AN ABSTRACT OF THE THESIS OF

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Title: THE DISTRIBUTION OF PLANKTONIC DIATOMS IN YAQUINA ESTUARY, OREGON

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C. David McIntire

Plankton samples were obtained from four sampling sites along the Yaquina Estuary, Oregon from the western edge of Yaquina Bay to a point 16.2 km from the river mouth. Collections were made at a high and a low tide at intervals of two weeks from May 26, 1974 to May 20, 1975. Concurrent water samples were taken for the determination of temperature, salinity, and concentrations of nitrate-nitrite, phosphate, silicate and chlorophyll a. Incident light and rainfall data were obtained for the sampling year. Diatoms were identified and counted in samples from 12 selected dates. The relative abundance values of these taxa were utilized for the computation of various community composition parameters (information measure, redundancy, niche breadth, difference values) which were used for comparisons of spatial and temporal distributions of planktonic diatom assemblages within the estuary. Multivariate analyses (clustering, discriminant analysis, canonical correlation) of species and environmental data

were employed to analyze the distribution of planktonic diatom assemblages relative to sampling strategy and to environmental gradients.

The distribution of planktonic diatoms in the Yaquina Estuary was closely associated with hydrographic factors which were regulated primarily by the seasonal changes in rainfall and the introduction of a large volume of fresh water into the river system during the fall and winter months. The spring, summer and fall assemblages demonstrated a distributional continuum corresponding to horizontal gradients of temperature and salinity. Downstream collections were characterized by marineand brackish-water taxa, while upstream communities were dominated by brackish- and fresh-water forms. The assemblages of spring, summer and fall were relatively low in diversity and showed high redundancy of species. In winter the horizontal gradients of temperature and salinity were disrupted by fresh-water runoff, and planktonic diatom assemblages throughout the estuary exhibited a large degree of similarity. Diversity of taxa was maximum at this time, while redundancy was extremely low. These assemblages also exhibited a high proportion of pennate diatoms, indicating dislocation of benthic and periphytic forms from their natural habitat and subsequent inclusion in the planktonic communities.

The statistical analysis indicated that 40% of the variation in the species data could be associated with the environmental variables monitored in this study. Species of Thalassiosira and Chaetoceros were dominant in summer and fall. These taxa indicated strong relationships with higher water temperatures, salinities and light intensities than the flora of winter and spring which was largely comprised of brackish-water and pennate forms (e.g., Melosira spp., Amphiprora alata and Surirella ovata).

The Distribution of Planktonic Diatoms in Yaquina Estuary, Oregon

by

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Redacted for Privacy

Chairman of Department of Botany and Plant Pathology

Redacted for Privacy

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INTRODUCTION AND LITERATURE REVIEW

An estuary is defined as "a semi-enclosed coastal body of water which has free connection with the open ocean and within which sea water is measurably diluted with fresh water derived from land drainage" (Pritchard, 1955). The existence of this transition zone, neutralizing the oceanic influence and acting as a viniculum between the realms of marine and freshwater, creates a unique and perpetually changing environment. The daily rhythm of the tides, involved in an alternating pattern of discord and harmony with the seaward flow of the river, creates turbulent movement of waters. This process results in the chaotic fusion of large water masses which have initially exhibited great differences in physical, chemical and biological properties (Ketchum, 1951, 1952; Campbell, 1973). The continual process of counteraction between ocean and river waters results in wide fluctuations of hydrographic properties in the estuarine zone. Horizontal gradients of physical and chemical parameters are established, extending from the river mouth inland. The length of this horizontal plane of transition is unique to each estuary. In many cases, depending primarily on basin and inlet morphology, vertical gradients may also be observed. The variation

of water properties spans relatively short intervals of time in relation to daily tidal cycles. Broad, large-scaled patterns are found in response to seasonal changes which occur in the volume and chemical composition of river flow (Ketchum, 1951a, 1951b). The characteristic eternal unstabilization of waters is of fundamental importance in the consideration of the biological components associated with an estuarine environment (Pratt, 1959; Frolander, 1964; McConnaughey, 1964; Hedgepeth, 1967).

Assemblages of diatoms in estuarine habitats can be classified as benthic, periphytic or planktonic. Benthic communities[1] are assemblages of organisms associated with bottom sediments. Diatoms occurring in these communities include both epipelic and episammic forms and are usually members of the subdivision Pennatae (McIntire and Moore, unpublished). Epipelic species usually possess a raphe and move freely in the spaces which occur between sedimentary particles. Epipsammic species are non-motile (araphed) and adapted for attachment to individual sand grains. Periphytic refers to biological assemblages which exist in close association with substrates other than benthic sediments (Reid, 1961; Main, 1973). This group includes those organisms which are epiphytic

[1] Due to the variety of definitions for the term community in ecological literature, use in this paper will be confined to the following definition of Williams and Lambert (1959): A community is "a convenient neutral term to denote any set of species growing together without implying a particular statistical or ecological status."

(attached to other plants), as well as those which have colonized the surfaces of large rocks (epilithic), wooden pilings (lignicolous) and other non-living surfaces. Like the benthic diatoms, the majority of diatoms in periphytic assemblages are motile and non-motile pennate forms. Species in these attached communities may secrete mucilaginous stalks and sheaths which allow secure adhesion to substrates (Patrick and Reimer, 1966). Plankton, in the most general sense of the term, refers to life forms which are free-floating in the water column as individuals or colonies (Parsons and Takahashi, 1971). In more recent years, algae represented in this group have been classified to distinguish between cells larger in length or diameter than approximately 10 μm (net plankton) and those with dimensions less than 10 μm (nannoplankton) (Patrick and Reimer, 1966). For simplification, diatoms observed in samples obtained during this study were not partitioned on the basis of size and will be referred to as planktonic, without the distinction of net plankton or nannoplankton.

Although estuarine attached diatoms may outnumber planktonic forms in terms of the number of species and absolute cell counts, diatoms comprise a large proportion of the organisms in phytoplanktonic assemblages of estuarine habitats (Smayda, 1957; Patten et al., 1963; Patten, 1966; Lackey, 1967; Campbell, 1973). The importance of phytoplankton as an essential component in the estuarine ecosystem is well established (Lackey, 1967; Patrick, 1967). As primary

producers, these microscopic autotrophs function as the energy source for the support of successive trophic levels. In this capacity, the presence or absence of phytoplankton essentially determines, and is simultaneously controlled by, the quality and quantity of zooplanktonic, nektonic and benthic herbivores and omnivores in a given area. In many estuarine systems, the interrelationship between the plankton flora and the aquatic fauna is of major economic importance, e.g., fish hatcheries and oyster culture (Ryther, 1969; Parsons and Takahashi, 1971). Planktonic diatoms are also important as a factor in the evolution of oxygen, aiding in the maintenance of a proper energy balance in nature (Hull, 1963; Lackey, 1967; Patrick, 1967).

Planktonic diatoms display a wide variety of morphological adaptions for flotation, e.g., long spines and processes, "bladder" type construction of frustule, threadlike cells and colonies, or markedly flattened valves (Gran, 1912). The classification of planktonic diatoms can be subdivided into three groups on the basis of certain life cycle characteristics: holoplanktonic, meroplanktonic and tychoplanktonic (Hendey, 1964; Patrick, 1967). These terms refer to general, naturally occurring groups and although many species can be easily categorized in this system, holoplankton, meroplankton and tychoplankton do not necessarily constitute mutually exclusive classes.

Holoplankton are the "true" plankton organisms, distinguished by the fact that both their vegetative growth and reproductive functions occur in the pelagic environment. These species are not natural inhabitants of benthic or periphytic assemblages during any phase of their life cycle (Hendy, 1964; Patrick and Reimer, 1966). Holoplanktonic diatoms are oceanic in nature and include nearly all diatoms encountered in the open sea. In the ocean, the existence of large homogeneous units of water provide a relatively stable set of external conditions for resident organisms (Hutchinson, 1961). Moreover, temperature and salinity do not undergo significant fluctuations, and nutrient levels tend to change gradually as the result of biological processes. In contrast to an estuary with continual inflow and outflow of different water masses, the open ocean is more closely analogous to a closed, self-sufficient system. In the North Pacific Ocean, phytoplankton biomass remains fairly constant throughout the year, with a slight increase in the fall related to a decrease in the existing zooplankton population (Heinrich, 1962). The constancy of the phytoplankton standing crop is the result of an equilibrium between phytoplankton production and phytoplankton mortality (Ketchum et al., 1958). Death and disappearance of phytoplankters in the open ocean is due to sinking or grazing. In this environment, these processes tend to establish a stable cycle of nutrient regeneration (Ketchum, 1947; Nielsen, 1958). The frequent occurrence of oceanic diatoms in

coastal and estuarine areas is the result of transport by winds and tides (Patrick, 1967). Survival of holoplanktonic species in these nearshore areas is dependent on the tolerance and adaptability of an organism to the existing environmental conditions.

Meroplankton and tychoplankton are essentially "part-time" members of planktonic assemblages and are the most common constituents of coastal and estuarine planktonic communities. Meroplanktonic diatoms spend only the vegetative phase of their life cycle suspended in the water column. Unlike holoplanktonic species which exist in a relatively stable environment, neritic diatoms must be capable of tolerating daily and seasonal fluctuations in the chemical and physical properties of their habitat. One major adaptation of these plants in estuarine systems and shallow coastal areas is the formation of resting spores which enable survival of the species through adverse external conditions (Patrick and Reimer, 1966). These spores then settle out into benthic communities until favorable conditions will initiate germination and subsequent return to a planktonic existence.[2] Thus, meroplanktonic species are "opportunistic," utilizing the pelagic environment only during periods which are conducive to their growth and well-being (Richerson et al., 1970).

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[2] There are very few diatom species (e.g., Biddulphia aurita) which are known to be capable of reproduction in both the pelagic and benthic habitats (Cupp, 1943).

Tychoplanktonic organisms are actually benthic and periphytic species which have been displaced from their natural habitat by the action of hydrographic processes (Patrick, 1967). These organisms do not reproduce in the water column, and their ability to continue vegetative growth in a planktonic state is uncertain. Tychoplanktonic diatoms are not adapated for a free-floating existence. The residence time of these taxa in the water column is a function of both the specific gravity of the cell and the nature of the prevailing water chemistry and turbulence.

It is generally agreed that there are essentially no holoplanktonic diatoms in freshwater environments. Diatoms observed in plankton samples from lakes, rivers and streams are considered to be meroplanktonic and tychoplanktonic forms. In a river system, these species may originate from the river bed or from the benthic and periphytic communities of upstream impoundments (Butcher, 1932; Patrick, 1948, 1949; Blum, 1956; Lackey, 1964; Patrick and Reimer, 1966). Therefore, the species composition of planktonic diatom assemblages in an estuarine system is a composite of:

1. oceanic plankton species transported into the coastal zone by ocean currents and wind, and carried into the estuary by tidal movements;
2. freshwater benthic and periphytic flora which have been dislocated and transported seaward by the river;

3. freshwater meroplanktonic diatoms, also transported by river currents;
4. benthic and periphytic estuarine forms which have been dislodged by tidal action and/or river flow; and
5. meroplanktonic species indigenous to the estuary.

The initial distribution of diatoms from the various habitats mentioned above is regulated by the circulation and interaction of fresh and salt water (Ketchum, 1951; Patten, 1962). These processes are affected by the geomorphology of the estuary, seasonal changes in current patterns, the degree of difference in the chemical composition of the water masses, and wind action. The actual composition of the resulting planktonic diatom assemblages, in terms of relative abundances of the constituent taxa, is modified by factors inherent in the physiology of each individual organism. Of primary concern is the ability of displaced individuals to adapt and reproduce under a new set of environmental conditions. Oceanic species will be subjected to lower salinities, while freshwater species must be adapted to higher concentrations of salt. These groups must also adjust to changing temperatures and nutrient concentrations. Diatoms dislodged from attached communities may not be capable of maintaining a planktonic existence. The subsequent occurrence of differential reproduction rates among species, along with the selective pressures of the environment, will regulate the relative abundance of each taxon

within the community. Consequently, the structure of an estuarine planktonic diatom assemblage is the net result of a complex pattern of physiological reactions of individuals to their environment and of interactions among species (Patten, 1962; Levandowsky, 1972; Buchanan and Lighthart, 1973).

Major environmental factors affecting the physiological processes that control the development, succession and seasonal cycles of diatom species in estuarine waters are the availability of light energy for photosynthesis and the availability of nutrients (Ryther, 1956; Bolin and Abbott, 1963). A proper balance is necessary between light and nutrients to sustain a phytoplankton population and only the simultaneous abundance of light energy and nutrients will initiate "blooms" of algal cells (Riley, 1942; Ryther, 1956; Small et al., 1972; Sakshaug and Myklestad, 1973). The relationship of sunlight and nutrient concentrations, in terms of phytoplankton production, tends to follow the principle of Leibig's law of minimum (Patrick and Reimer, 1966; Dugdale and Goering, 1967; Parsons and Takahashi, 1971).

The availability of sunlight to phytoplanktonic organisms is directly affected by climatological and hydrographical processes. Incident radiation in most temperate areas of the world is lower during the winter than in the summer months owing to shortened day lengths. In western Oregon, the decrease in incident radiation during

the winter is more pronounced, due to perpetually rainy weather. Seasonal hydrographic patterns of an estuary will affect the quality and quantity of light which penetrates the water column. Large volumes of water from land drainage will cause stratification and also increase turbidity (Armstrong and LaFond, 1966). As a result of these factors, light may become limiting to phytoplankton growth during the winter season and during periods of high freshwater runoff (Taylor, 1966; Welch et al., 1972; Sakshaug and Myklestad, 1973).

Changes in the nutrient concentrations of estuarine waters are related to biological and to hydrographical processes. In a typical system, low biological activity occurs during the winter and results in the accumulation of nutrients. The increase of light levels in the spring, and the presence of a large nutrient pool, stimulate biological activity. Consequently, nutrients are rapidly depleted and remain at low levels throughout the winter (Sverdrup et al., 1942; Ryther, 1956; Smayda, 1957; Ketchum et al., 1958; Armstrong and LaFond, 1966). Freshwater runoff is a major source of nutrients in an estuary. The increase in river flow during rainy seasons is associated with the leaching of organic and inorganic compounds from terrestial areas and their subsequent transport to aquatic habitats (Ketchum, 1967). Land drainage provides large volumes of fresh water which alter the salinity and temperature of the estuary. The balance of nutrients is affected by the exchange of materials between the water column and

the river bottom (Wood, 1956). These exchanges are highly correlated with the degree of mixing which occurs within the system. Recycling of nutrients through grazers and the natural decomposition of organisms in the water column also contribute to the dynamics of the nutrient cycles. Supplemental to these processes which occur in all estuaries, river systems along the Oregon coast are subjected to periodic upwellings of deep ocean water. The surfacing of relatively cold, nutrient-rich water masses adjacent to river mouths results in the transport of these nutrients into the estuary by the tides. The extent to which these waters are carried upstream is unique to the dynamics of each estuarine system.

The occurrence of grazing (most especially if it is selective) can greatly affect the development and succession of a planktonic diatom community. Studies concerned with the effect of grazing on the structure of diatom assemblages and the dynamic relationships between zooplankton and phytoplankton communities have been approached in many ways. The results of such investigations and the development of deterministic mathematical models are found in numerous publications (Fleming, 1939; Clark, 1939; Riley, 1946; Riley and Bumpus, 1946; Rice, 1954; Nielsen, 1958; Cushing, 1959; Hellier, 1962; McDonnell, 1965; Parsons et al., 1967; Martin, 1968; McAllister, 1970). In Yaquina Bay, Deason (1975) conducted an in situ study of the differences in the short-term development of

grazed and ungrazed phytoplankton assemblages. In this work, it was concluded that zooplankton grazing in the estuary is a selective process and plays a major role in the productivity and taxonomic structure of local phytoplanktonic communities.

The monitoring of hydrographical and biological patterns in an estuary, in terms of time and space, can result in the accumulation of a large number of observations. Many mathematical methods have been developed for the analysis of this type of ecological data. One approach to the statistical interpretation of taxonomic structure within and among phytoplankton communities involves the estimation of community composition parameters (e.g., diversity statistics). The general concept of diversity implies both species richness and the equitable distribution of individuals among the taxa. Diversity is considered to be an important property of natural assemblages of organisms. Numerous equations have been proposed for the determination of diversity within a community. From these, additional species composition parameters have been derived, e.g., redundancy and similarity measures (Fisher et al., 1943; MacArthur, 1955; Margalaef, 1958; Hairston, 1964; Pielou, 1965, 1966a, 1966b, 1966c; McIntosh, 1967; Hurlbert, 1971). The choice of a particular set of composition parameters depends on how an investigator wants to scale his data for interpretation. Such decisions are governed by the objectives of a specific study. Diversity indices and associated

measures can be utilized to compare communities separated in time or space in relation to their taxonomic structure and to discern patterns of species succession, as well as spatial heterogeneity of assemblages in a given area (Margalaef, 1958).

The data can also be subjected to clustering processes which will identify closely associated assemblages of organisms. This approach is often used to identify recurrent groups of taxa (McConnaughey, 1964; Pritchard and Anderson, 1971; Allen and Koonce, 1973). Cluster analysis has been successfully applied to planktonic diatom assemblages in the North Pacific Ocean by Vernick (1971) and to attached diatom assemblages in the Yaquina Estuary by Main (1973) and McIntire (1973). Clustering of communities or species often provides insight into relationships between biological and environmental variables. In addition to classification procedures, species and environmental data can be subjected to various multivariate analyses, such as principal component, canonical correlation and discriminant analysis (Seal, 1966; Morrison, 1967; Cooley and Lohnes, 1971; Cassie, 1972a, 1972b; McIntire and Moore, unpublished). Selection of a specific multivariate procedure is also dependent on the sampling strategy and purpose of the investigation.

Implicit in the application of a statistical method is the assumption that a particular algorithm will "reveal an underlying

structure simpler than that of the raw matrix of association" (Williams and Lambert, 1959). A mathematical analysis of ecological data can only serve as an aid to interpretation of results. The statistical reduction of data implies that a certain proportion of the information contained in the data set will be uninterpretable. However, for the determination of basic trends in community structure and the relationships between species and environmental variables, statistical analyses of observations may disclose patterns otherwise obscured in large, complex data sets.

Purpose of the Study

The purpose of the study reported in this thesis was to determine the spatial and temporal distribution of planktonic diatoms in the Yaquina Estuary, and to relate such distributional patterns to selected climatic and hydrographical factors. This work was oriented toward both the autecology of dominant taxa and relationships, relative to taxonomic structure, between the various diatom communities present. Previous field studies of the phytoplankton of the Yaquina Estuary include the work of Deason (1975) and current physiologically-oriented investigations by Frye, Head and McMurray (unpublished). A series of studies on the diatom flora of attached communities has been conducted within the past seven years. McIntire and Overton (1971) described distributional patterns of diatoms colonizing

artificial substrates of polyvinyl chloride (PVC). In this study, diatom assemblages were analyzed relative to gradients of salinity, temperature and desiccation, and to seasonal changes in solar radiation. Riznyck (1969, 1973) studied the horizontal and vertical distribution of benthic microalgae on two tidal mud flats in Yaquina Bay, and Martin (1970) investigated the effects of salinitv on the distribution of benthic diatoms in the Yaquina River. Epiphytic diatoms of the Yaquina Estuary were characterized by Main (1973) and McIntire (1973). These data revealed that epiphytic assemblages were similar to the assemblages that developed on PVC substrates (McIntire and Overton, 1971). At the present time, the diatom flora of the intertidal sediments of the estuary is being investigated by Amspoker (unpublished). Additional ecological studies of planktonic organisms in the estuary have involved seasonal cycles in zooplankton populations and the distribution of Foraminifera (Manske, 1968; Zimmerman, 1972; Frolander et al., 1973). The results obtained in the present work will contribute further information about biological and physical processes within the Yaquina Estuary, and may provide some basis for future investigations.

DESCRIPTION OF YAQUINA ESTUARY

The Yaquina River is located along the central portion of the Oregon coast at 44°37' north latitude, and enters the Pacific Ocean near the town of Newport (Fig. 1). The estuary is classified as a drowned river or coastal plain type (Burt and McAllister. 1959; Baldwin, 1964). The general characteristics of coastal plain estuaries include: (1) the formation of a delta by deposition of sediment by river water; (2) the existence of a shallow basin; and (3) a large degree of variability in the physical and chemical properties of the water mass that results from changes in such environmental factors as air temperature, sunlight, wind and freshwater runoff (Marmer, 1932; Frolander, 1964; Cronin and Mansuetti, 1971).

During the past 90 years, the mouth of the Yaquina River has been continually modified by man to prevent the deposition of sediment and the subsequent formation of a delta.[3] The entrance to the estuary is presently projected in a seaward direction beyond the natural coastline by the construction of two jetties which establish an initial inlet width of 305 m (Percy et al., 1973). This distance gradually increases until Yaquina Bay is reached at river kilometer 3.5. Maximum width of the bay is 3.2 km across two extensive and

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[3] In the Yaquina River system sedimentation averages 30,000 tons per year (Atkins and Jefferson, 1973; Percy et al., 1973).

