts. Since B. blancoensis closely resembles B. tenerrima and occupies the same general environment it may well be a variety of the latter.

Buccella tenerrima (Bandy) = Rotalia tenerrima Bandy, 1950, Jour. Paleontology, vol. 24, no. 3, p. 278, pl. 42, fig. 3.

Buccella frigida depressa Andersen = Buccella depressa Andersen, 1952, Wash. Acad. Sci., Jour. vol. 42, no. 5, p. 147, fig. 7.

Buliminella curta Cushman, 1925, Contr. Cushman Lab. Foram. Research, vol. 1, pt. 2, p. 33, pl. 5, fig. 13.

Buliminella elegantissima (d' Orbigny) = Bulimina elegantissima d' Orbigny, 1839, Voy. Amér. Mérid., Foraminifères, vol. 5, pt. 5, p. 51, pl. 7, figs. 13, 14.

Cassidella sp.

Cassidulina limbata Cushman and Huges, 1925, Contr. Cushman Lab. Foram. Research, vol. 1, pt. 1, p. 12, pl. 2, fig. 2.

Cibicides fletcheri Galloway and Wissler, 1927, Jour. Paleontology, vol. 1, no. 1, p. 64, pl. 10, figs. 8, 9.

Cibicides lobatus (Montagu) = Serpula lobata Montagu, 1803, Test. Brit., pp. 515, 516.

Cyclogyra sp.

Discorbis columbiensis Cushman, 1925, Contr. Cushman Lab. Foram. Research, vol. 1, pt. 2, p. 43, pl. 6, fig. 13.

Discorbis ornatissimus Cushman, 1925, Contr. Cushman Lab. Foram. Research, vol. 1, pt. 2, p. 42, pl. 6, figs. 11, 12.

Eggerella advena (Cushman) = Verneuilina advena Cushman, 1922, Contr. Canadian Biology, no. 9, p. 141.

Elphidiella hannai (Cushman and Grant) = Elphidium hannai Cushman and Grant, 1927, Trans. San Diego Soc. Nat. Hist., vol. 5, no. 6, p. 77, pl. 8, fig. 1.

Elphidium excavatum (Terquem) = Polystomella excavata Terquem, 1875, Soc. Dunkerquoise, Mém., Dunkerque, France, vol. 19, p. 429, pl. 2., fig. 2.

Elphidium incertum incertum (Williamson) = Polystomella umbilicatula incerta Williamson, 1858, On the Recent Foraminifera of Great Britain, p. 44, pl. 3, fig. 82. This appears to be the same species that Lankford (1962) called Elphidium cf. E. Clavatum.

Elphidium magellanicum Heron-Allen and Earland, 1932, Discovery Repts., vol. 4, p. 440, pl. 16, figs. 26-28. Elphidium sp. cf. E. subarcticum reported off San Diego, California by Uchio (1960) and Elphidium sp. reported off the Oregon Coast by Jarman (1962) appear similar to Elphidium magellanicum.

Elphidium microgranulosum Galloway and Wissler, 1951, Eclog. Geol. Helv., vol. 43, no. 2, p. 222.

Elphidium subarcticum Cushman, 1944, Contr. Cushman Lab. Foram. Research, Spec. Publ. 12, p. 27, pl. 3, figs. 34, 35. This species was not distinguished from E. microgranulosum during the population counts.

Elphidium translucens Natland, 1938, Bull. Scripps Inst. Oceanography, tech. ser., vol. 4, no. 5, p. 144, pl. 5, figs. 5, 6.

Eponides columbiensis (Cushman) = Pulvinulina columbiensis Cushman, 1925, Contr. Cushman Lab. Foram. Research, vol. 1, pt. 2, p. 43, pl. 7, fig. 1.

Haplophragmoides columbiensis evolutus Cushman and Mc Culloch, 1939, Allan Hancock Pacific Exped., vol. 6, p. 73, pl. 5, figs. 11, 12, pl. 6, figs. 1, 2.

Haplophragmoides hancocki Cushman and Mc Culloch, 1939, Allan Hancock Pacific Exped., vol. 6, p. 79, pl. 6, figs. 5, 6.

Lagena acuticosta apiopleura Loeblich and Tappan = Lagena apiopleura Loeblich and Tappan, 1953, Smithsonian Inst., Misc. Coll. 121, no. 7, p. 59, pl. 10, figs. 14, 15.

Lagena filicosta Reuss, 1863, K. Akad. Wiss. Wien, Math. - Naturw. C l, Sitzber., Wien, Österreich, Bd. 46, Abth, 1, p. 328, pl. 4, figs. 50, 51.