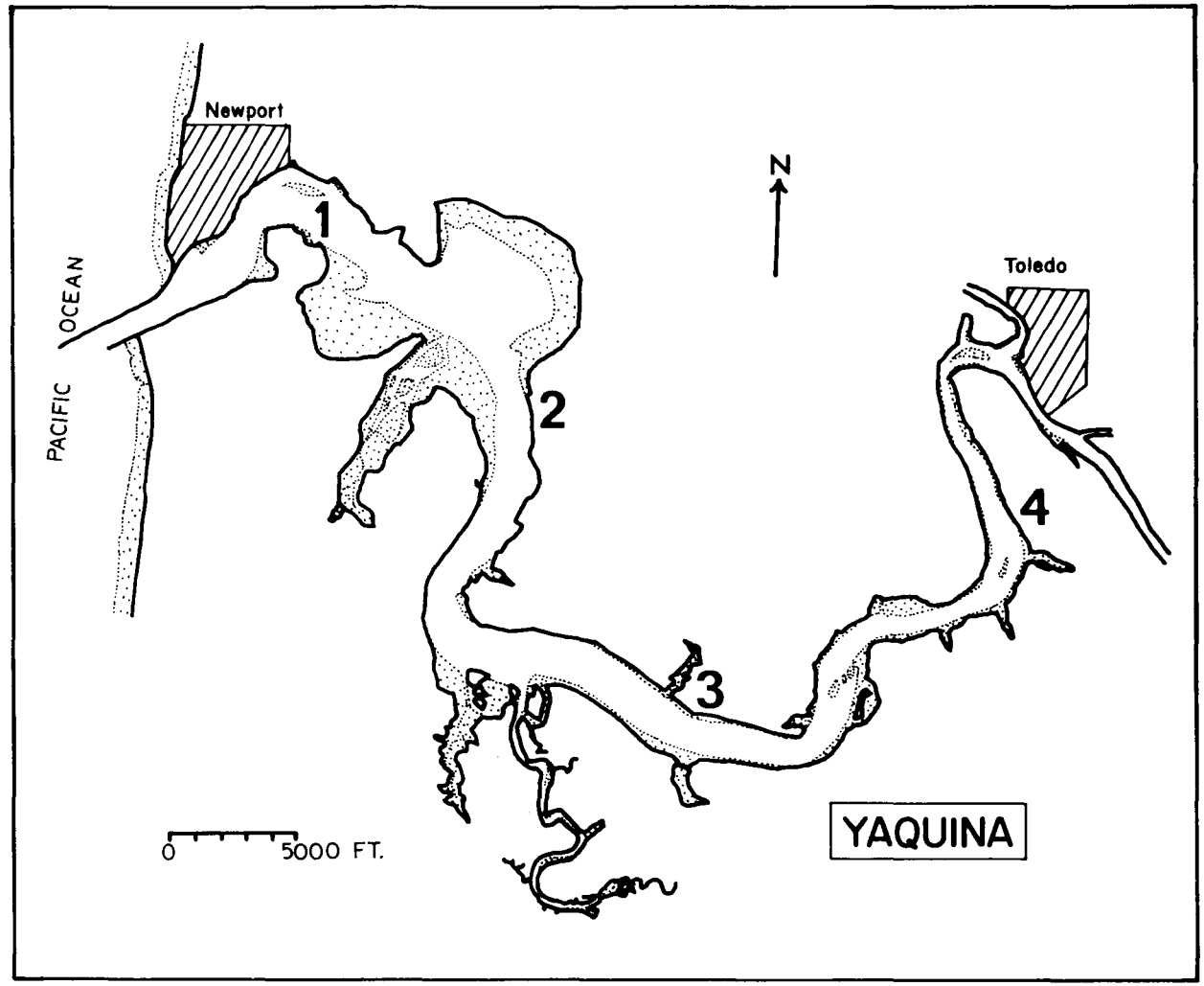

Figure 1. Yaquina Bay and Estuary, Oregon. Numbers indicate locations of four sampling stations.

highly productive tidal mud flats and the total area encompassed by the tidelands in the bay is 548 sq km (Kulm and Byrne, 1966; Atkins and Jefferson, 1973). The Army Corps of Engineers supervise periodic dredging operations in order to maintain a channel depth of approximately 7.3 m from the end of the jetties to the eastern side of the embayment (Kulm and Byrne, 1966; Percy et al., 1973). Beyond the bay, the river extends 85 km to its origin as its width and depth dimensions gradually decrease (River Mile Index, 1968).

The Yaquina Estuary is subjected to mixed semi-diurnal tides which are typical along the northwestern coast of the United States (Neal, 1966; McIntire and Overton, 1971). The upstream limit of observable tidal influence, in terms of water elevation and salt intrusion, is at river kilometer 42 near Elk City, Oregon (Kulm and Byrne, 1966; McIntire and Overton, 1971; Percy et al., 1973). The mean tidal range within the river is 1.65 m, mean tidal level is approximately 1.3 m, and the tidal prism is 2.4×10^7 m^3 (Goodwin et al., 1970; Percy et al., 1973). A lag period from 30 to 60 minutes occurs between the time of the tide change at the mouth of the estuary and a corresponding change at Toledo, Oregon, the farthest upstream point sampled for this study (Neal, 1966; Goodwin et al., 1970).

Within a complete tidal cycle, approximately 70% of the water in the bay is exchanged with ocean water (Goodwin et al., 1970; Frolander et al., 1973). As a result, the physical and biological

properties of the water in Yaquina Bay resemble those of adjacent coastal waters. Upstream beyond the bay, exchange with oceanic waters lessens, while horizontal mixing within the system is increased. The most obvious reason for this phenomenon is the increased distance from the river mouth, but the effect is magnified by the twisting nature of the river's course which tends to obstruct free interchange between upstream and bay waters. The relatively shallow depth and narrow width at the eastern end of the bay, also allows for a greater influence of movement of incoming and outgoing tides on the internal structure of water masses which are, in a sense, "trapped" between the bends and turns of the river.

Climate along the central portion of the Oregon coast offers relatively cool, dry summers and warm, wet winters. Water temperatures during the winter and spring are cooler than those of summer and fall due to seasonal patterns of insolation and rainfall. Temperatures in the bay are considered to remain fairly stable throughout the year, while upstream areas exhibit temperature differences of 10 to 15 C between winter and summer readings. The yearly pattern of precipitation in the Newport area is most clearly reflected in the seasonal fluctuations in salt concentrations, freshwater discharge, and sedimentation which occurs in the river (Burt and McAllister, 1959; Kulm and Byrne, 1966; Manske, 1968). The rainy season begins in late fall and continues throughout the winter

months. After four to eight weeks of rainfall, the land, which becomes parched during the prevailing dry conditions of summer, reaches a point of saturation sufficient to allow runoff into the river system (Kulm and Byrne, 1966). The large volumes of fresh water introduced at this time do not become evenly integrated with the marine and brackish waters of the estuary, so that during winter and spring the estuary is classified as a partially mixed system (Burt and McAllister, 1959; Kulm and Byrne, 1966). There is a sharp decline in salinity values throughout the river with the onset of freshwater runoff, and the greatest seasonal changes in salinity tend to occur in the central portion of the estuarine system. A vertical salinity gradient is established during the period of incomplete mixing in winter and spring. Salinity differences of 4 to 19‰ have been recorded between surface and bottom waters at this time. In addition to stratification of the water column, maximum transport and deposition of sediments also occur at this time, increasing the turbidity of the water. In a partly mixed state, the net upstream movement of water is along the river bottom, while a net downstream movement exists at the surface (Burt and McAllister, 1959).

As summer approaches, runoff volumes into the river are reduced due to a decrease in precipitation. The absence of large freshwater inflow allows for a more complete mixing of marine and fresh water, transforming the estuary from a partially mixed to a

well mixed system (Burt and McAllister, 1959; Kulm and Byrne, 1966). The well mixed condition continues through summer and fall. The vertical salinity gradient established in winter and spring is non-existent at this time, and the difference between surface and bottom values is rarely greater than 3‰ (Burt and McAllister, 1959). As summer proceeds there is a gradual increase in the overall salinity of the estuary. Along the Oregon coast, upwelling begins in mid or late summer. The colder, more saline nutrient-rich waters of the deep ocean are brought to the ocean surface and subsequently carried into the bay (Manske, 1968). The phenomenon of upwelling, along with the lack of land drainage to dilute the upwelled waters, are the major contributing factors to the summer increase in salinity. The well mixed condition at this time results in a net non-tidal seaward drift of estuarine water, rather than distinct upstream and downstream currents characteristic of winter and spring when the river is partially mixed. During this period of complete mixing, transport and deposition of sediments is greatly reduced, and the water becomes less turbid relative to the winter and spring months.

METHODS AND MATERIALS

Sampling Methods

Four sampling stations were established along the Yaquina River from Newport to Toledo, Oregon (Fig. 1). Stations were located on boat docks which extended into or near the central channel of the river. Station 1 was on the South Beach boat dock of the Oregon State University Marine Science Center, near Newport. This station was situated at the western end of Yaquina Bay, 2.4 km from the river mouth. Station 2 was located at Sawyer's Boat Landing in Yaquina, Oregon (river kilometer 6.4), a short distance from the eastern edge of the bay. Station 3 was established on a boat dock owned by Mr. Jack Rowland at river kilometer 11.3; and station 4 was at the Toledo Public Boat Launch, 16.2 km from the river mouth.

A total of 208 water samples was collected on 26 days, at approximately two-week intervals, for a period extending from May 26, 1974 to May 20, 1975. Samples were obtained at high and low tide at each station on every collecting date. Throughout this paper, samples will be referred to by a station number (1, 2, 3 or 4) followed by an H or an L to designate high or low tide (i.e., 1H indicates a collection made at station 1 at high tide). These water samples were analyzed for species composition, and concentrations of

chlorophyll *a*, nitrate-nitrite, phosphate and silicate in the estuary. Sampling began at station 1 and time of collection was based on the predicted times of each tide as recorded in the 1974 and 1975 tide tables (National Oceanic and Atmospheric Administration, 1974, 1975). An average of 50 minutes was required to complete a sampling series on each tide from station 1 at the O.S.U. Marine Science Center to station 4 at the Toledo Public Boat Launch. Water samples were obtained from approximately 0.75 m below the surface. The water sampler was a 1 gal (3.785 l) plastic jar fastened to a wooden rig. The lid was connected to the bottom of the jar by a short length of rubber tubing. A metal chain was fastened to the upper surface of the lid to allow opening and closing of the sampler at the desired depth. The wooden frame was submerged four or five times at each station, and the water was transferred to a large plastic bucket. At this time, temperature and salinity readings were taken with a salinity-temperature meter (Yellow Springs Instrument, model #33).

In the field, a subsample of 100 to 250 ml for nutrient analyses was transferred to a polyethylene bottle and immediately stored in dry ice. An additional two liters of the sample were transferred to polyethylene bottles to be used in the determination of the concentration of chlorophyll *a*. The remaining portion of the sample was reserved for the identification and enumeration of the diatom species present.

Nutrient Analyses

The frozen subsamples retained for nutrient analyses were rapidly thawed by submerging the containers in hot water. Quick thawing is recommended for the analysis of nitrate-nitrite and phosphate concentrations, while slow thawing is suggested for the determination of silicate (Mateson, 1964). Since the same water sample was to be used for all three analyses, samples were processed to provide the most accurate determination of nitrate-nitrite and phosphate. Nutrient analyses were performed by a Technicon Autoanalyzer I and a Technicon Autoanalyzer II. Procedures were based on methods of Armstrong et al. (1967) and Bernhardt and Williams (1967) as modified by Atlas et al. (1971).

Analysis of Chlorophyll a

Determinations of the concentration of chlorophyll a were made using a modification of the method described by Strickland and Parsons (1968). The major alteration from their standard procedure was the filtration of samples through 3 μm micropore membrane filters rather than the recommended 0.45 μm filters. This modification was necessary because of the high turbidity of the water during most of the year. Usually two filters were required to extract an adequate concentration of pigment for analysis. After filtration, a

small amount of concentrated $MgCO_3$ (1 g/100 ml) was passed through the filters which were then ground for 10 minutes with 90% acetone in a small Waring blender. The blender was packed in ice to prevent destruction of chlorophyll by frictional heat. The extract was transferred to a vial and placed in a freezer overnight. The extracts were then centrifuged, and absorbancies of the supernatant were determined on a Beckman D-10 spectrophotometer at wavelengths of 480, 630, 645, 665 and 750 nm. The equations of Strickland and Parsons (1968) were employed to calculate the concentrations of chlorophyll a.

Collection of Climatic Data

Incident radiation was measured with two Eppley pyranometers located at the O.S.U. Marine Science Center, Newport, Oregon. One pyranometer recorded total incident radiation, while the other measured filtered radiation approximately equivalent to the visible or photosynthetically-active spectrum of light. Rainfall data were obtained from Mr. Clayton Creech at the O.S.U. Marine Science Center, Department of Physical Oceanography. Daily measurements of precipitation were taken with a tipping bucket (Weather Measure, model #p-501).

Analysis of Community Structure

Approximately 12 l of the original sample were filtered through

a small plankton net constructed of NITEX (registered trademark of Tobler, Ernst, and Traver, Inc.) nylon monofilament high-capacity screen cloth with mesh openings of 10 μm (4% open area). The use of this net allowed for rapid filtration of water and resulted in retention of nearly all diatoms in the sample. This procedure eliminates selectivity frequently encountered in towing a net and allows for a precise measurement of the volume of water to be filtered (Biological Methods, 1969). Salt and fine particles of sedimentary or detrital matter was eliminated by repeated rinsings with distilled water. Filtrates were periodically refiltered on 1.2 μm or 3.0 μm micropore filters. These filters were then cleared with immersion oil and scanned under the microscope to determine the efficiency of the NITEX net. Occasionally a few ?Cyclindropyxis sp. or narrow pennate forms were observed, but this amount of error--on the order of only several cells out of thousands--had a negligible effect on the final cell counts.

The concentrated samples of phytoplankton were preserved in 70% ethanol. Several drops of a sample were dried on a number 1-1/2 coverslip which was then inverted over a drop of pleurax on a microscope slide (Hanna, 1947). To avoid destruction of delicate and weakly silicified forms, cells were not subjected to any type of clearing process other than heating on a hot plate. Four slides were made from each of the 208 samples. A complete set has been

deposited in the herbarium of Dr. C. David McIntire, Department of Botany and Plant Pathology, Oregon State University. Diatom taxa were identified with a Zeiss standard research microscope. Species or genera which could not be identified were labeled numerically. Whenever applicable, the number designations corresponded to those previously assigned to unknown taxa in the Yaquina Estuary. Drawings and measurements were made for each of the unknowns.

Cell counts were made on slide sets from 12 of the 26 sampling dates (total of 96 individual collections). Selection of the sets to be counted was made in relation to the rate of change in community structure. During May and June of 1974 the community structure of planktonic diatom assemblages in the Yaquina Estuary underwent relatively rapid changes, and samples obtained at two week intervals were quantitatively evaluated. From July to November of 1974, a slower rate of succession was observed, and cell counts from this period were made once each month. Samples obtained from December 1974 to March 1975 revealed a relatively sparse, but diverse flora. A sample set from February was selected to represent the characteristics of community structure which occurred at this time. Bi-monthly counts were resumed in the spring of 1975.

The relative abundances of the taxa in each assemblage were determined by identifying and counting the first 500 cells encountered on each slide. The value of 500 was based on the conclusions of

McIntire and Overton (1971), who determined the effects of sample size on the estimation of community composition parameters for assemblages of benthic diatoms in the Yaquina River. They found that values for such parameters change very little as sample size is increased above 300 cells.

The enumeration of individuals was based on the occurrence of whole cells; i.e., diatoms were counted only if both valves were present and unbroken (broken cells were counted if all fragments appeared to be present). The procedure of counting only entire frustules was possible because no harsh type of clearing process was employed in the mounting procedure. This approach reduced the error encountered when acid cleaning or a similarly destructive method is used. Such procedures often result in the separation of the epitheca and hypotheca of the diatom frustule. The subsequent enumeration of single valves is non-discriminatory toward the inclusion of non-living cells from the original sample into the resulting set of observations. When chain-forming species were encountered, each cell in the chain was recorded as a single individual (Margalaef, 1968). Spores occurred randomly throughout the samples; whenever possible, these were identified and recorded as individuals of their respective species.

Data Analysis

A detailed mathematical description of the statistical methods employed in this study will not be given in this thesis. However, some of the mathematical principles underlying the analyses of the biological data will be presented and references for the mathematical theory will be cited. All computations were performed on a Control Data Corporation 3300 computer (*AIDONE, *AIDN, *CLUSB and *BMD07M programs) and a Control Data Corporation CYBER 70 computer (CORREL and CANON programs from Cooley and Lohnes, 1971).

Community Composition Parameters

The common information measure (H') and a redundancy index (REDI) were calculated for each of the 96 samples. A discussion of these indices has been presented by Pileou (1965, 1966, 1966b, 1966c, 1969) and Margalaef (1958). Both statistics allow for a numerical expression of community structure in relation to certain species composition characteristics of a given assemblage of organisms. H' is estimated by

$$H' = -\sum_{i=1}^{S} \left(\frac{n_i}{N} \log_e \frac{n_i}{N}\right),$$

where S equals the number of species in the sample, n_i is the number of individuals of the i^{th} species, and N is the total number of

organisms in the sample. H'' represents a quantitative evaluation of species richness and equitability within a community. H'' is zero when all individuals in a sample are of the same species. Maximum value is obtained when each individual is from a different taxon. The magnitude of H'' will increase for a given N as the number of species increases, and as individuals become more evently distributed among the taxa.

Conditional maximum $[H''_{(max\,|\,S)}]$ and minimum $[H''_{(min\,|\,S)}]$ values of H'' for a given number of species S and sample size N are computed from the expressions

$$H''_{(max\,|\,S)} = \log_e S$$

$$H''_{(min\,|\,S)} = -\left[\frac{S-1}{N} \log_e \left(\frac{1}{N}\right) + \left(\frac{N-S+1}{N}\right) \log_e \left(\frac{N-S+1}{N}\right) \right] .$$

It follows that a measure of redundancy is

$$REDI = \frac{H''_{(max\,|\,S)} - H''}{H''_{(max\,|\,S)} - H''_{(min\,|\,S)}} .$$

REDI is a species composition parameter which expresses the degree of dominance in a given assemblage relative to the partitioning of individuals among species. Values of REDI range from 0 when individuals are equally distributed among the taxa to 1 when all but one species are represented by a single individual.

The niche breadth of an individual species (B_j) is calculated from

$$B_j = \exp\left[-\sum_{i=1}^{Q} \left(\frac{n_{ij}/N_j}{R_j}\right) \log_e \left(\frac{n_{ij}/N_j}{R_j}\right)\right]$$

where

$$R_j = \sum_{i=1}^{Q} \frac{n_{ij}}{N_j}, \text{ and}$$

n_{ij} is the number of individuals of the j^{th} taxon in the i^{th} sample, and N_j is the total number of individuals of the j^{th} taxon observed in Q samples. B_j is an expression of the ability of a particular taxon to do equally well at all sample sites relative to the other taxa under consideration. Its value ranges from 1 when the taxon is present in only one sample to Q when it is equally common in all samples. B_j may or may not be directly related to abundance, as a rare species can have the same niche breadth value as an abundant species. B_j was computed for each species in terms of its occurrence in the eight samples of each collection date. These values could range from 1 to 8. Niche breadth values also were computed for the 148 most abundant taxa based on the observations from collections obtained at high tide on eight of the 12 sampling days (May 26, June 23, August 19, September 16, November 17 of 1974 and February 22, April 20, May 4 of 1975). This analysis involved 32 diatom assemblages, establishing a possible range of niche breadth values from 1 to 32.

These latter values reflect both the temporal and spatial occurrence of each taxon.

MacArthur's difference measure (D_{hk}) is a statistic that expresses the degree of difference between the taxonomic structure of two communities (MacArthur, 1965). The magnitude of difference is determined by

$$D_{hk} = \exp (H''_T - \overline{H}''),$$

where H''_T is the common information measure for the combined h^{th} and k^{th} assemblages treated as one community, and $\overline{H}''$ is the mean H'' value for the two individual assemblages. These terms were computed from

$$H''_T = - \sum_{i=1}^{S} \left[\frac{(n_{ih}/N_h + n_{ik}/N_k)}{2} \log_e \frac{(n_{ih}/N_h + n_{ik}/N_k)}{2} \right]$$

and

$$\overline{H}'' = \frac{(H''_h + H''_k)}{2} .$$

The value of D_{hk} ranges from 1.00 when the pair of communities is identical in term of taxonomic structure (same taxa and equitability) to 2.00 when the assemblages have no taxa in common. MacArthur's difference measure was computed for all possible pairs of the eight samples within each collection series.

Multivariate Methods

Environmental variables included in the multivariate analyses

performed were: rainfall, visible radiation, water temperature, salinity, concentrations of nitrate-nitrite, phosphate and silicate, the ratio of nitrate-nitrite to phosphate concentration, tidal height, and concentration of chlorophyll a. The species data set was reduced to include only the 20 most prominent taxa, and their relative abundance values were subjected to transformation and standardization. The reduction in the rank of the species data matrix served to eliminate numerical "static" which may be caused by the pretentious incorporation of less abundant and rare species into an analytical scheme designed to evaluate broad patterns and relationships between selected variables (Austin and Greig-Smith, 1968). Transformation of relative abundance values and standardization of species and environmental data are expressed by

$$Y_{ij} = \log_e (Y^*_{ij} + 1),$$

$$Y_{ij} = \frac{(Y_{ij} - \overline{Y}_j)}{s_j}, \text{ and}$$

$$x_{ik} = \frac{(X_{ik} - \overline{X}_k)}{s_k}.$$

Y^*_{ij} represents the relative abundance of species j in the i^{th} sample, X_{ik} is the value of the environmental variable k associated with the i^{th} sample, $\overline{Y}_j$ and $\overline{X}_k$ are means and s_j and s_k are standard deviations corresponding to Y_{ij} and X_{ik} (Cassie and Michael, 1968). In this case the logarithmic transformation of cell counts yielded higher

correlations within the species data matrix and between the species and the environmental variables than the raw data.

A correlation matrix corresponding to a combined matrix of species and environmental variables was calculated. A canonical correlation analysis of this matrix was performed to examine the interrelationships between 20 selected taxa and ten environmental variables. Canonical correlation analysis attempts a holistical correlation of two matrices. The process finds linear combinations that will maximize the correlation between the two sets of data (Cooley and Lohnes, 1971; Cassie, 1972). Geometrically, canonical correlation can be described as the degree to which individual observations will occupy the same relative position in the two realms of measurement space established by the data matrices (Cooley and Lohnes, 1971). The canonical correlation algorithm progresses in a sequential manner, such that successive functions are orthogonal. The number of linear combinations obtained from this analysis is equal to the rank of the smaller of the two original data matrices. Criteria for the statistical significance of each canonical correlation coefficient are outlined by Cooley and Lohnes (1971). Output from the canonical correlation program included:

1. The factor structure matrices for the species and environmental variables (i.e., the correlation matrices between the canonical variables and the original variables);

2. the amount of total variance extracted from each data matrix during the analysis; and
3. the amount of redundancy in each data set, given the other set.

To examine diatom distribution relative to the sampling strategy, the 96 samples (assemblages) were clustered over 20 dimensions (taxa). The clustering method determined the minimum variance partition of a set of n observations in p dimensions into k clusters. The algorithm is an iterative approach which terminates when no observation can be shifted to another group and the within cluster variance reduced (McIntire, 1973). In this study, a nine cluster structure was considered biologically significant in terms of expressing broad seasonal and spatial relationships. Further partitioning of the data into more than nine clusters generated groups containing three observations or less.

The species matrix, reordered in terms of the nine clusters, was subjected to a stepwise discriminant analysis to determine the degree of cohesiveness with a cluster, and to ascertain the degree of intergradation among the various clusters. A stepwise discriminant analysis involves the successive additions of species variables into the discriminant model in the order of their relative ability to discriminate. The determination of the discriminanting ability of a given species is based on certain criteria which have been outlined by Sampson (1967). In general, these criteria involve F values,

multiple correlation coefficients and variance ratios. The details of the mathematical theory of discriminant analysis are discussed by Cooley and Lohnes (1971). Essentially, the discriminant function generated for each variable is the result of the reduction of a number of observations in multidimensional space to single points on a canonical axis which maximizes the ratio of the among group sum of squares to the within group sum of squares. Orthogonal canonical variables can be plotted against each other to determine the relationships between the original m cluster groups in m-1 or less dimensions. A discriminant analysis was also performed on the environmental data matrix. This matrix was restructured to correspond with the nine clusters obtained from the species observations.

RESULTS

Chemical and Physical Properties of the Yaquina Estuary

From May 1974 through May 1975 a total of 184.1 cm of rain fell in the area of the Yaquina River (Fig. 2). Measurable precipitation occurred on 204 days during this period. Monthly totals of rainfall ranged from 0.3 cm in August 1974 to 32.6 cm in January 1975. From May through July 1974 rainfall averaged approximately 6.0 cm per month. In August, September and October, values decreased to less than half of this average figure. The onset of the rainy season occurred in November when the rainfall total increased 26.6 cm over the total of the previous month. High monthly values (22 to 32 cm) were observed throughout the winter months until April 1975.

Mechnical malfunctions interferred with the operation of both pyranometers at various times during the sampling period. Since data from the past seven years exhibited nearly identical values and patterns for yearly solar radiation, the pyranometer records for 1972 and 1973 were utilized to fill gaps in the data collected during 1974 and 1975. Seasonal patterns of incident radiation were inversely related to patterns of precipitation (Figs. 2 and 3). Highest values were obtained from May through August of 1974, and corresponded to the period of minimum rainfall. During this time, a mean of

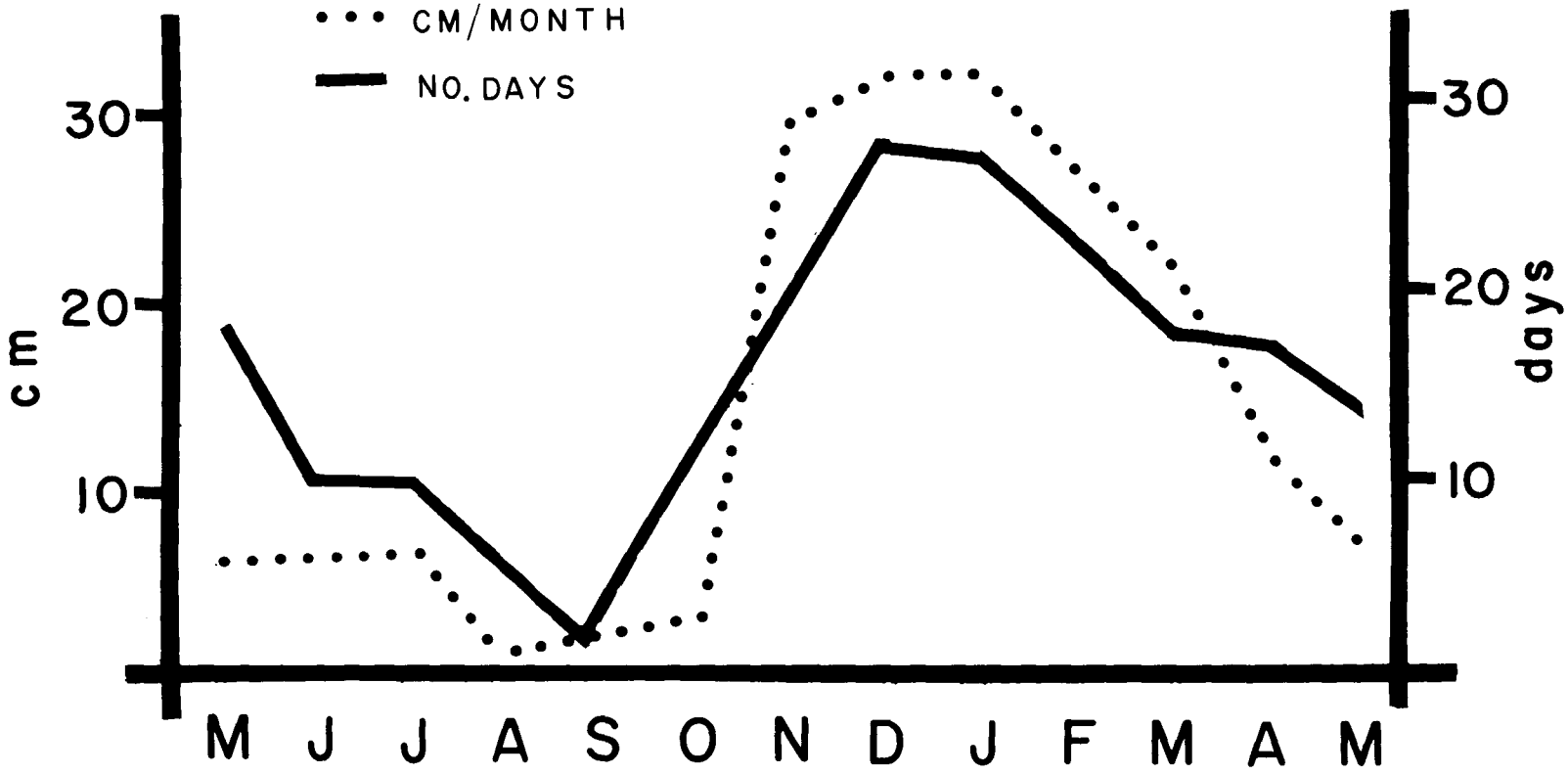

Figure 2. Monthly total rainfall (cm) and number of days of rain which occurred in the vicinity of the Yaquina Estuary from May 1974 to May 1975.

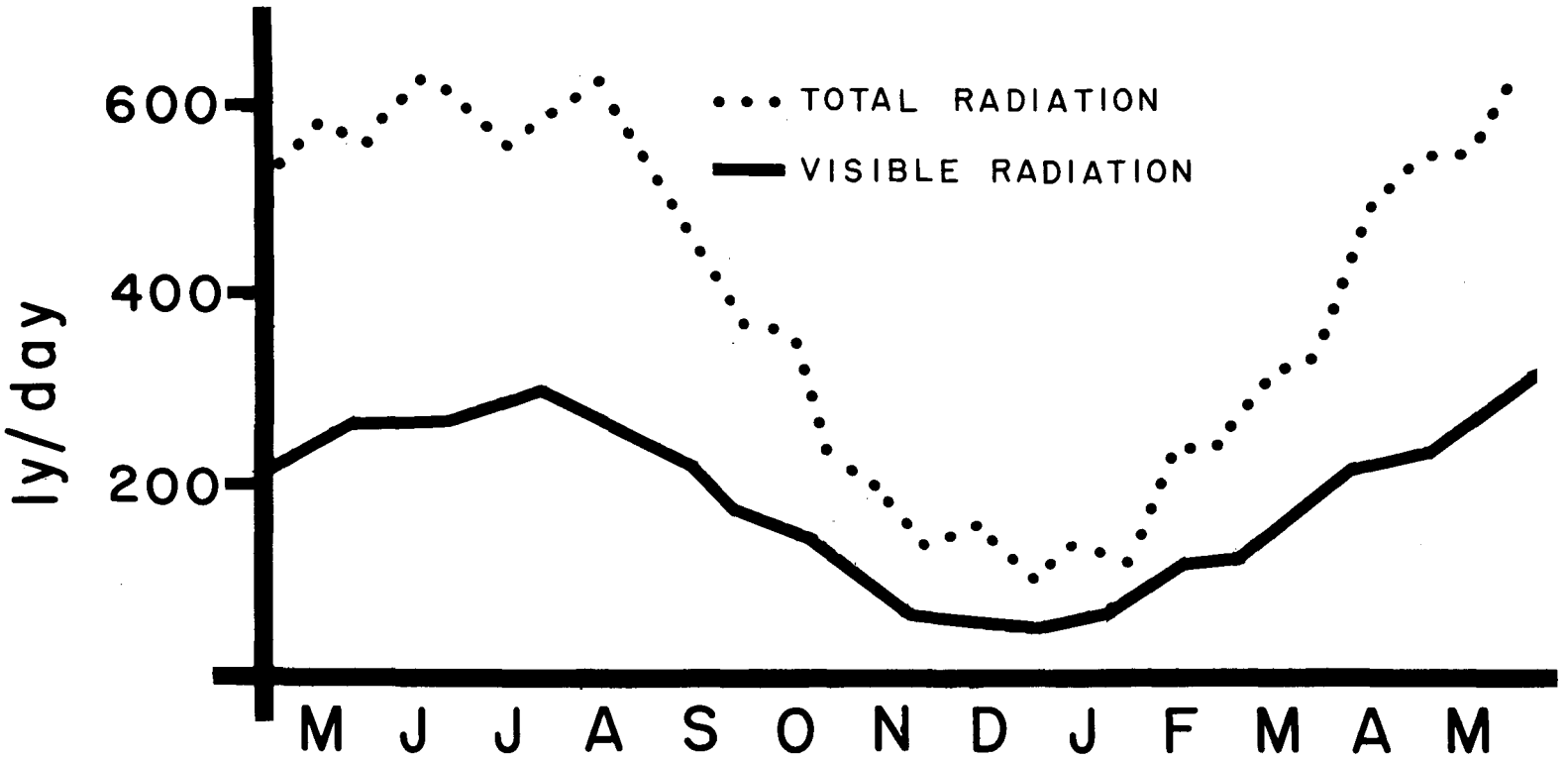

Figure 3. Yearly pattern of light intensities (ly/day) in the vicinity of the Yaquina Estuary based on data obtained from May 1972 to May 1975.

560 ly/day was recorded for total incident radiation, and a mean of 275 ly/day was recorded for visible light. Solar radiation decreased through the fall and early winter months, reaching a minimum level in December of 1974. Total incident insolation averaged 125 ly/day during December and January, while visible radiation averaged 60 ly/day. From February through May 1975, a gradual increase occurred in both total and visible incident light.

Total incident radiation and radiation in the visible wavelengths exhibited identical seasonal patterns relative to periods of increase and decrease. However, they did not exhibit consistent differences in intensity. From April to September 1974, monthly averages of the daily difference between total and visible radiation varied from 350 to 250 ly. This difference decreased through fall, and was approximately 115 ly by mid-winter. This phenomenon was probably the result of selective filtration of light by the omnipresent cloud cover of the fall, winter and early spring skies.

Similar seasonal patterns of salinity were observed at all stations (Fig. 4). Highest values were obtained from August through November. A sharp decline in concentration occurred throughout the estuary in late November, concurrent with the initial period of high freshwater discharge. Salinities remained at relatively low levels from December through May, and demonstrated a relatively large degree of variability during this time. Station 1 exhibited a range of

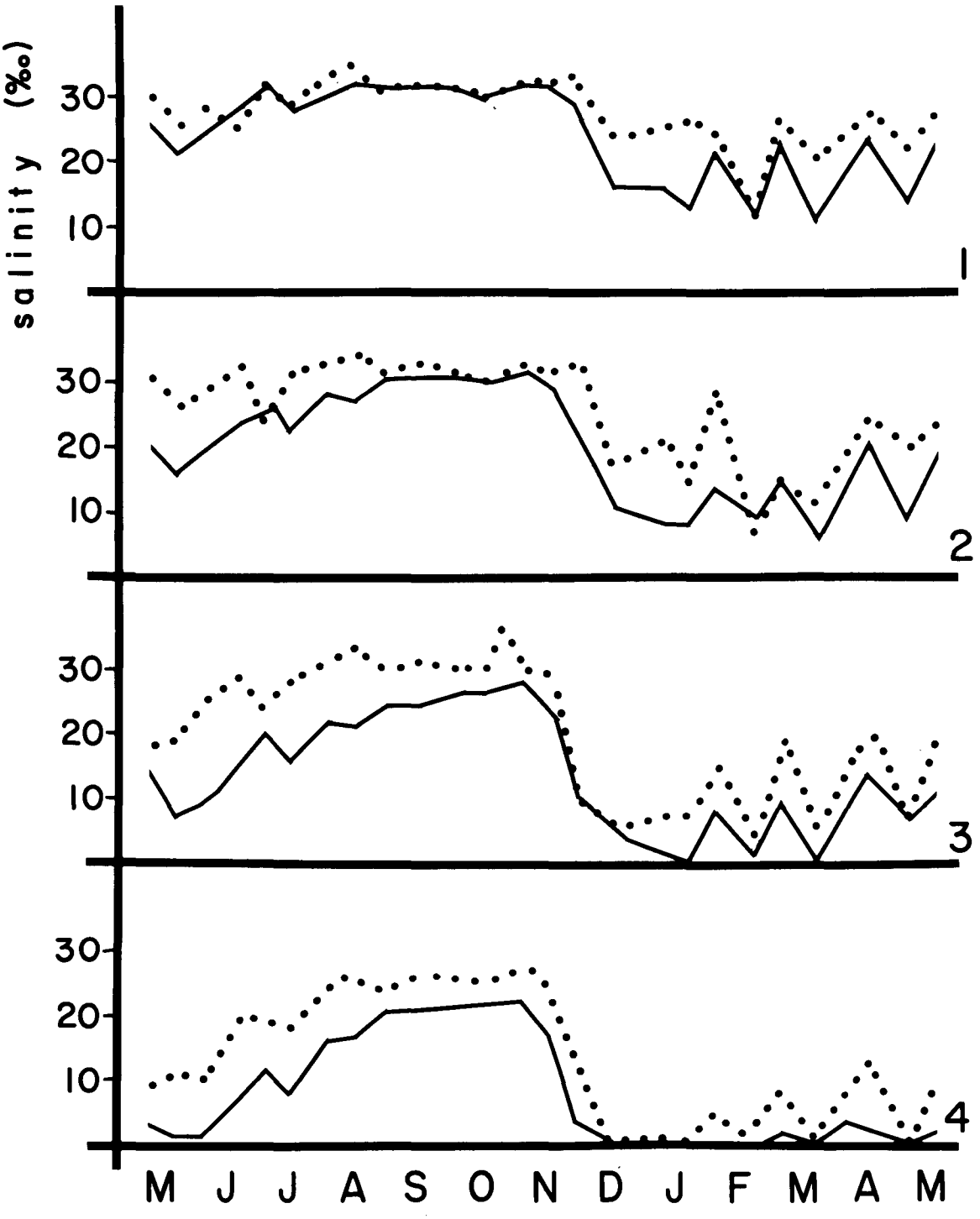

Figure 4. Salinities (°/oo) obtained from each station at high tide (broken line) and low tide (solid line) at two week intervals from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

23.2‰ throughout the sampling year. Values at this station remained high from July through early November. Salinity ranges at station 2 and 3 were 28.5 and 33.1, respectively. The spring increase at these stations continued into the summer months. Stabilization of relatively high salinities at these two stations occurred for a period from August to November. Salinities at station 4 varied from 0.0 to 26.3‰ over the year. Concentrations at this station exhibited a gradual increase from May through September. During the winter, values obtained at low tide were near zero, while greater concentrations were observed at high tides.

At all stations, temperature values exhibited seasonal trends similar to those observed for salinity (Figs. 4 and 5). Warmer temperatures occurred during the summer and cooler temperatures during the winter. Throughout the summer, temperature values observed at low tide for stations 1, 2 and 3 were generally higher than those of the corresponding high tide. This type of difference between high and low tide did not exist during the winter. On two occasions in the summer (June 26 and August 18, 1974) temperatures measured at high and low tide demonstrated a large degree of difference. These observations are probably related to the introduction of upwelled coastal waters into the estuary. In contrast to salinity, which displayed a simultaneous decrease at all stations within a two-week period, temperatures underwent a gradual and

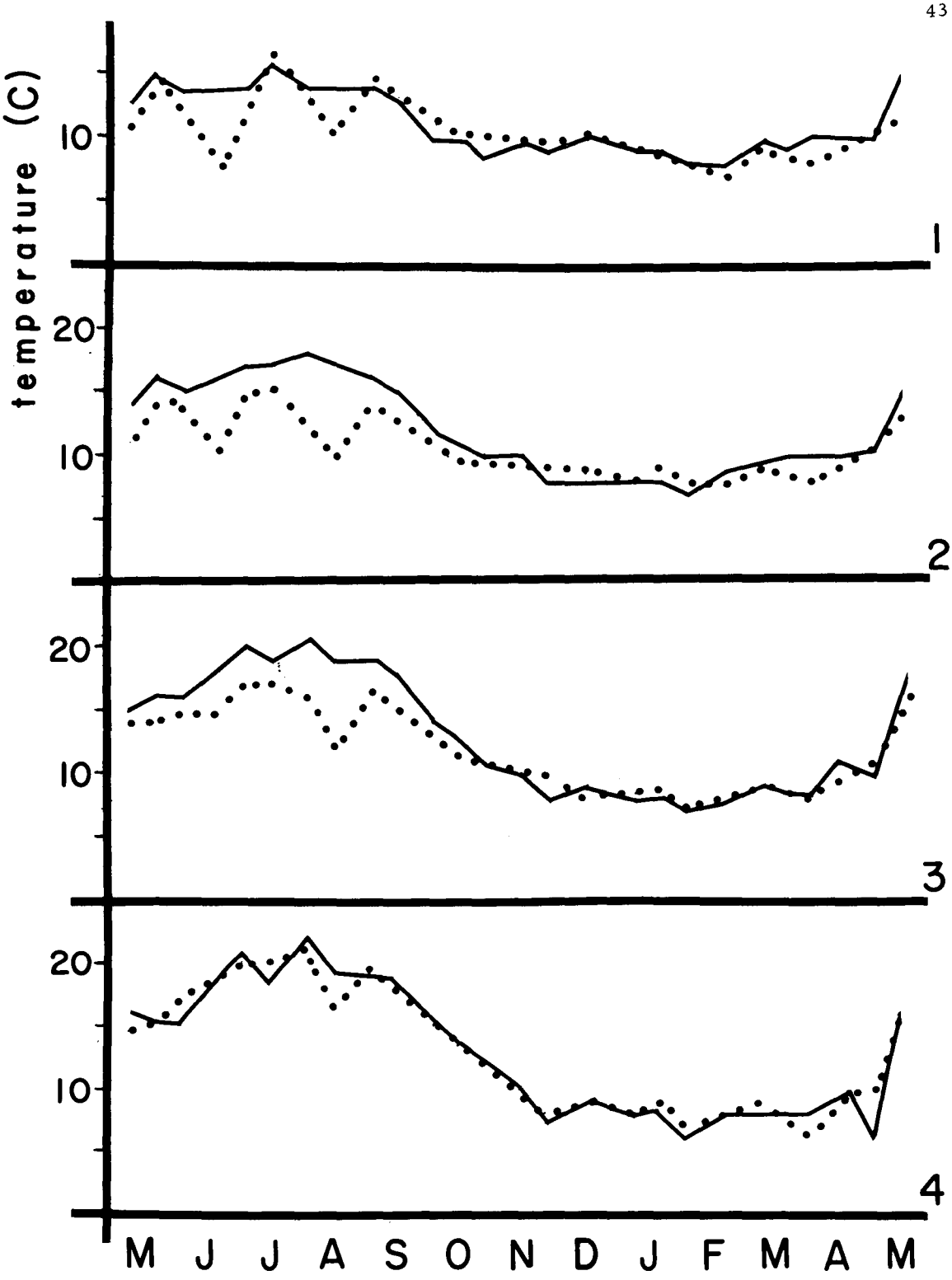

Figure 5. Water temperatures (C) obtained from each station at high tide (broken line) and low tide (solid line) at two week intervals from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

non-synchronous decline from maximum to minimum levels. Water temperature decreased from late summer through early fall and winter. The duration and magnitude of this decrease varied at each station. Station 1 exhibited a temperature range of 8 C. This represents the smallest range for all of the stations monitored. The temperature values at station 1 began to decrease in September, reaching a minimum in February. Station 2 displayed nearly the same temperature range and seasonal pattern as recorded for station 1. Station 3 exhibited a larger temperature range (13.3 C) than stations 1 or 2, and a slightly smaller variation than that observed at station 4 (14.2 C). Water temperatures at stations 3 and 4 began to decrease in August and reached minimum values in the winter. The lowest (5.8 C) and the highest (20.5 C) readings taken in the estuary throughout the sampling year were obtained at these two upstream stations.