Legena laevis (Montagu) = Vermiculum laeve Montagu, 1803, Test. Brit., p. 524.

Miliammina frigida (Parker) = Quinqueloculina frigida Parker, 1958, Bull. Mus. Comp. Zoology, Harvard, vol. 106, no. 9, p. 406, pl. 3, fig. 20. This species was not distinguished from M. fusca during the population counts. Since the two species resemble each other and occupy much of the same environment in Netarts Bay, they may be only varieties of the same species.

Miliammina fusca (Brady) = Quinqueloculina fusca Brady, 1870, Ann. Mag. Nat. Hist., ser. 4, vol. 6, p. 286, pl. 11, fig. 2.

Nonionella auricula Heron - Allen and Earland, 1930. Jour. Roy. Micr. Soc., ser. 3, vol. 50, p. 192, pl. 5, figs. 68-70.

Nonionella japonica (Asano) = Pseudononion japonicum Asano, 1936, Jour. Geol. Soc. Japan, vol. 43, no. 512, p. 347, text. figs. A-C.

Nonionella stella Cushman and Moyer = Nonionella miocenica stella Cushman and Moyer, 1930. Contr. Cushman Lab. Foram. Research, vol. 6, pt. 3, p. 56, pl. 7, fig. 17.

Oolina melo d'Orbigny, 1839, Voy. Amér. Mérid., Foraminifères, vol. 5, pt. 5, p. 20, pl. 5, fig. 9.

Pateoris hauerinoides (Rhumbler) = Quinqueloculina subrotunda hauerinoides Rhumbler, 1936, Kiel Meeresf., Kiel, Deutschland, Bd. 1, Heft 1, pp. 206, 217, 226, tf. 167.

Pateoris suborbicularis (d'Orbigny) = Quinqueloculina suborbicularis d'Orbigny, 1905. Fornasini, 1905, R. Accad. Sci. Inst. Bologna, Mem. Sci. Nat. ser. 6, tomo 2, p. 67, pl. 4, fig. 3.

Quinqueloculina akneriana bellatula Bandy, 1950, Jour. Paleontology, vol. 24, no. 3, p. 273, pl. 41, fig. 1.

Quinqueloculina lamarckiana d'Orbigny, 1839, in de la Sagra, Hist. Phys. Pol. Nat. Cuba. "Foraminifères," p. 189, pl. 11, figs. 14, 15.

Spiroplectammina biformis (Parker and Jones) = Textularia agglutinans biformis Parker and Jones, 1865, Phil. Trans. Roy. Soc. London, vol. 155, p. 370, pl. 15, figs. 23, 24.

Reophax nanus (Rhumbler) = Reophax nana Rhumbler, 1911, Plankton-Exped. Humboldt - Stiftung, Ergeb., Kiel u. Leipzig, Deutschland, (Bd. 3, L. c., p. 182, pl. 8, figs.

6-12. This species was not distinguished from Ammobaculites exiguus during the population counts.

Textularia earlandi Parker, 1952, Bull. Mus. Comp. Zoology, Harvard, vol. 106, no. 10, p. 458. This species has been reported off the Oregon Coast by Enbysk 1960, under the name Textularia tenuissima Earland 1933. Parker 1952, discovered that name was preoccupied by Haüsler 1881, and gave the species its present name.

Trochammina charlottensis Cushman, 1925, Contr. Cushman Lab. Foram. Research, vol. 1, pt. 2, p. 39, pl. 6, fig. 4.

Trochammina squamiformis Cushman and Mc Culloch, 1939, Allan Hancock Pacific Exped., vol. 6, p. 108, pl. 12, fig. 4. This species was not distinguished from T. charlottensis when the population counts were made.

Trochammina inflata inflata (Montagu) = Nautilus inflatus Montagu, 1808, Test. Brit. Supp., p. 81, pl. 18, fig. 3.

Trochammina inflata macrescens Brady, 1870, in: Brady, G. S., and Robertson, D. Ann. Mag. Nat. Hist., ser. 4, vol. 6, p. 290, pl. 11, fig. 5.

Trochammina kellettae Thalmann, 1932, Eclog. Geol. Helv., vol. 25, no. 2, p. 313.

Uvigerina peregrina Cushman, 1923, Bull. U.S. Nat. Mus., vol. 104, pt. 4, p. 166, pl. 42, figs. 7-10.