Changes in nitrate-nitrite concentration over time, like salinity and temperature, were similar at all stations (Fig. 6). The lowest concentrations were observed from May to December 1974. In contrast to the sharp decrease in salinities which was observed during November 1974, an abrupt increase occurred in nitrate-nitrite values. Relatively high concentrations persisted throughout the winter months and values began to decline in April and May of 1975. The maximum concentration recorded for each station, as well as the

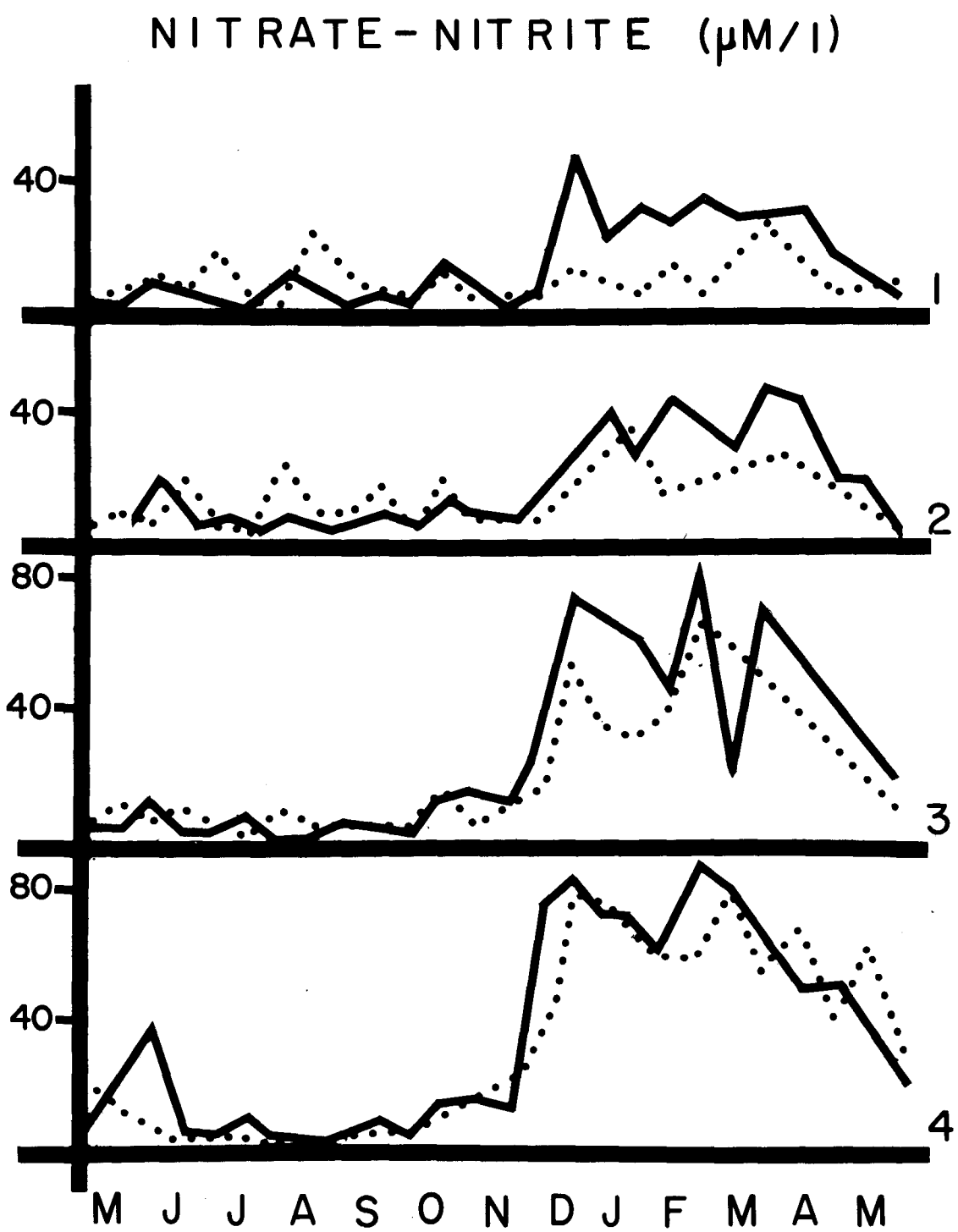

Figure 6. Nitrate-nitrite concentrations (μM/l) obtained from each station at high tide (broken line) and low tide (solid line) at two week intervals from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

magnitude of nitrate-nitrite range over the sampling year, increased moving upstream from station 1 to station 4. Stations 1 and 2 exhibited ranges of 48 and 68 μM/l respectively; while at stations 3 and 4, corresponding ranges were 86 and 88 μM/l.

During the sampling year, phosphate concentrations in the estuary were less variable than any of the other selected physical or chemical properties (Fig. 7). While extremes of 3.45 and 0.04 μM/l were recorded, concentrations usually ranged from 0.75 to 1.22 μM/l. Station 1 exhibited the largest range (3.38 μM/l) during the sampling year. The range at station 2 was nearly half of the range at station 1 (1.62 μM/l). Stations 3 and 4 had ranges of 2.02 and 1.81 μM/l, respectively. In general, phosphate concentrations were slightly higher in the summer and early fall than in the winter and spring.

The seasonal patterns in silicate concentrations at the four stations are presented in Figure 8. Relatively low concentrations (usually less than 50 μM/l) were recorded at all stations from May through November of 1974. Silicate values at stations 1, 2 and 3 did not increase sharply until February 1975. At station 4, an increase occurred in December and continued through early spring of 1975. The smallest yearly range of silicate concentration was observed at station 1 (125.1 μM/l). Stations 2 and 3 had ranges of 151.8 and 151.5 μM/l, respectively. The largest range of silicate values was recorded at station 4 (211.7 μM/l).

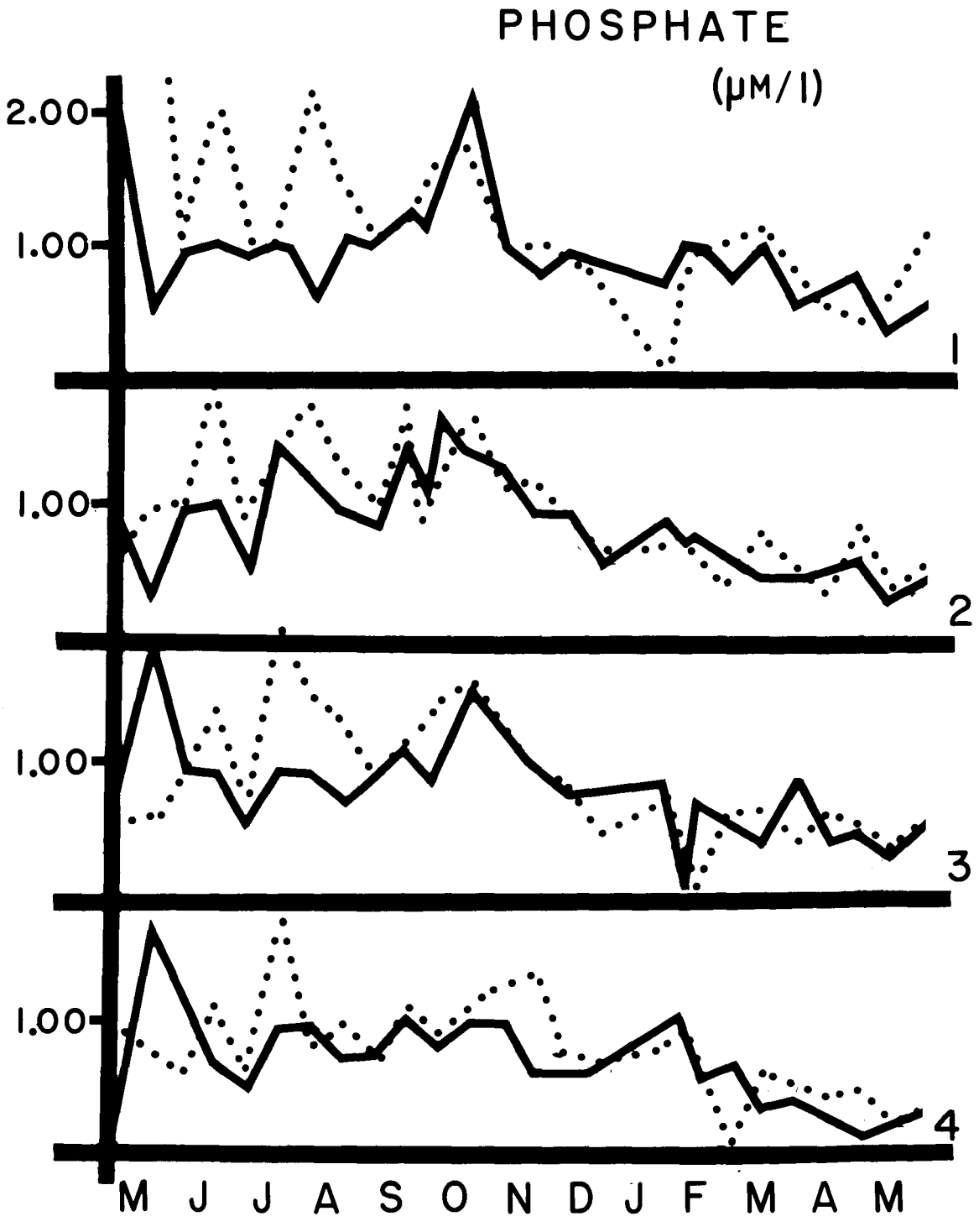

Figure 7. Phosphate concentrations (μM/l) obtained from each station at high tide (broken line) and low tide (solid line) at two week intervals from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

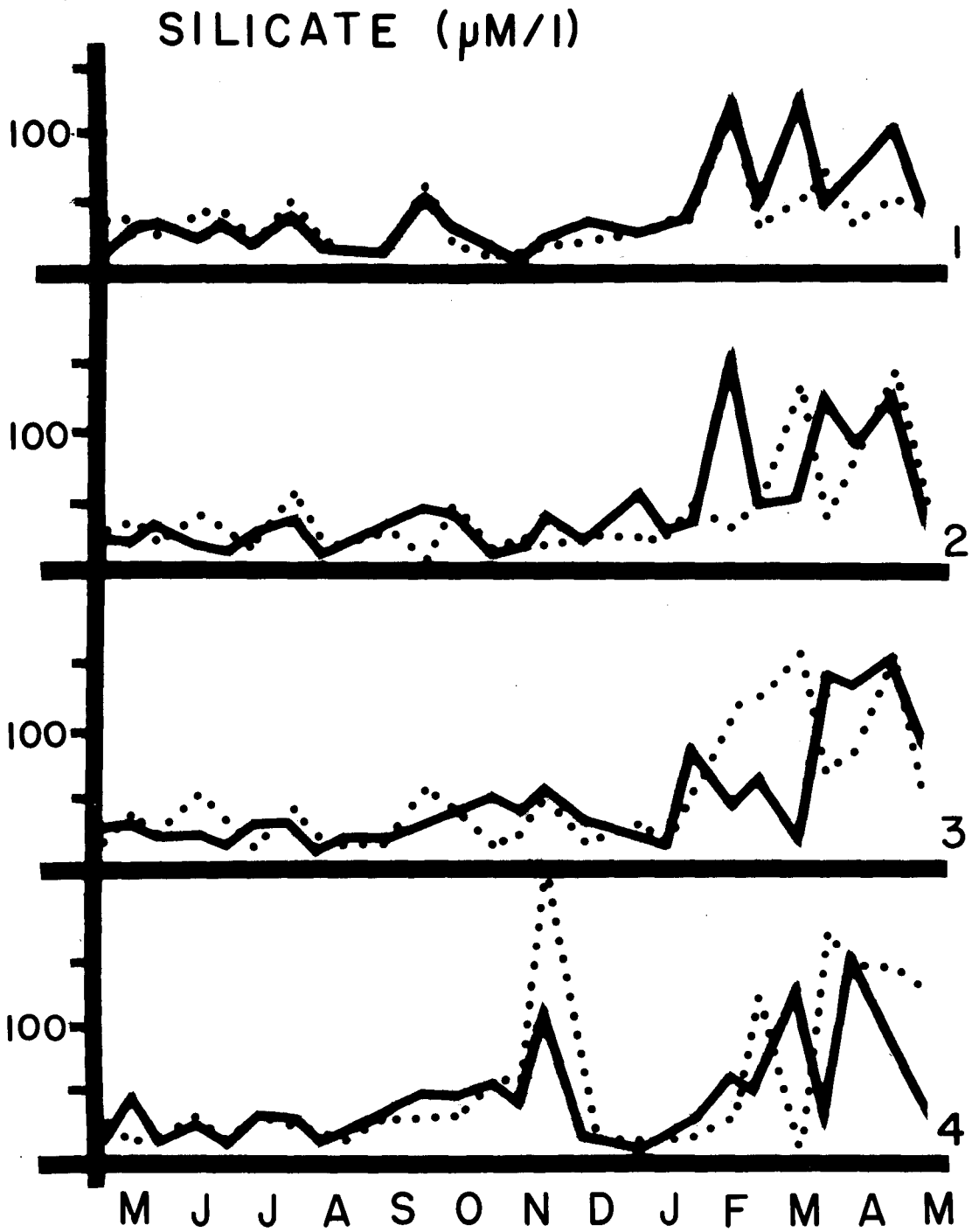

Figure 8. Silicate concentrations (μM/l) obtained from each station at high tide (broken line) and low tide (solid line) at two week intervals from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

Maximum concentrations of chlorophyll a were obtained in June 1974 and May 1975 (Fig. 9). Concentrations at all stations gradually decreased to minimum values in December 1974 and January 1975, increasing again during late winter and spring of 1975. Chlorophyll a concentration at station 1 varied between 0.4 (January 1975) and 6.0 mg/m^3 (May 1975). Station 2 exhibited a larger range of concentrations with a minimum of 0.3 (January 1975) and a maximum of 8.8 mg/m^3 (May 1975). Chlorophyll a ranged from 0.5 (January 1975) to 14.5 mg/m^3 (June 1974) at station 3 and from 0.4 (December 1974) to 19.7 mg/m^3 (May 1975) at station 4. During the winter and spring, concentrations of chlorophyll a were usually higher in upstream areas, whereas in summer and fall, chlorophyll a was more evenly distributed throughout the estuary.

The Diatom Flora

Approximately 48,800 diatoms were identified and counted from a total of 96 samples which represented collections obtained on 12 dates. These specimens represented 361 taxa (species and varieties) from 71 genera. Five taxa totaling 62 individuals could not be identified to the genus level, and 67 taxa could not be identified to species. In addition, one group of diatoms presented an interesting taxonomic problem. Throughout the sampling year, 158 cells were encountered which clearly exhibited morphologically different valves.

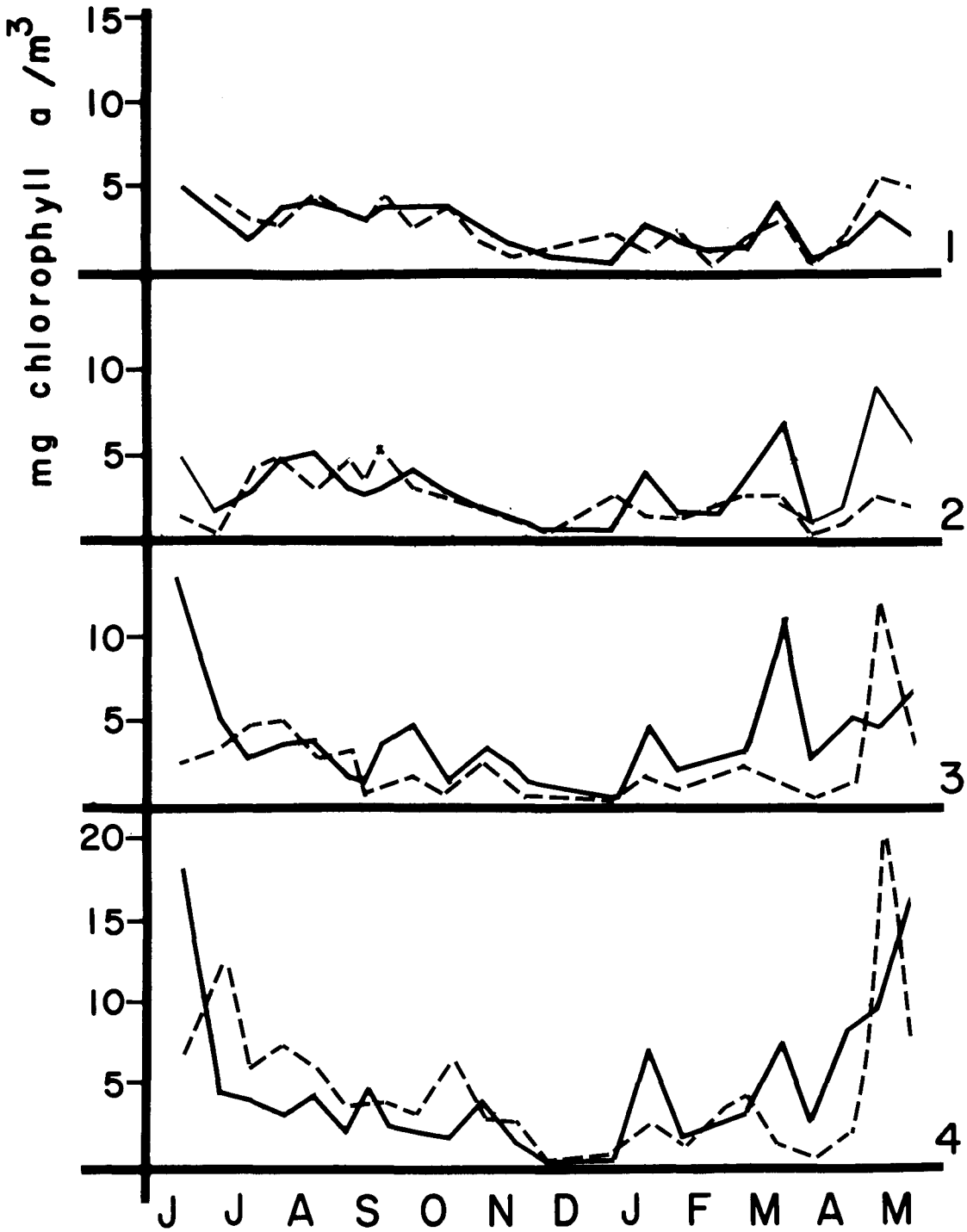

Figure 9. Chlorophyll a concentrations (mg/m^3) obtained from each station at high tide (broken line) and low tide (solid line) at two week intervals from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

These diatoms were identified as members of the genus Thalassiosira. However, one valve usually fit the description of T. decipiens, while the other corresponded to that of T. pacifica. These two species are differentiated by the arrangement and incrementation of both the areolae and the marginal tubuli (Gran and Angst, 1931). For the purposes of this study, the frustules of this group were considered as a taxon separate from T. decipiens and T. pacifica, and were designated as Thalassiosira no. 3. Several other cases of dissimilar valves were observed within the genus Thalassiosira. With these specimens, one valve always resembled T. decipiens, while the other corresponded to T. aestivalis, T. fluviatilis or T. nordenskiöldii.

Of the 71 diatom genera encountered during this study, 27 were represented by one species, and another 28 were represented by less than ten taxa. The largest number of species belonged to the genera Nitzschia (70), Navicula (47) and Amphora (30). Achnanthes, Chaetoceros, Coscinodiscus, Gyrosigma, Pleurosigma and Thalassiosira were represented by 10 to 20 species. In terms of cell counts, species of Chaetoceros contributed the largest number of individuals (26% of the total cells). Other abundant genera were Thalassiosira (15%), Cylindropyxis (12%), Melosira (10%), Amphiprora (5%), Surirella (5%) and Plagiogramma (4%).

All of the taxa together with their relative abundances are listed in Appendix Table 1. Fifty-four taxa were recorded at least

once at every station in a collection at both high and low tide, and 21 taxa were recorded at least once on every sampling date. Sixteen taxa were in both of these categories: Actinoptychus senarius, Amphiprora alata, Cyclotella meneghiana, ?Cylindropyxis sp., Fragilaria pinnata, Gyrosigma fasciola, Melosira moniliformis, Melosira sulcata, Navicula gregaria, Nitzschia fundi, Plagiogramma brockmanni, Surirella ovata, Synedra fasciculata, Thalassiosira decipiens, T. pacifica and Thalassiosira no. 3. Of the 361 taxa encountered during the study, 119 were observed in only one sample, and 87 of these were represented by a single individual. Thirty-seven taxa totaled from 100 to 1000 individuals, while 11 different taxa were represented by more than 1000 cells.

The most abundant taxon throughout the entire sampling period was a small centric diatom with a diameter range of 4 to 7 μm. The valve surface was decorated with nearly parallel rows of punctae (12 to 15 in 10 μm). Positive identification of this organism is questionable, although it may be a species of Cylindropyxis. This diatom made up 12% of the total cell counts and was observed in all but four of the 96 samples (Figs. 10 and 11). A maximum relative abundance occurred in June and again in September of 1974.

Chaetoceros subtilis (Fig. 12) was the second most abundant diatom taxon (8% of total count). Unlike ?Cylindropyxis sp. which was present during the entire year throughout the estuary, C. subtilis was

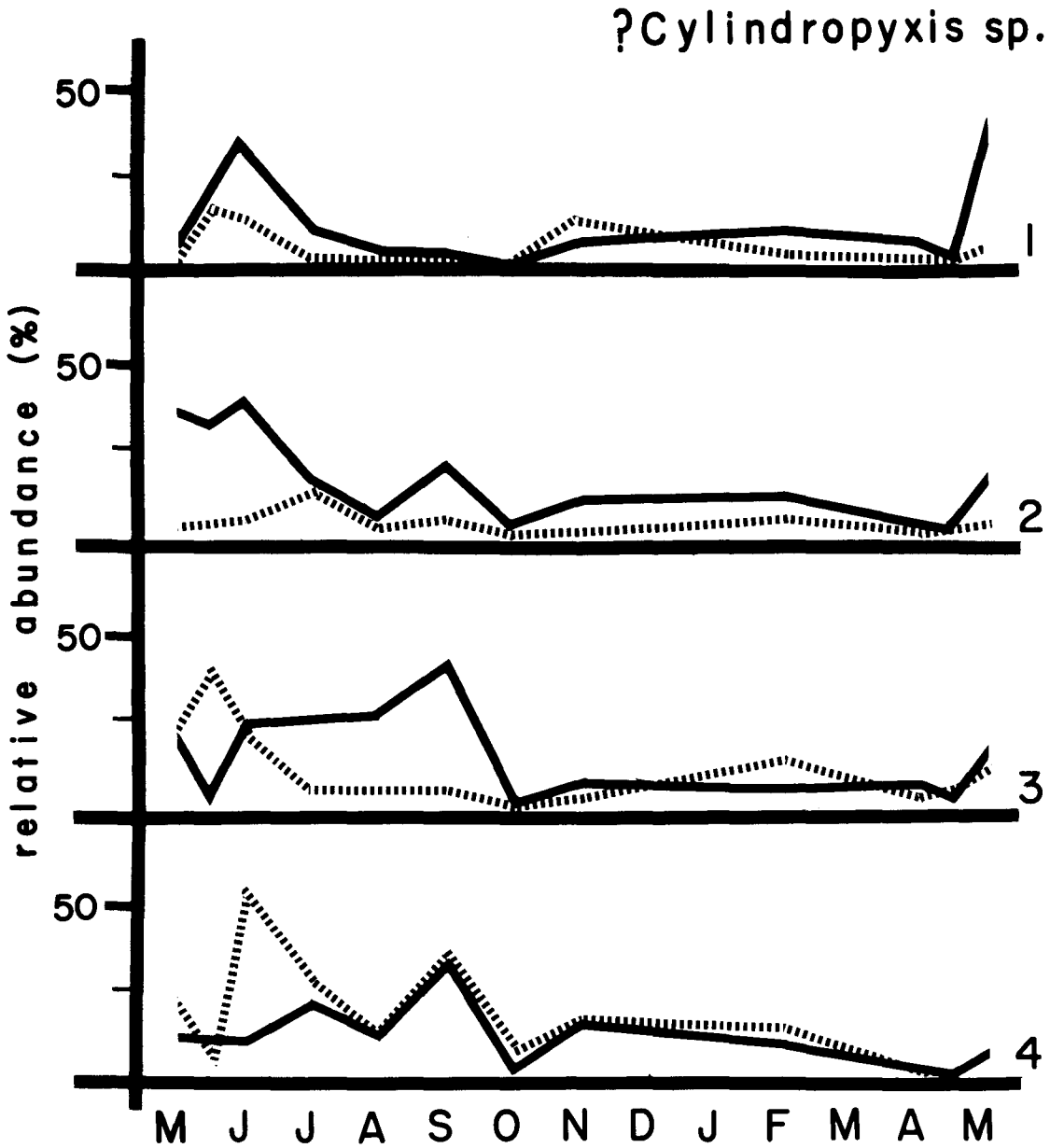

Figure 10. Relative-abundance of ?Cylindropyxis sp. in planktonic diatom assemblages collected at high tide (broken line) and low tide (solid line) at each station on 12 selected dates from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

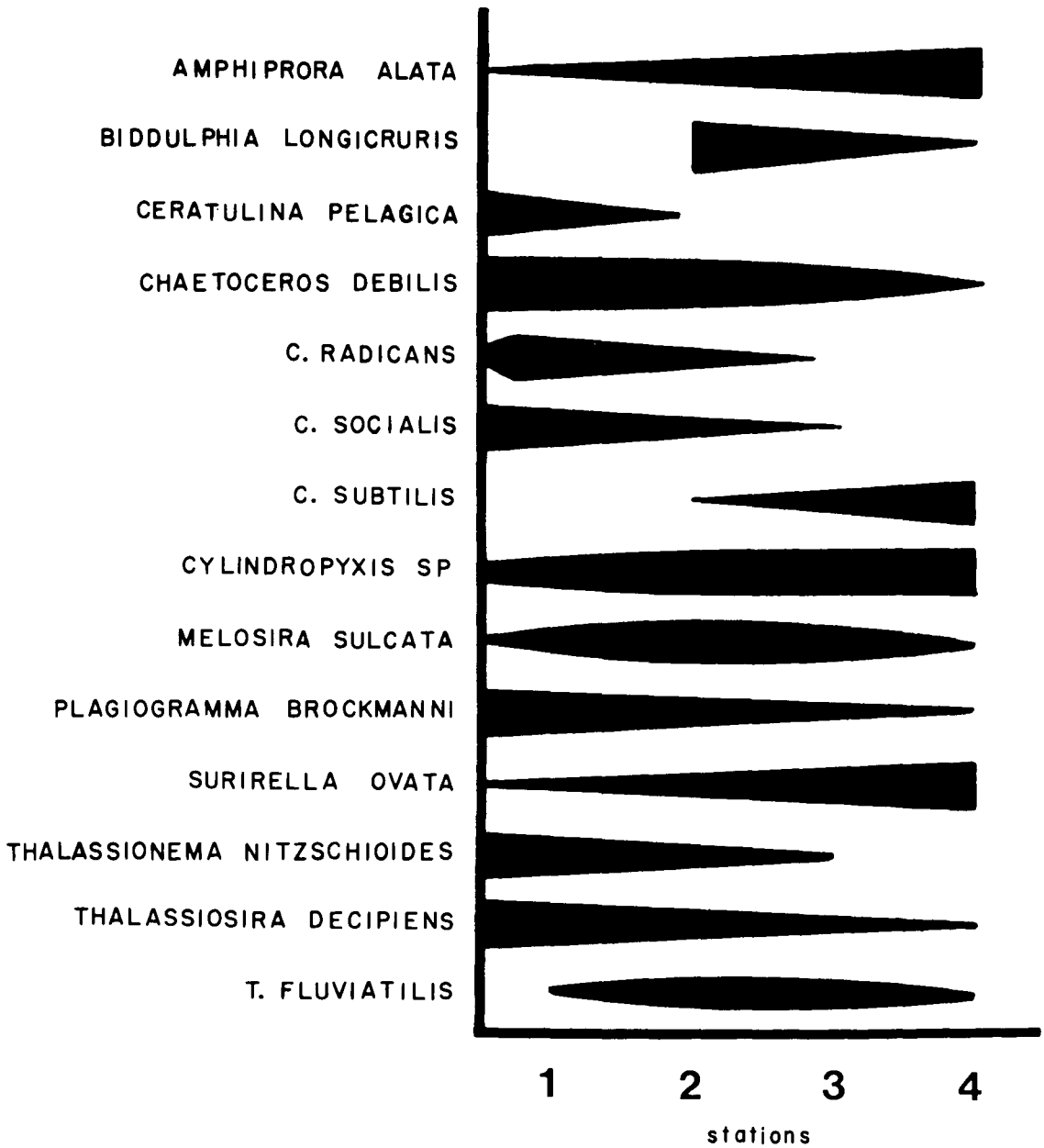

Figure 11. Spatial distribution of some diatoms commonly encountered in plankton samples from the Yaquina Estuary. These representations are based on data collected at the indicated stations at high and low tide during one year (May 1974 to May 1975).

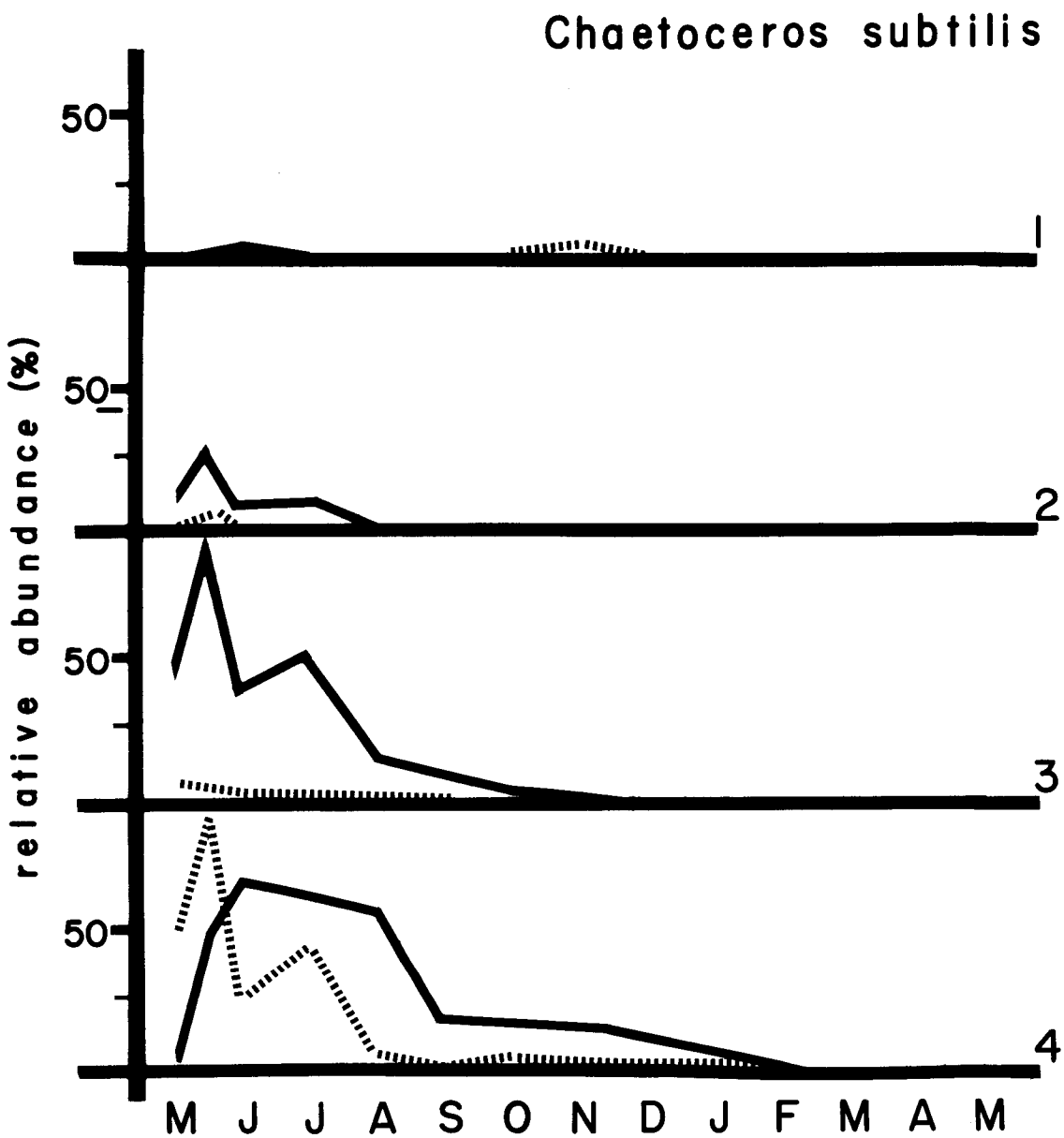

Figure 12. Relative abundance of Chaetoceros subtilis in planktonic diatom assemblages collected at high tide (broken line) and low tide (solid line) at each station on 12 selected dates from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

primarily observed in the summer in areas of relatively low salinity (Fig. 11). The greatest relative abundance of C. subtilis was observed in early June 1974, and the first indications of a pronounced decrease in relative abundance occurred in early fall.

Melosira sulcata constituted 7% of the diatoms in the estuary over the year (Fig. 13). This species was present throughout the year at all stations (in 85 of the 96 samples, Fig. 11). During most of the year M. sulcata averaged about 3% of the total cell counts for each month. Its peak relative abundance occurred in November 1974, and at this time it was the most dominant taxon in all assemblages. M. sulcata exhibited a distributional pattern similar to ?Cylindropyxis sp. The greatest concentrations of individuals occurred in the central portion of the estuary, at stations 2 and 3. M. dubia, M. moniliformis and M. nummuloides were also observed throughout the estuary during most of the sampling year. However, these species were represented by relatively small numbers of individuals, and the dynamics of their individual populations closely resembled the seasonal occurrence of M. sulcata. M. granulata was observed only in February and its occurrence was limited to stations 2, 3 and 4.

Thalassiosira decipiens represented 7% of the diatoms in the plankton assemblages and was recorded in all except six of the collections (Figs. 11 and 14). This taxon exhibited its largest relative abundance in the downstream region of the estuary during August 1974.

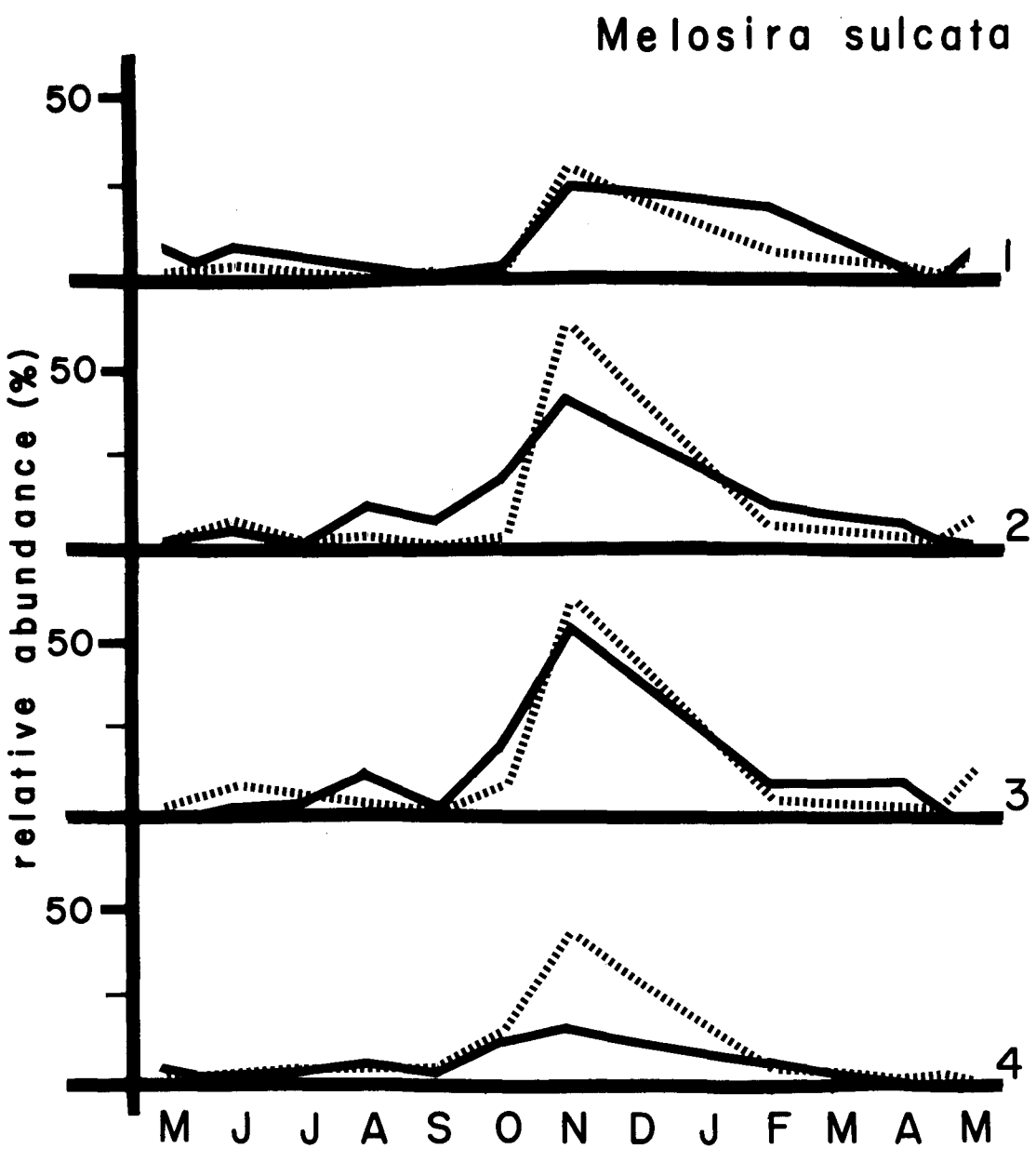

Figure 13. Relative abundance of Melosira sulcata in planktonic diatom assemblages collected at high tide (broken line) and low tide (solid line) at each station on 12 selected dates from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

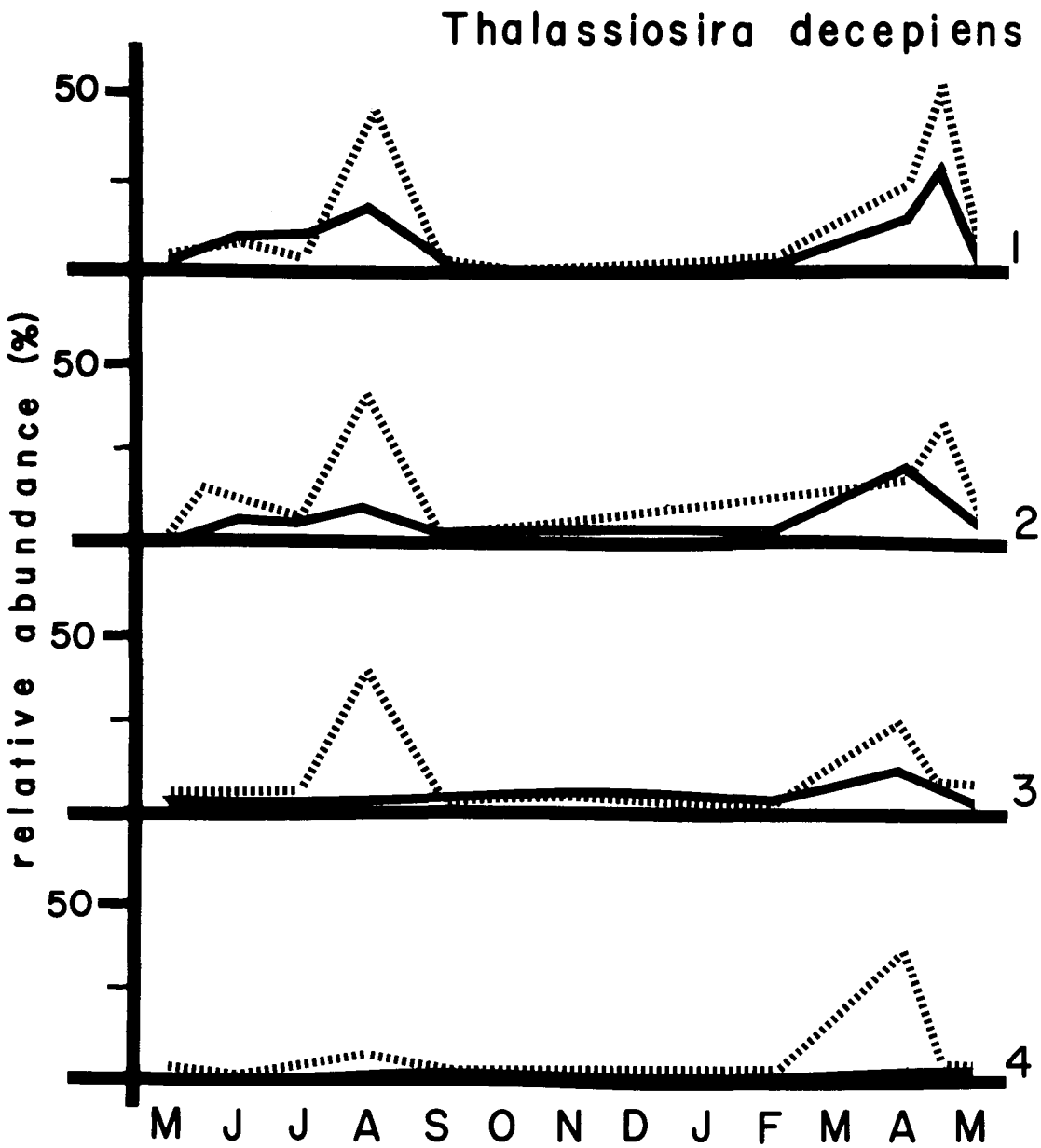

Figure 14. Relative abundance of Thalassiosira decipiens in planktonic diatom assemblages collected at high tide (broken line) and low tide (solid line) at each station on 12 selected dates from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

Throughout fall and winter T. decipiens averaged a relative abundance of 9% in monthly counts. In the spring of 1975 a second increase in relative abundance occurred. T. pacifica was not as common as T. decipiens, although it exhibited a similar pattern of seasonal and spatial distribution. The initial maximum for this species was observed in May 1974, two months prior to the maximum relative abundance recorded for T. decipiens. A second peak of relative abundance for T. pacifica occurred in the spring of 1975 and coincided with a maximum for T. decipiens. Thalassiosira no. 3, which possessed one valve of T. decipiens and one of T. pacifica, was encountered randomly throughout the samples. Its maximum relative abundance of 3% occurred in May 1975 at station 1 during a period of maximum abundance for both T. decipiens and T. pacifica. T. nordenskiöldii exhibited an increase in relative abundance during spring 1974 and again in spring 1975, coinciding with the increase of T. decipiens and T. pacifica (Fig. 15). The spring maxima for T. nordenskiöldii were of short duration and limited to stations 1 and 2 at high tide. T. subtilis was first observed in August 1974 and its maximum relative abundance at this time also coincided with that of T. decipiens. T. fluviatilis increased during spring 1975, concurrent with increases of T. decipiens, T. pacifica, T. nordenskiöldii and T. subtilis. However, the largest concentrations of T. fluviatilis were located further upstream than other species of Thalassiosira (Fig. 11).