APPENDIX F AGGLUTINATED AND CALCAREOUS POPULATIONS, THEIR RATIO TO EACH OTHER AND THE TYPE OF SUBSTRATE FROM WHICH THEY WERE COLLECTED

Station number	Agglutinated population	Calcareous population	Agglutinated/ calcareous	Sediment type	Station number	Agglutinated population	Calcareous population	Agglutinated/ calcareous	Sediment type	Station number	Agglutinated population	Calcareous population	Agglutinated/ calcareous	Sediment type
1	0	19	0	S	26	111	217	.51	M	51	1344	11	*	S
2	0	14	0	S	27	184	52	3.5	M	52	224	19	12	M
3	0	7	0	S	28	14	204	.07	S	53	3778	152	25	M
4	0	6	0	S	29	24	515	.05	S	54	445	28	16	Ma
5	0	9	0	S	30	28	47	.67	S	55	185	7	26	Ma
6	1	10	.10	S	31	4	20	.20	S	56	1062	2	*	Ma
7	2	5	.40	S	32	80	190	.46	MS	57	553	3	*	Ma
8	0	13	0	S	33	8	82	.10	S	58	3344	0	*	Ma
9	194	998	.19	M	34	3	17	.18	S	59	1027	44	23	Ma
10	0	3	0	S	35	233	665	.35	S	60	2287	14	*	Ma
11	3	15	.20	S	36	46	77	.60	MS	61	4269	0	*	Ma
12	2	7	.29	S	37	55	61	.90	MS	62	13	0	*	Ma
13	5	112	.04	S	38	8	10	.8	S	63	5110	0	*	Ma
14	77	25	2.8	M	39	67	256	.26	S	64	611	0	*	Ma
15	170	2	85.	M	40	101	35	2.8	M	65	4851	0	*	Ma
16	388	3	*	M	41	445	343	1.3	M	66	6727	0	*	Ma
17	48	30	1.6	MS	42	323	456	.71	M	67	776	0	*	Ma
18	2	16	.12	S	43	381	403	.95	S	68	423	1	*	Ma
19	41	200	.20	S	44	174	168	1.0	S	69	252	0	*	Ma
20	0	3	0	S	45	1171	69	17.	M	70	26	0	*	Ma
21	40	1878	.02	S	46	311	99	3.1	M	71	1	0	*	Ma
22	12	118	.10	S	47	432	128	3.4	MS	72	0	0	-	Ma
23	4	38	.11	S	48	0	1	0	S	73	1	7	.14	S
24	68	45	1.5	S	49	1421	189	7.5	M					
25	178	98	1.8	M	50	672	52	13.	M					

* => 100; S = Sand; MS = Muddy sand; M = Mud; Ma = Salt marsh

APPENDIX G COLLECTION TIME AND ENVIRONMENTAL NOTES FOR SEASONAL STATIONS

Station number	Sampling Periods 1964 May 2	Jul 14, 15, 22, 23	Oct 10	1965 Jan 22, 23	Feb 6	Apr 16	Remarks
9		X	X	X		X	Boat basin; approximately three meters of water; low energy level; sediment composed of black mud. This environment has proven to be unstable as the April sampling disclosed that the sediment had changed from mud to sand.
*13	X	X	X		X	X	Main channel of the outer bay; very high energy level; sandy bottom free of vegetation.
15	X	X	X	X		X	Muddy bank of a tidal creek; vegetation consists of a thin algae mat; exposed between 60 and 80 percent of the tidal cycle.
*23		X	X		X	X	Main channel midway up the bay; environment similar to station 13.
24		X	X	X		X	Both stations 24 and 25 located in the bottom of a small vegetation-free creek channel on the mud flats; low energy level; sediments are composed of muddy sand at station 24 and soft mud at station 25. Station 25 is subject to near fresh water conditions during normal low tides.
25		X	X	X		X	
30		X	X		X	X	Central bay sand flats approximately 300 meters from shore; moderate energy level; substrate supports a very sparse cover of eel grass; exposed by most low tides.
51		X	X	X		X	Tidal flats approximately six meters from the marsh at the head of the bay; sediment composed of muddy sand; low energy level; algae mats present in small patches; exposed between 60 and 80 percent of the time.
53		X	X	X		X	Bottom of a small marsh tidal creek near its juncture with the bay; sediment is composed of soft black mud; surface covered by thin algal mat and very sparse growth of eel grass. This tidal creek drains only the marsh and has no source of fresh water.
55	X	X		X		X	Bottom of Jackson Creek; low energy level; sediment of soft black mud with a pH of 6.7 and a surface free of all vegetation. This creek drains the marsh but also has a source of fresh water.
56	X	X	X	X		X	Low marsh at the head of the bay; covered at least briefly by all high tides; low energy level; sediment composed of firm black mud with a pH of 7.0. Vegetation consists of a sparse growth of perennials in the latter part of the spring, summer, and early fall.

*Samples taken using a grab. All others were taken with a corer.