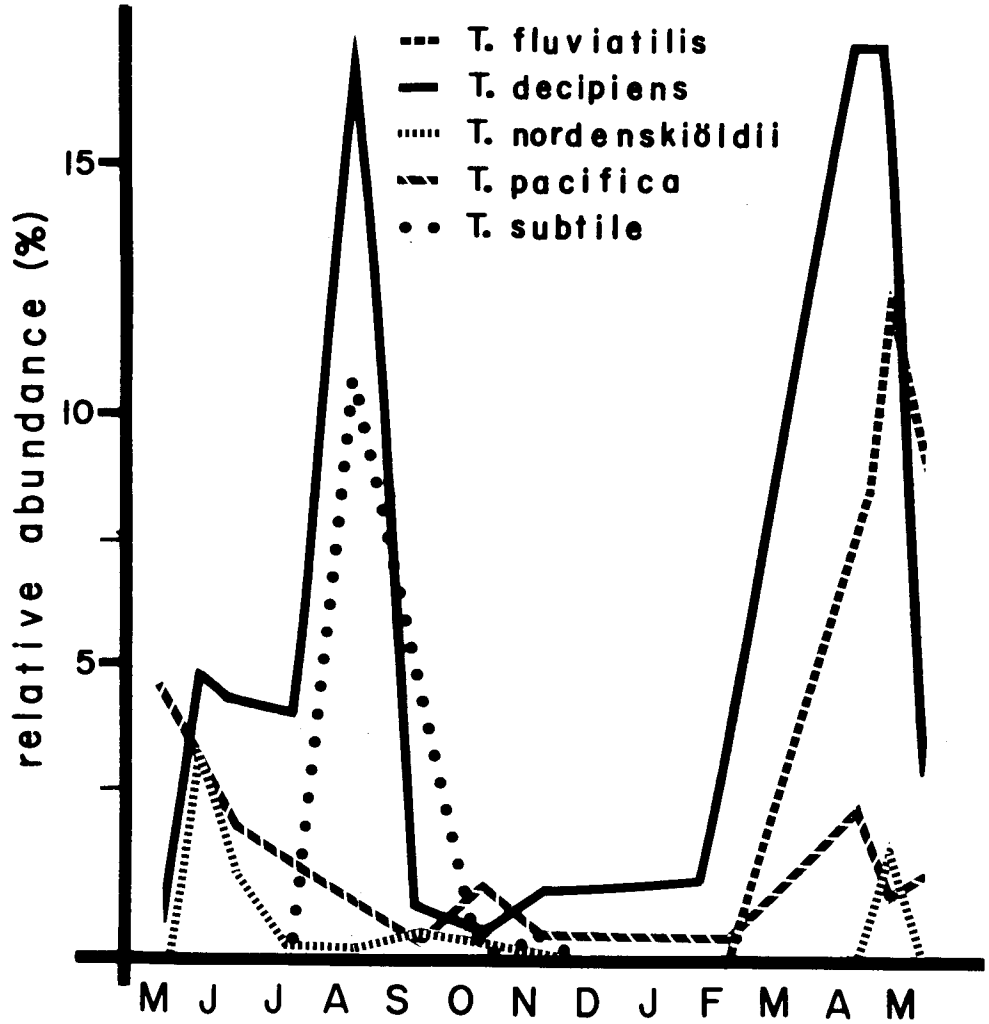

Figure 15. Relative abundances of five Thalassiosira species based on combined values of eight samples from each of 12 dates during the sampling year (May 1974 to May 1975).

Chaetoceros socialis comprised nearly 7% of the total cell counts (Fig. 16). This species attained its maximum relative abundance in July 1974, and the largest values were recorded in downstream collections (Fig. 11). C. debilis exhibited the same type of spatial distribution as C. socialis (Figs. 11 and 17). C. debilis increased in relative abundance in September 1974 and was a dominant species in the estuary through October. The initial appearance or increase in relative abundance of C. didymus, C. laciniosus, C. radicans, C. lorenzianum, C. compressus and C. constrictus within the estuary was closely associated with the seasonal increase of C. debilis (Fig. 18).

Amphiprora alata and Surirella ovata exhibited nearly identical seasonal cycles and patterns of distribution (Figs. 11, 19, 20). During the year these taxa co-occurred throughout the estuary, with highest concentrations at the upstream stations. An increase in relative abundance of both species was observed during the winter. In February 1975, S. ovata was more abundant than A. alata, however, in late May, A. alata was one and a half times as abundant as S. ovata and composed nearly 80% of the diatom flora sampled from station 4 at low tide. Plagiogramma brockmanni and P. van huerckii were also similar in their seasonal and spatial occurrence. Highest values for these species were recorded in downstream samples, and their maximum relative abundance was observed in June of 1974.

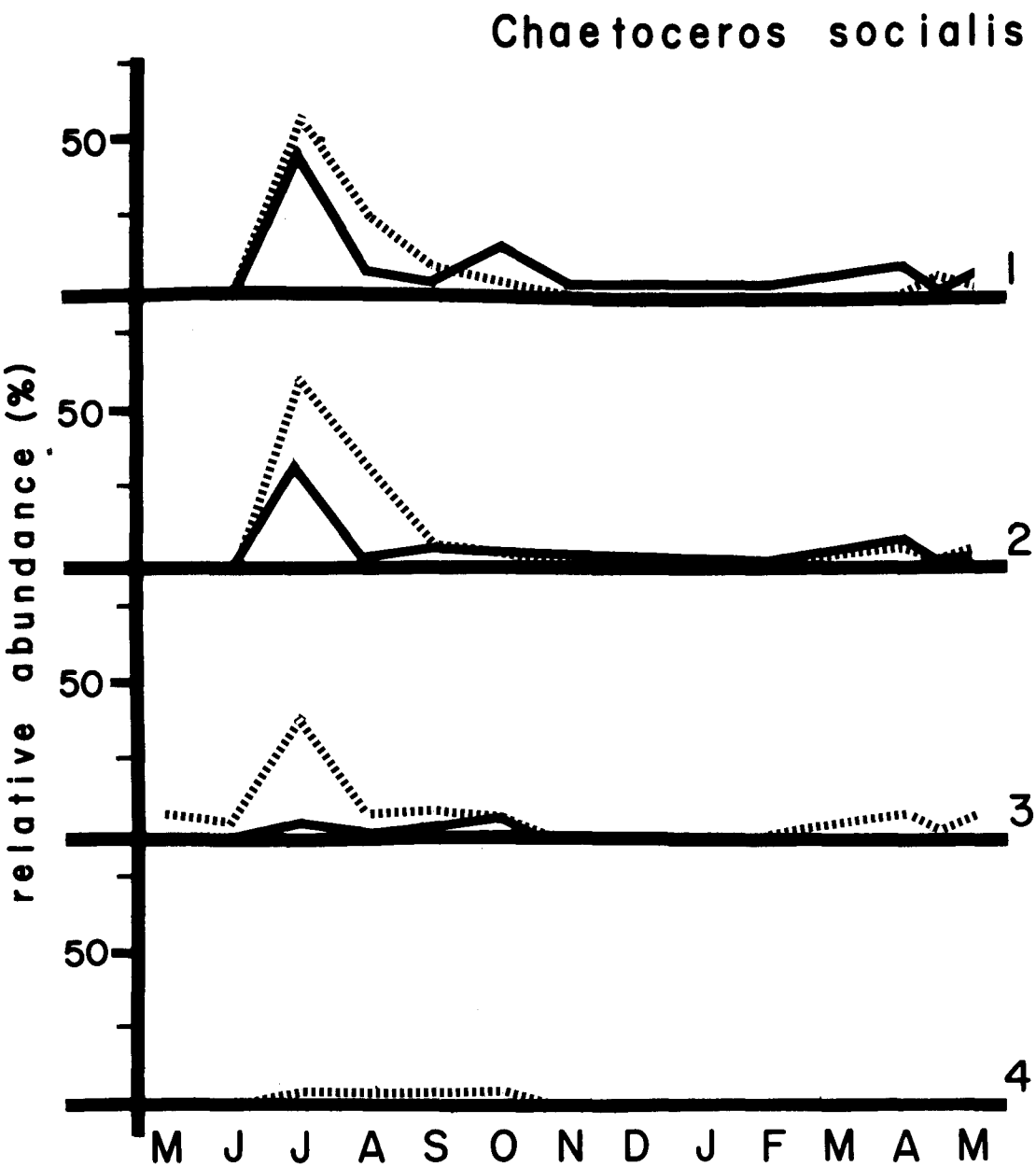

Figure 16. Relative abundance of Chaetoceros socialis in planktonic diatom assemblages collected at high tide (broken line) and low tide (solid line) at each station on 12 selected dates from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

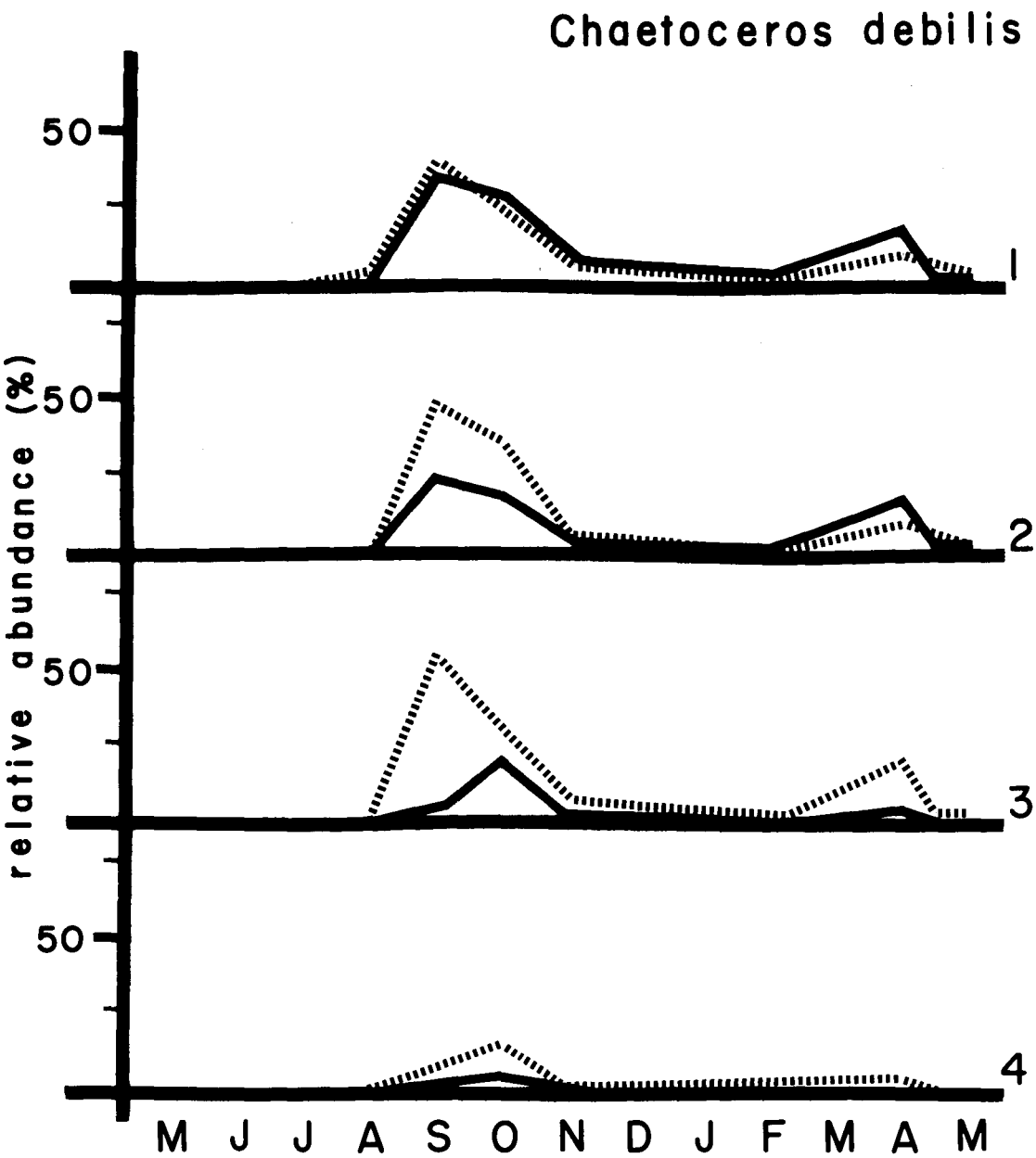

Figure 17. Relative abundance of Chaetoceros debilis in planktonic diatom assemblages collected at high tide (broken line) and low tide (solid line) at each station on 12 selected dates from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

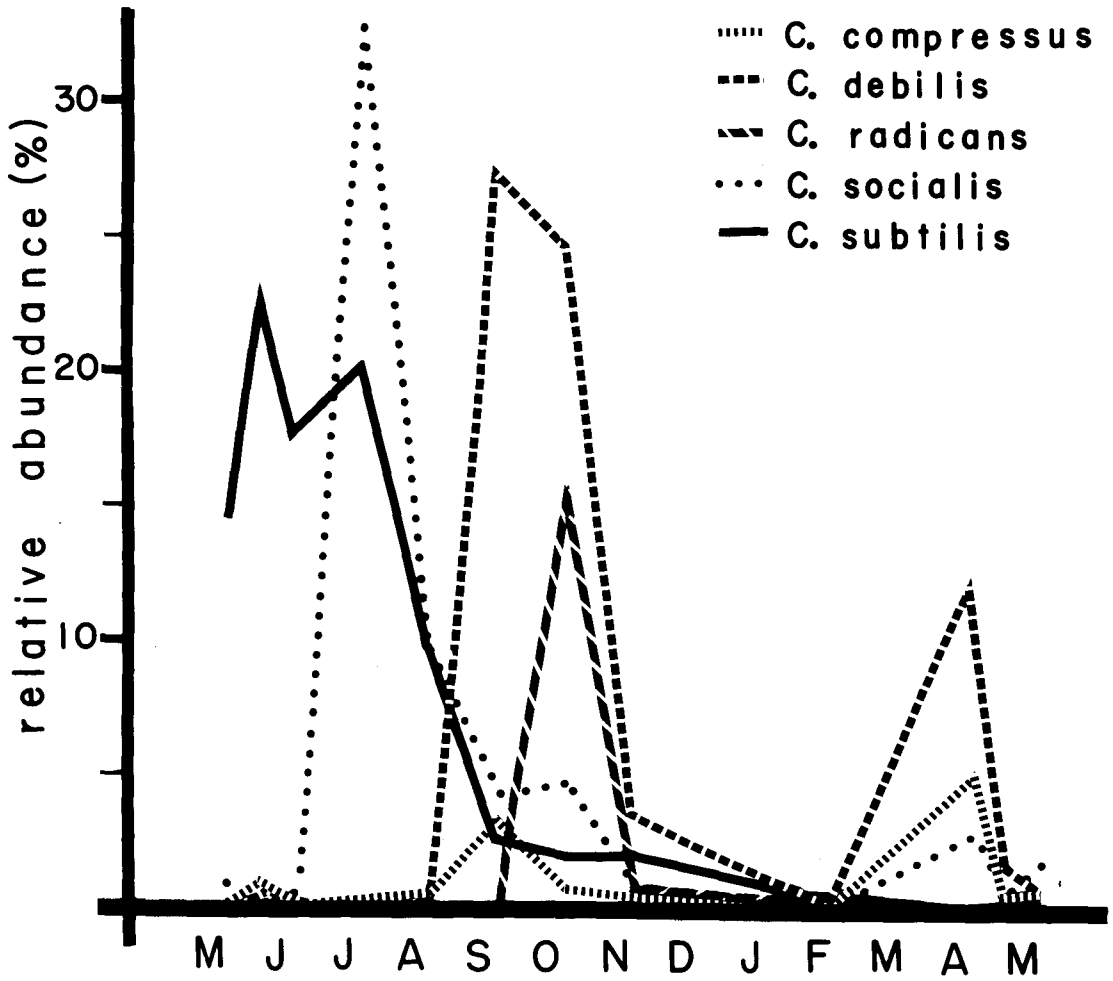

Figure 18. Relative abundances of five Chaetoceros species based on combined values of eight samples from each of 12 dates during the sampling year (May 1974 to May 1975).

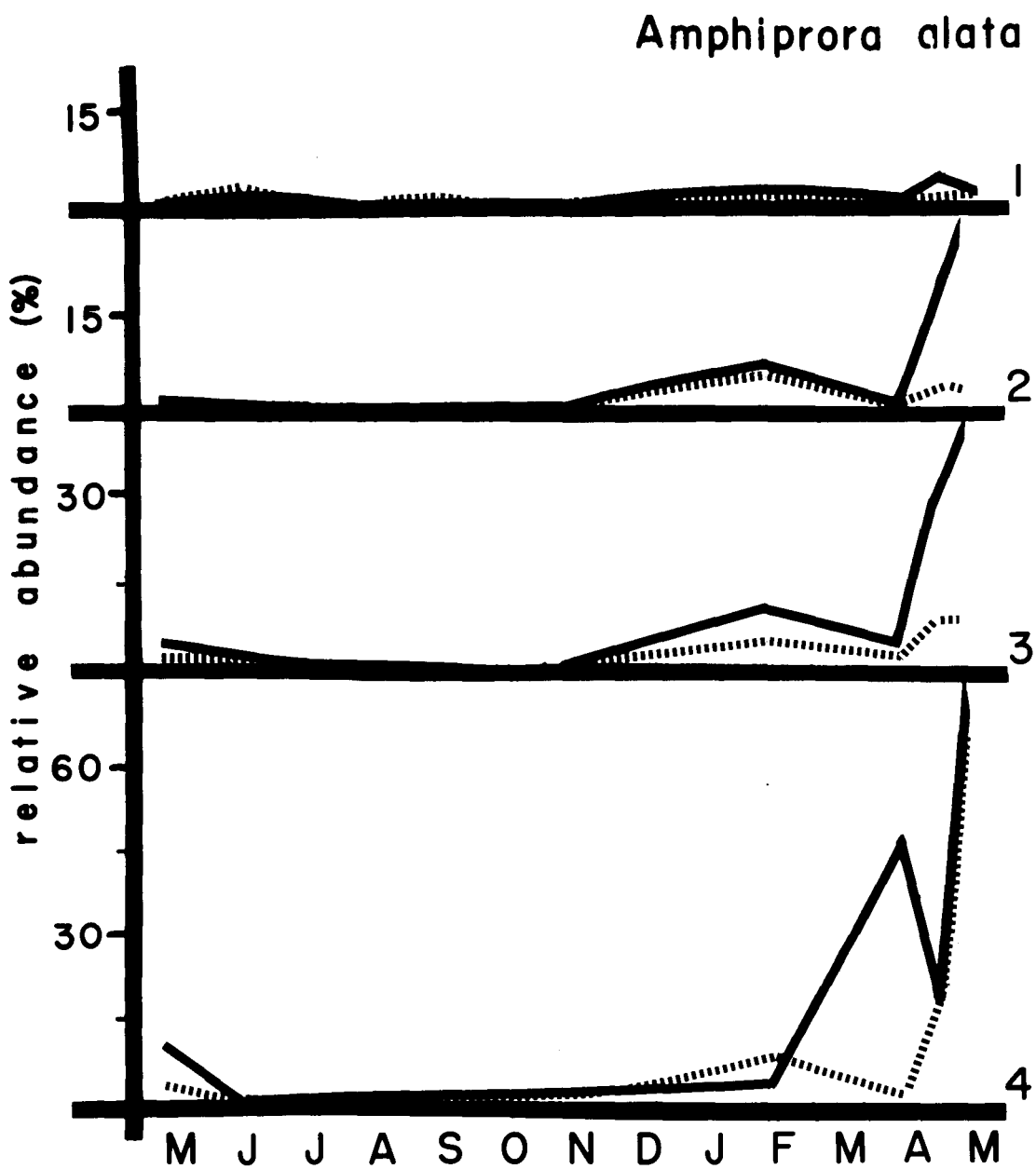

Figure 19. Relative abundance of Amphiprora alata in planktonic diatom assemblages collected at high tide (broken line) and low tide (solid line) at each station on 12 selected dates from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

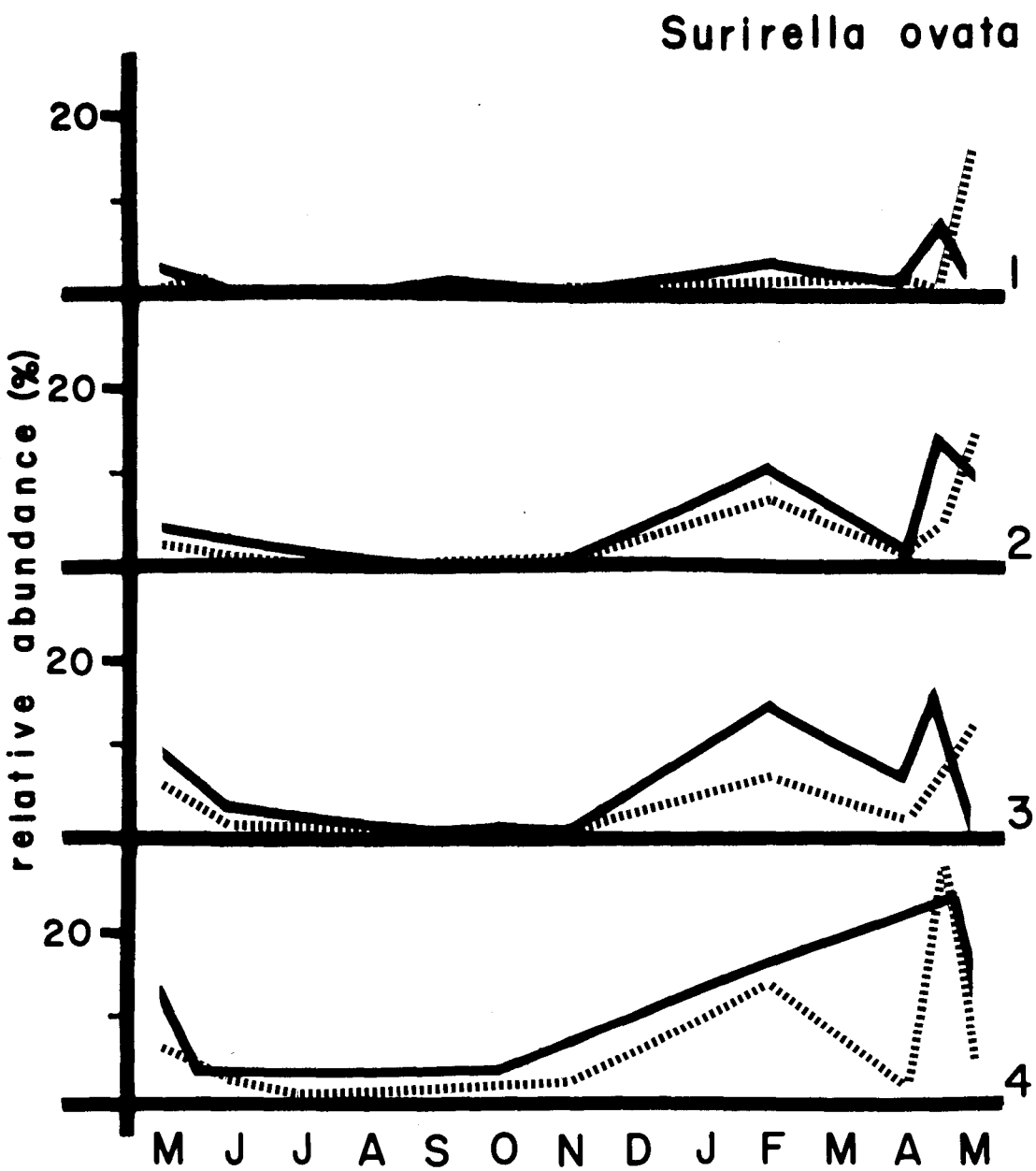

Figure 20. Relative abundance of Surirella ovata in planktonic diatom assemblages collected at high tide (broken line) and low tide (solid line) at each station on 12 selected dates from May 1974 to May 1975. Numbers in lower right corner of each plot refer to station 1, 2, 3 or 4.

The total number of species encountered at each station throughout the sampling year (including collections at both tides) ranged from 221 at station 1 to 201 at station 2. Totals at stations 3 and 4 were 213 and 209, respectively. The number of taxa in each assemblage varied from 10 to 78 (Table 1). All stations exhibited a similar seasonal trend of fewer species per sample in spring, summer and early fall, and a larger number of taxa per sample in late fall and winter. Associated with a smaller number of species was the obvious dominance of several taxa within the estuary. During spring, summer and early fall, it was combinations of two, three or four different taxa which were responsible for the major portion of the diatom flora (Table 2). By November 1974, several species, primarily Melosira sulcata and ?Cylindropyxis sp., continued to represent a relatively large proportion of the community; however, in most cases, the number of species encountered in each sample was nearly twice the number found in the October samples. In February 1975, the largest percentage attributed to a single taxon in one assemblage was 18% (M. sulcata). The February samples were distinctly characterized by large numbers of species with low measures of relative abundance. In the November and February samples, certain species of the genera Achnanthes, Actinoptychus, Amphora, Cyclotella, Cymbella, Diatoma, Diploneis, Epithemia, Eunotia, Fragilaria, Frustulia, Gomphonema, Gyrosigma, Meridion,

Table 1. List of 96 collections (representing 96 assemblages of planktonic diatoms) indicating sample size (N), total number of species (S), value of common information measure (H''), and measure of redundancy (REDI).

Date	Collection	N	S	H''	REDI
74-5-26	1L	516	42	2.79	0.30
	2L	509	46	2.49	0.42
	3L	534	41	2.07	0.52
	4L	550	43	2.64	0.35
	1H	523	26	1.23	0.70
	2H	516	21	1.48	0.55
	3H	511	49	2.85	0.33
	4H	558	40	2.06	0.51
74-6-8	1L	496	41	2.56	0.37
	2L	492	32	2.09	0.46
	3L	517	14	0.55	0.89
	4L	518	24	1.71	0.51
	1H	520	40	2.76	0.30
	2H	508	28	2.49	0.29
	3H	530	39	2.24	0.45
	4H	515	10	0.43	0.86
74-6-23	1L	505	45	2.34	0.46
	2L	509	30	2.21	0.40
	3L	509	31	2.08	0.45
	4L	536	22	1.40	0.60
	1H	527	55	3.09	0.28
	2H	507	46	2.80	0.32
	3H	520	45	2.63	0.37
	4H	524	27	1.62	0.57
74-7-17	1L	515	30	2.05	0.45
	2L	524	38	2.39	0.40
	3L	509	37	1.85	0.57
	4L	507	26	1.40	0.64
	1H	504	32	1.79	0.55
	2H	505	25	1.49	0.60
	3H	499	30	2.15	0.42
	4H	504	30	1.97	0.48

(Continued on next page)

Table 1. (Continued)

Date	Collection	N	S	H''	REDI
74-8-18	1L	512	37	2.45	0.38
	2L	500	43	2.44	0.42
	3L	504	38	2.42	0.39
	4L	506	40	1.96	0.55
	1H	506	20	1.69	0.48
	2H	501	21	1.61	0.52
	3H	503	30	2.07	0.45
	4H	510	42	2.63	0.35
74-9-16	1L	501	33	2.40	0.36
	2L	514	43	2.61	0.36
	3L	517	42	2.22	0.48
	4L	505	50	2.35	0.43
	1H	512	24	2.06	0.39
	2H	509	26	1.95	0.45
	3H	462	33	1.78	0.57
	4H	504	41	2.20	0.48
74-10-20	1L	507	33	2.30	0.39
	2L	499	33	2.54	0.32
	3L	505	39	2.57	0.35
	4L	507	33	2.52	0.32
	1H	503	20	1.83	0.43
	2H	503	30	1.90	0.50
	3H	507	31	2.26	0.39
	4H	505	49	2.83	0.33
74-11-17	1L	503	60	3.21	0.27
	2L	501	59	2.56	0.47
	3L	511	48	2.14	0.54
	4L	509	66	3.10	0.33
	1H	501	48	2.62	0.39
	2H	487	42	2.08	0.53
	3H	501	46	1.92	0.60
	4H	504	49	2.33	0.49

(Continued on next page)

Table 1. (Continued)

Date	Collection	N	S	H''	REDI
72-2-22	1L	508	76	3.32	0.31
	2L	504	76	3.43	0.27
	3L	505	68	3.32	0.28
	4L	515	61	3.32	0.24
	1H	510	73	3.53	0.23
	2H	504	69	3.51	0.22
	3H	510	78	3.56	0.24
	4H	501	57	3.22	0.26
75-4-20	1L	506	33	2.54	0.32
	2L	525	42	2.76	0.31
	3L	504	34	2.22	0.43
	4L	503	14	1.11	0.62
	1H	500	26	2.17	0.38
	2H	510	23	2.14	0.35
	3H	509	44	2.85	0.29
	4H	504	24	1.89	0.45
75-5-4	1L	500	30	2.14	0.42
	2L	502	23	2.03	0.39
	3L	502	25	1.94	0.45
	4L	501	20	1.11	0.69
	1H	501	24	1.73	0.51
	2H	508	28	2.16	0.40
	3H	503	21	1.89	0.42
	4H	507	18	1.51	0.52
75-5-20	1L	506	46	2.63	0.38
	2L	504	37	2.31	0.42
	3L	503	26	1.58	0.58
	4L	503	11	0.81	0.70
	1H	515	42	2.97	0.24
	2H	491	45	2.99	0.26
	3H	501	48	3.01	0.27
	4H	502	14	1.17	0.60

Table 2. List of dominant taxa (greater than 10% relative abundance) in 96 planktonic diatom assemblages collected on 12 dates from May 1974 to May 1975.

Date	Station	High tide	Low tide
74-5-26	1	74% Ceratulina pelagica	20% Ceratulina pelagica 15% Thalassiosira pacifica 11% Bacteriastrum delicatulum
	2	61% Ceratulina pelagica 16% Bacteriastrum delicatulum	38% ?Cylindropyxis sp. 11% Chaetoceros subtilis
	3	13% Ceratulina pelagica 26% ?Cylindropyxis sp.	21% ?Cylindropyxis sp. 43% Chaetoceros subtilis
	4	23% ?Cylindropyxis sp. 44% Chaetoceros subtilis	27% Surirella ovata 12% ?Cylindropyxis sp. 10% Amphiprora alata 11% Diatoma elongatum var. tenue
74-6-~~6~~8	1	17% ?Cylindropyxis sp. 15% Plagiogramma brockmanni 12% Thalassiosira nordenskiöldii	27% ?Cylindropyxis sp. 14% Plagiogramma brockmanni 10% Thalassiosira decipiens 10% Thalassiosira pacifica
	2	22% Plagiogramma brockmanni 17% Thalassiosira nordenskiöldii 16% Thalassiosira decipiens	35% ?Cylindropyxis sp. 27% Chaetoceros subtilis
	3	44% ?Cylindropyxis sp. 13% Plagiogramma brockmanni	89% Chaetoceros subtilis

(Continued on next page)

Table 2. (Continued)

Date	Station	High tide	Low tide
	4	91% Chaetoceros subtilis	45% Chaetoceros subtilis 19% Cyclotella meneghiana 13% ?Cylindropyxis sp.
74-6-23	1	17% ?Cylindropyxis sp. 17% Navicula cryptocephala	34% ?Cylindropyxis sp. 21% Plagiogramma brockmanni 11% Thalassiosira decipiens
	2	16% Plagiogramma brockmanni 15% ?Cylindropyxis sp. 13% Thalassiosira decipiens	40% ?Cylindropyxis sp. 12% Plagiogramma brockmanni 10% Biddulphia longicruris
	3	26% ?Cylindropyxis sp. 21% Plagiogramma brockmanni	37% Chaetoceros subtilis 27% ?Cylindropyxis sp. 10% Asterionella formosa
	4	54% ?Cylindropyxis sp. 24% Chaetoceros subtilis	65% Chaetoceros subtilis 11% ?Cylindropyxis sp.
74-7-17	1	61% Chaetoceros socialis	49% Chaetoceros socialis 11% Thalassiosira decipiens 11% ?Cylindropyxis sp.
	2	65% Chaetoceros socialis	32% Chaetoceros socialis 17% ?Cylindropyxis sp. 11% Biddulphia longicruris
	3	45% Chaetoceros socialis	49% Chaetoceros socialis 25% ?Cylindropyxis sp.

(Continued on next page)

Table 2. (Continued)

Date	Station	High tide	Low tide
	4	41% Chaetoceros subtilis 28% ?Cylindropyxis sp.	60% Chaetoceros subtilis 23% ?Cylindropyxis sp.
74-8-18	1	44% Thalassiosira decipiens 26% Chaetoceros socialis	31% Chaetoceros socialis 19% Thalassiosira decipiens
	2	41% Thalassiosira decipiens 34% Chaetoceros socialis	35% Biddulphia longicruris 12% Melosira sulcata
	3	40% Thalassiosira decipiens 20% Thalassiosira subtile	29% ?Cylindropyxis sp. 15% Biddulphia longicruris 13% Melosira sulcata 13% Chaetoceros subtilis
	4	29% Biddulphia longicruris 13% ?Cylindropyxis sp.	53% Chaetoceros subtilis 14% ?Cylindropyxis sp.
74-9-16	1	42% Chaetoceros debilis 14% Chaetoceros compressus 11% Chaetoceros socialis	40% Chaetoceros debilis
	2	49% Chaetoceros debilis 11% Skeletonema costatum	25% Chaetoceros debilis 22% ?Cylindropyxis sp.
	3	63% Chaetoceros debilis	42% ?Cylindropyxis sp. 14% Biddulphia longicruris 11% Thalassiosira no. 2

(Continued on next page)

Table 2. (Continued)

Date	Station	High tide	Low tide
	4	36% ?Cylindropyxis sp. 23% Biddulphia longicruris 11% Thalassiosira subtilis	35% ?Cylindropyxis sp.
74-10-20	1	36% Chaetoceros radicans 31% Chaetoceros debilis 10% Chaetoceros didymus	33% Chaetoceros debilis 17% Chaetoceros radicans 15% Chaetoceros socialis
	2	41% Chaetoceros debilis 30% Chaetoceros radicans	20% Chaetoceros debilis 19% Melosira sulcata
	3	34% Chaetoceros debilis 21% Chaetoceros radicans	20% Chaetoceros debilis 21% Melosira sulcata 12% Biddulphia longicruris
	4	18% Coscinodiscus excentricus 15% Chaetoceros debilis 15% Melosira sulcata	18% Biddulphia longicruris 17% Coscinodiscus excentricus 13% Chaetoceros subtilis 12% Melosira sulcata 10% Thalassiosira pacifica
74-11-17	1	33% Melosira sulcata 16% ?Cylindropyxis sp.	26% Melosira sulcata
	2	55% Melosira sulcata	46% Melosira sulcata 10% ?Cylindropyxis sp.
	3	62% Melosira sulcata	55% Melosira sulcata

(Continued on next page)

Table 2. (Continued)

Date	Station	High tide	Low tide
	4	44% Melosira sulcata 17% ?Cylindropyxis sp.	15% ?Cylindropyxis sp. 14% Melosira sulcata 12% Melosira moniliformis 12% Chaetoceros subtilis
72-2-22	1	13% Fragilaria pinnata	18% Melosira sulcata 11% Gyrosigma fasciola 12% Cylindropyxis sp.
	2		13% Melosira sulcata 12% ?Cylindropyxis sp. 11% Surirella ovata
	3	16% ?Cylindropyxis sp.	16% Surirella ovata 11% Amphiprora alata
	4	15% Surirella ovata 14% ?Cylindropyxis sp.	14% Surirella ovata 12% Achnanthes 14
75-4-20	1	30% Thalassionema nitzschioides 25% Thalassiosira decipiens 11% Chaetoceros debilis	19% Chaetoceros debilis 16% Thalassiosira decipiens 14% Thalassionema nitzschioides
	2	22% Chaetoceros debilis 21% Thalassionema nitzschioides 19% Thalassiosira decipiens 12% Chaetoceros compressus 11% Chaetoceros constrictus	21% Chaetoceros debilis 19% Thalassiosira decipiens 11% Chaetoceros compressus

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Table 2. (Continued)

Date	Station	High tide	Low tide
	3	25% Thalassiosira decipiens 14% Chaetoceros debilis	42% Thalassiosira fluviatilis 10% Thalassiosira decipiens
	4	39% Thalassiosira decipiens 28% Diatoma elongatum var. tenue 10% Thalassiosira fluviatilis	49% Amphiprora alata 42% Surirella ovata
75-5-4	1	54% Thalassiosira decipiens 16% Thalassiosira nordenskiöldii	32% Thalassiosira decipiens 22% Thalassiosira fluviatilis 15% Diatoma elongatum var. tenue
	2	34% Thalassiosira decipiens 27% Diatoma elongatum var. tenue	26% Amphiprora alata 20% Thalassiosira fluviatilis 17% Diatoma elongatum var. tenue 15% Surirella ovata 11% Thalassiosira decipiens
	3	33% Thalassiosira fluviatilis 32% Diatoma elongatum var. tenue	27% Amphiprora alata 20% Surirella ovata 20% Diatoma elongatum var. tenue 16% Thalassiosira fluviatilis
	4	52% Surirella ovata 19% Amphiprora alata 14% Diatoma elongatum var. tenue	68% Surirella ovata 20% Amphiprora alata
75-5-20	1	15% Surirella ovata 15% Thalassionema nitzschioides	36% ?Cylindropyxis sp.

(Continued on next page)

Table 2. (Continued)

Date	Station	High tide	Low tide
	2	16% Surirella ovata	36% Amphiprora alata 16% ?Cylindropyxis sp. 12% Thalassiosira fluviatilis 11% Surirella ovata
	3	13% Surirella ovata 13% Thalassiosira fluviatilis 11% ?Cylindropyxis sp.	46% Amphiprora alata 26% Thalassiosira fluviatilis 16% ?Cylindropyxis sp.
	4	68% Amphiprora alata 14% Thalassiosira fluviatilis	77% Amphiprora alata 15% Surirella ovata

Navicula, Nitzschia, Opephora, Raphoneis and Rhopalodia demonstrated either a significant increase in relative abundance or an initial appearance in the plankton. With the exceptions of Actinoptychus and Cyclotella, these genera are pennate diatoms most commonly associated with attached communities.

Community Composition Parameters

Computation of the information measure (H") as an index of species diversity for the 96 communities resulted in values ranging from 0.43 to 3.56; redundancy (REDI) ranged from 0.22 to 0.89 (Table 1). During the spring, summer and fall months, diversity was relatively low and redundancy was relatively high in comparison to the winter months. Nearly all of the assemblages collected during spring, summer and fall were characterized by the presence of one or several dominant taxa. The lowest diversity values reflecting high redundancy or dominance were associated with upstream stations during the spring of 1974 and 1975. This pattern was related to "blooms" of Amphiprora alata, Surirella ovata and Chaetoceros subtilis which, in some samples, comprised 59-90% of the individuals present. Over the entire sampling year, the maximum values of H" and minimum values of REDI were obtained for samples collected in February 1975. These communities had the largest number of different taxa, all of which had small relative abundance values.

Niche breadth values were calculated for approximately 300 species of diatoms. Such measures were associated with each of 12 sampling dates and ranged from 1.00 to 7.48 (Table 3). The number of species with niche breadth values above 5.00 varied from three in early June 1974 to 19 in February 1975. The general trend was the occurrence of fewer species with relatively large niche breadths in spring and summer than in fall and winter. Several species demonstrated consistently high niche breadth values for each collection date throughout the year. These species most likely have a tolerance for a wide range of ecological conditions in the estuary. Taxa in this category were ?Cylindropyxis sp. (3.92 to 7.30), Melosira sulcata (4.31 to 7.44), Gyrosigma fasicola (2.56 to 6.75) and Surirella ovata (2.22 to 6.55). Chaetoceros cinctus, C. debilis, C. didymus, C. radicans and C. socialis tended to exhibit their largest niche breadth values concurrent with or shortly after their periods of greatest relative abundance. ?Cyclindropyxis sp., M. sulcata, Thalassiosira decipiens, T. pacifica and T. fluviatilis exhibited a similar relationship between maximum relative abundance and niche breadth. Niche breadth measurements for many species were at maximum in February when species richness was relatively high in each assemblage. Taxa included in this group were Amphiprora alata (6.39), Biddulphia longicruris (5.58), C. subtilis (5.36), Cyclotella meneghiana (6.88), ?Cylindropyxis sp. (7.30), Fragilaria pinnata

Table 3. Niche breadth values for 42 taxa including the number of different taxa encountered and the total number of taxa with niche breadths greater than 5.00

Species	1974								1975				Based on high tide values from eight selected dates
	May 26	June 8	June 26	July 17	Aug 18	Sept 16	Oct 20	Nov 17	Feb 22	Apr 20	May 4	May 20	
Achnanthes hauckiana	5.20	3.62	1.83	1.89	4.48	5.37	1.00	1.89	3.08	1.00		1.00	5.41
Actinoptychus senarius	1.78	1.89	1.00	2.00	1.89	2.91	3.16	7.48	4.56	1.00	1.00	2.00	9.49
Amphiprora alata	3.93	4.79	5.50	5.44	3.39	2.57	2.42	2.77	6.39	1.86	5.76	4.73	5.51
Amphora no. 25						1.00	4.46	5.71	1.00	1.00			4.12
Asterionella japonica				1.87	1.38	5.09	2.57	1.62					5.09
Biddulphia aurita	2.00		2.00			1.89	2.87	5.76	4.51	1.89		2.93	15.00
B. longicruris	5.01	3.66	2.79	2.96	3.27	3.10	3.45	4.48	5.58	1.00	1,89	3.16	4.51
Chaetoceros cinctus		1.00		4.50	5.28	6.18	6.26	5.35	5.71	1.75	1.00	3.00	12.43
C. debilis		1.00		2.00	1.00	5.03	7.01	6.99	2.75	5.76	2.87	3.89	7.74
C. didymus	1.00					3.14	6.10	5.13	2.00	2.70		2.84	9.28
C. radicans	3.77						5.23	4.69	2.87	1.00	1.98	3.55	4.49
C. socialis	1.00		1.00	5.29	3.39	4.75	5.50	4.77	1.00	3.87	3.52	4.14	9.08
C. subtilis	3.52	4.07	3.54	3.58	2.27	1.80	1.56	1.94	5.36		1.00	1.76	4.46
Coscinodiscus excentricus					1.00	1.00	3.42	5.51	4.71				3.38
Cyclotella meneghiana	4.03	1.90	6.65	2.36	3.79	1.00	1.96	4.11	6.88	2.61	3.00	2.83	11.02
?Cylindropyxis sp.	6.15	6.30	7.15	6.68	6.13	5.23	3.92	6.96	7.30	5.64	5.76	4.91	18.00
Diatoma elongatum var. tenue	1.49	3.50							3.00	1.13	6.29	3.06	2.75
Fragillaria pinnata	1.00	1.93	5.04	4.58	1.38	3.70	1.55	6.75	7.15	1.00	1.76	3.16	8.21
Gyrosigma fasicola	4.61	3.70	4.42	3.94	4.89	3.37	2.50	4.13	4.79	6.75	4.28	4.01	11.39
Melosira dubia	1.66	2.81	5.48	2.61	4.84	2.86	2.79	2.46	3.33			2.82	9.52
M. moniliformis	1.00	2.92	6.25	3.35	4.87	5.37	3.69	3.57	7.03	3.32	1.89	4.23	16.78
M. nummuloides	1.90		2.84	3.44	3.61	1.75	2.97	2.25	6.82		1.89	3.00	9.37
M. sulcata	5.06	5.41	5.54	5.73	5.66	5.67	5.64	7.44	7.16	4.31	6.02	4.59	12.73
Navicula directa			2.94		1.00				1.00	5.20	4.87	3.96	6.63

(Continued on next page)

Table 3. (Continued)

Species	1974								1975				Based on high tide values from eight selected dates
	May 26	June 8	June 26	July 17	Aug 18	Sept 16	Oct 20	Nov 17	Feb 22	Apr 20	May 4	May 20	
N. gregaria	3.71	1.74	2.14	2.57	1.00	1.00	1.89	4.48	6.29	3.45	1.89	3.44	6.87
Nitzschia frustulum var. perpusilla	3.35	1.00	1.69	2.52		1.00			5.26				6.39
N. fundi	5.28	4.67	5.71	4.64	4.31	3.87	2.83	5.00	7.15	1.00	2.00	5.35	14.14
Plagiogramma brockmanni	4.23	4.85	5.52	4.71	5.48	6.96	6.99	5.30	4.97	4.31	1.96	4.93	17.99
P. van huerckii	4.62	4.89	5.62	4.19	4.69	5.50		5.54	4.05	2.59	1.00	3.29	17.13
Raphoneis amphiceros	1.70	2.44	4.56	4.88	3.86	2.61	1.89	6.26	3.96	3.59		1.95	15.25
Rhicosphenia curvata				1.00	1.00	3.00			6.35	2.00	1.87	1.00	3.82
Skeletonema costatum		1.00		2.61	2.98	4.02	5.79	6.78	1.00	3.84	1.00	1.00	5.02
Surirella ovata	4.40	4.11	5.11	4.13	3.31	2.22	3.66	2.79	6.55	2.42	4.62	6.28	12.66
Synedra fasciculata	5.19	6.03	4.64	4.77	5.65	4.77	2.76	6.10	6.11	3.43	2.58	3.71	15.46
Thalassiosira decipiens	5.73	4.44	5.15	5.63	5.26	7.02	6.51	6.19	6.47	6.70	5.07	6.03	15.12
T. fluviatilis		1.00	4.85	2.45	2.00	1.00		1.00	1.00	3.93	5.46	5.99	6.66
T. nordenskioldii	1.00	2.48	4.53	2.87		4.19	1.94			1.00	1.61		4.09
T. pacifica	5.80	4.24	6.02	5.03	4.22	2.49	1.43	3.58	5.46	5.68	5.62	6.63	14.96
T. subtilis					5.95	7.21	2.58	3.43	3.00	1.00		1.00	7.15
Thalassiosira no. 1						4.85	5.73	5.90					5.42
Thalassiosira no. 2						2.46	3.08	7.39	5.33	3.94	2.69	2.68	9.85
Thalassiosira no. 3	1.00	4.16	2.91	4.08	3.65	2.00	2.59	4.76	2.82	5.17	5.20	2.57	10.78
no. of species - monthly total	131	87	119	96	117	105	91	143	191	87	71	93	
no. of species with niche breadth $\geq$ 5	8	3	13	6	7	11	9	18	19	7	8	5	

(7.15), M. moniliformis (7.03), M. nummuloides (6.82), Navicula gregaria (6.29), Nitzschia frustulum var. perpusilla (5.26), Nitzschia fundi (7.15), Rhicosphenia curvata (6.35), Surirella ovata (6.55) and Synedra fasciculata (6.11).

The calculation of niche breadth for samples taken at high tide from eight selected dates accounted for occurrence of a taxon in time along with its geographical distribution. Determination of this statistic resulted in a maximum value of 18.00 for ?Cylindropyxis sp. (Table 2). Relatively large values were also recorded for Plagiogramma brockmanni (17.99), P. vanhuerckii (17.13), M. moniliformis (16.78), S. fasciculata (15.46), Raphoneis amphiceros (15.25), T. decipiens (15.12), Biddulphia aurita (15.00), T. pacifica (14.96) and Nitzschia fundi (14.19). Only 16 taxa, representing less than 5% of all the species encountered in the estuary, exhibited niche breadth values above 10.00 in this particular analysis. Based on a possible maximum of 32.00, it would appear that the large majority of planktonic species were restricted in their spatial and temporal distributions in the estuary throughout the year.

Distribution Relative to Sampling Strategy

A comparison of the plots in Figure 21 indicates that the patterns of difference between samples collected on the same date, as expressed by MacArthur's difference measure (D_{hk}), were relatively

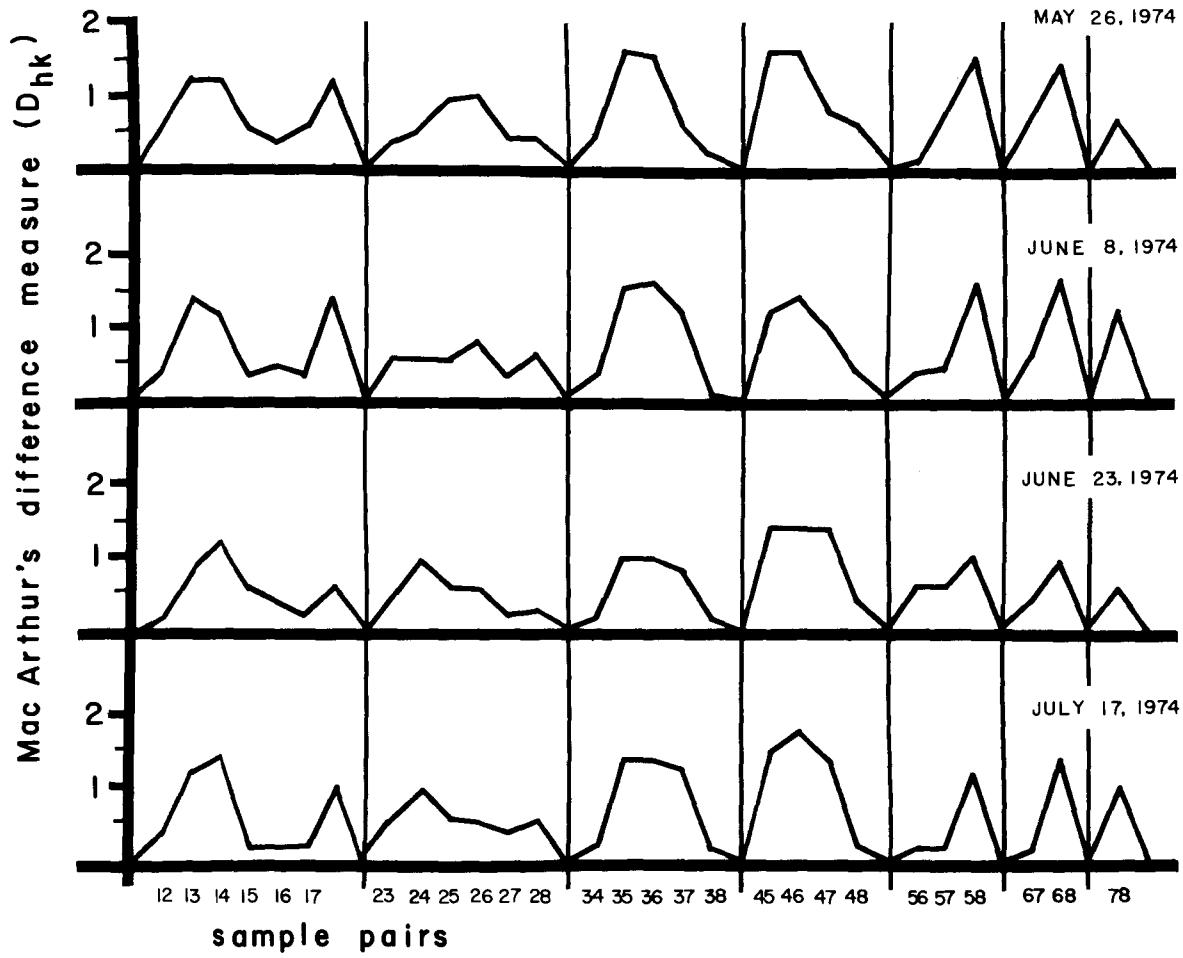

Figure 21. D_{hk} values for pairs of assemblages from 12 selected dates from May 1974 to May 1975. Numbers 1, 2, 3 and 4 refer to stations 1, 2, 3 and 4 at low tide; numbers 5, 6, 7 and 8 refer to stations 1, 2, 3 and 4 at high tide (e. g., 56 represents sample pair 2L-1H). Interpretation of this figure is based on comparison of graphs for each date. Similarities and differences between plots indicates temporal changes in the spatial relationships of planktonic diatom assemblages within the estuary.

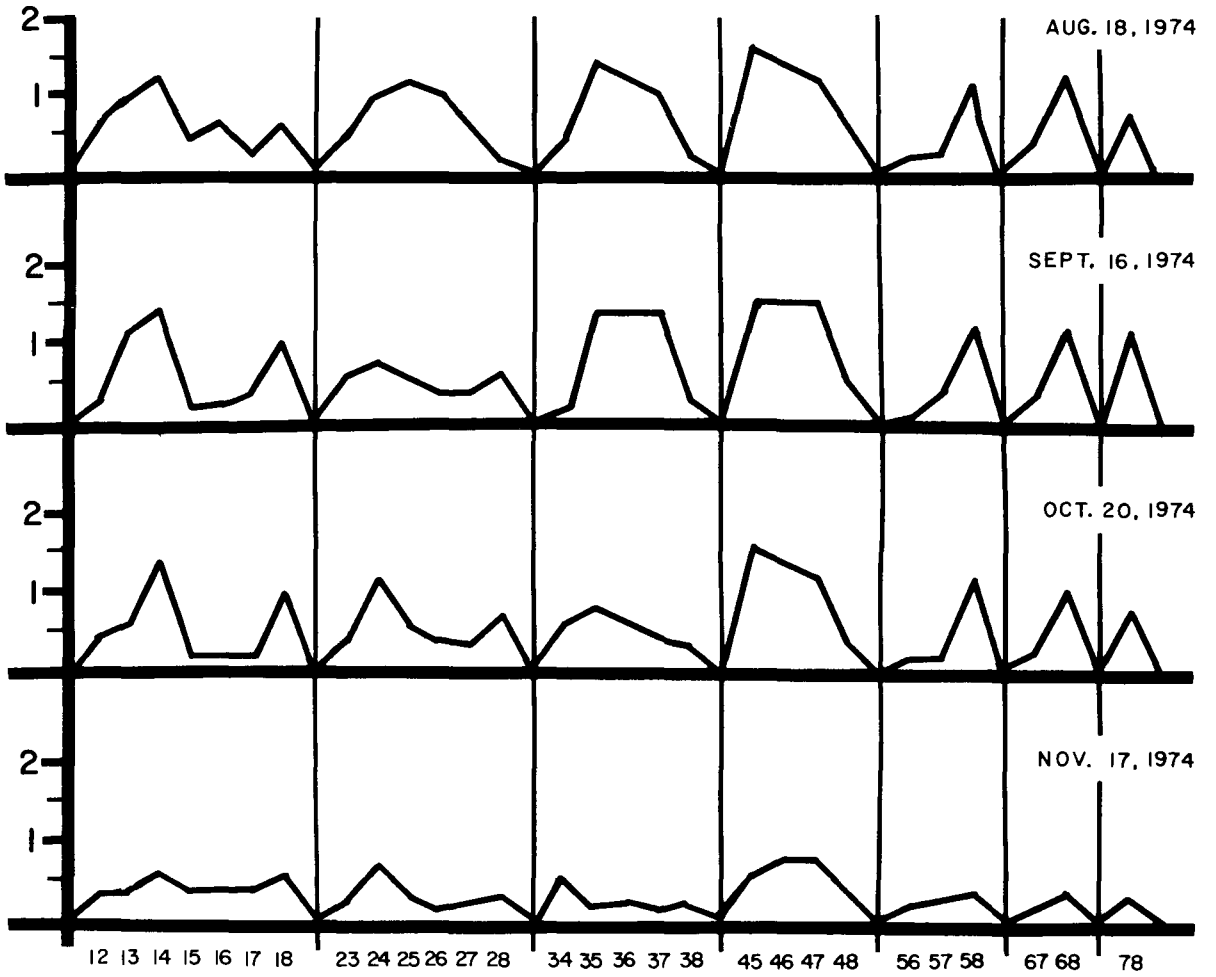

Figure 21. (Continued)

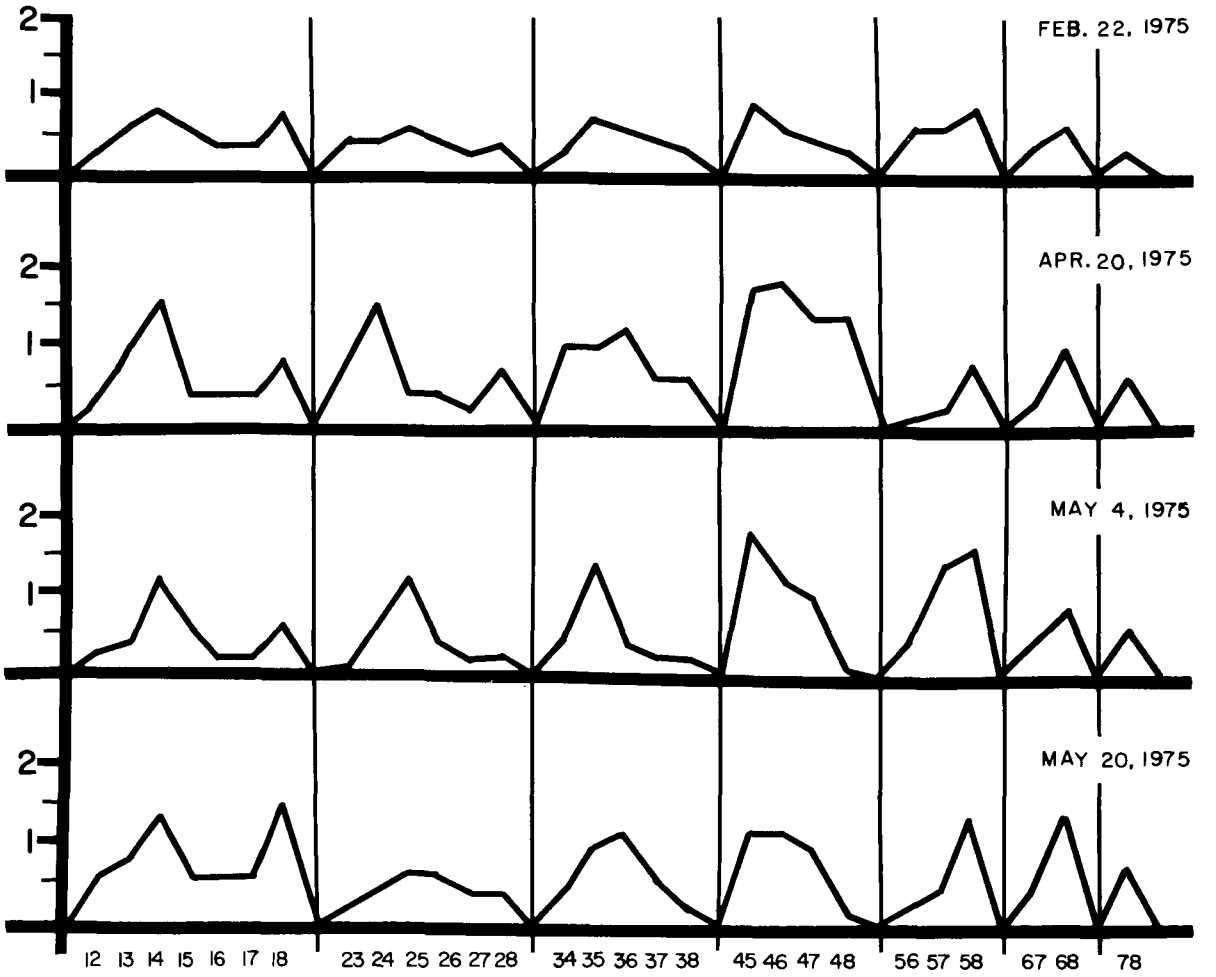

Figure 21. (Continued)

consistent throughout the year. Difference values within each date were lowest for pairs of samples taken from adjacent stations and were consistently high for the following pairs: 1H and 3L, 1H and 4H, 1H and 4L, 1L and 4H, 1L and 4L, 2H and 4H. For all dates, except November 1974 and February 1975, D_{hk} values ranged nearly full scale, indicating a sizable degree of similarity or difference among sample pairs. All comparisons for November and February were below 1.5, reflecting a greater degree of homogeneity among assemblages throughout the estuary.

Correlations of individual species indicated the tendency for certain taxa to co-occur (Table 4). Amphiprora alata and Surirella ovata exhibited the maximum correlation value (0.82). These two taxa had similar patterns of occurrence throughout the year. Both A. alata and S. ovata had relatively high correlations with Diatoma elongatum var. tenue and Thalassiosira fluviatilis. The latter two taxa also exhibited a high degree of correlation between themselves. These four taxa were typically upstream forms which became very abundant during the spring months. Chaetoceros debilis, C. compressus, C. didymus, and C. radicans were highly correlated with each other or with Skeletonema costatum and Nitzschia pungens var. atlantica. These taxa tended to co-occur in Yaquina Bay during late summer and fall of 1974, and have been reported as constituents of oceanic plankton communities (Cupp, 1943; Hendy, 1964). Their

Table 4. Correlation matrix for 40 selected taxa based on observations of relative abundance on 12 dates from May 1974 to May 1975.

	?Cylindropyxis sp.	Chaetoceros subtilis	Melosira sulcata	Thalassiosira decipiens	Chaetoceros socialis	Chaetoceros debilis	Amphiprora alata	Surirella ovata	Plagiogramma brockmanni	Thalassiosira fluviatilis
?Cylindropyxis sp.	1.0000									
Chaetoceros subtilis	0.5401	1.0000								
Melosira sulcata	0.2675	-0.0249	1.0000							
Thalassiosira decipiens	-0.1006	-0.3859	0.0333	1.0000						
Chaetoceros socialis	-0.1995	-0.3224	-0.0163	0.3154	1.0000					
C. debilis	-0.4356	-0.4047	0.1168	0.0479	0.4056	1.0000				
Amphiprora alata	-0.1116	-0.0174	-0.2666	-0.1163	-0.4107	-0.3534	1.0000			
Surirella ovata	-0.0423	0.1748	-0.1074	-0.1967	-0.5438	-0.3706	0.8227	1.0000		
Plagiogramma brockmanni	0.4921	-0.0378	0.3896	0.2346	-0.0196	-0.1708	-0.3122	-0.2750	1.0000	
Thalassiosira fluviatilis	-0.2673	-0.3409	-0.3334	0.4150	-0.0663	-0.0167	0.6124	0.4234	-0.2012	1.0000
Biddulphia longicruris	0.3694	0.3476	0.4833	-0.1473	-0.0701	-0.1088	-0.1576	-0.0295	0.1611	-0.3024
Ceratulina pelagica	0.1447	-0.0004	-0.0959	-0.0213	-0.1439	-0.2378	-0.1893	-0.0719	0.1291	-0.1699
Thalassiosira pacifica	0.1952	0.0475	-0.0546	0.3525	-0.0988	-0.3033	0.1044	0.1033	0.2802	0.3159
Diatoma elongatum var. tenue	-0.3456	-0.1514	-0.3366	0.2139	-0.2011	-0.1569	0.5531	0.5016	-0.2889	0.6395
Chaetoceros radicans	-0.3902	-0.2609	0.1463	-0.1469	0.2099	0.4522	-0.1249	-0.0713	-0.0735	-0.0426
Thalassionema nitzschioides	-0.1695	-0.3041	0.0064	0.4925	0.1851	0.2882	-0.0847	-0.0258	0.1835	0.3217
Thalassiosira subtilis	0.0897	-0.0990	0.0627	0.1278	0.2738	0.1542	-0.3624	-0.3729	0.1099	-0.2675
Melosira moniliformis	0.3753	0.3524	0.4070	-0.2703	-0.2717	-0.1552	0.1171	0.2238	0.0619	-0.2449
Fragillaria pinnata	0.3650	0.0627	0.3648	-0.0309	-0.1737	-0.1443	0.1148	0.0665	0.2454	-0.1903
Plagiogramma van huerckii	0.4962	0.0267	0.1684	0.1386	-0.0024	-0.2497	-0.2148	-0.2079	0.6512	-0.1308
Thalassiosira no. 2	0.0902	-0.1448	0.3866	0.0125	-0.0251	0.2975	-0.0073	-0.0052	0.1490	-0.0338

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Table 4. (Continued)

	?Cylindropyxis sp.	Chaetoceros subtilis	Melosira sulcata	Thalassiosira decipiens	Chaetoceros socialis	Chaetoceros debilis	Amphiprora alata	Surirella ovata	Plagiogramma brockmanni	Thalassiosira fluviatilis
Chaetoceros compressus	-0.3016	-0.2819	-0.0043	0.1629	0.3136	0.5914	-0.3275	-0.2635	-0.0268	-0.0271
Gyrosigma fasciola	0.1507	-0.2068	0.3345	0.3921	0.0004	0.0037	0.0838	0.1164	0.4144	0.1512
Skeletonema costatum	-0.2946	-0.3688	0.0810	0.148	0.4489	0.6804	-0.3879	-0.4620	-0.0709	-0.0864
Cyclotella meneghiana	0.3087	0.4699	0.0914	-0.4175	-0.5171	-0.4185	0.3327	0.4690	-0.0644	-0.2336
Thalassiosira nordenskiöldii	0.1065	-0.0758	-0.0498	0.2871	0.0089	0.0452	-0.2125	-0.2125	0.2432	-0.0543
Synedra fasciculata	0.2292	0.0478	0.5062	-0.0111	0.0225	-0.0507	-0.2187	-0.1182	0.2911	-0.2725
Bacteriastrum delicatulum	-0.0161	-0.1571	-0.0522	0.0820	0.0725	-0.0940	-0.0928	0.0725	0.1478	0.0285
Fragilaria capucinia	0.0295	-0.0456	0.1544	0.0732	0.2300	0.0352	-0.2149	-0.1868	-0.0089	-0.2625
Chaetoceros cinctus	0.0107	-0.2631	0.3821	0.0421	0.3529	0.2985	-0.3223	-0.3566	0.2976	-0.2896
C. didymus	-0.4132	-0.3104	0.2390	-0.2319	0.3008	0.7508	-0.3472	-0.3525	-0.1538	-0.2312
Coscinodiscus excentricus	-0.1839	0.0268	0.3855	-0.2341	0.0320	0.3579	-0.0997	-0.0586	-0.1632	-0.2345
Nitzschia fundi	0.6588	0.5962	0.1034	-0.2312	-0.3470	-0.4366	0.0752	0.1448	0.1874	-0.2923
Melosira dubia	0.4202	0.4009	0.3202	-0.0823	-0.1945	-0.2119	-0.1100	-0.0157	0.1104	-0.3042
Navicula gregaria	0.2292	-0.0445	0.2317	-0.0656	-0.2999	-0.2100	0.3931	0.3282	0.1197	0.1050
Melosira nummuloides	0.3058	0.3430	0.3113	-0.1542	-0.1952	-0.2435	0.1716	0.2471	0.0001	-0.2049
Asteriorella kariana	0.1116	-0.1978	-0.0080	0.3011	0.1352	-0.0938	-0.0996	-0.1423	0.2471	0.0614
A. formosa	0.2356	0.4800	-0.1549	-0.2841	-0.2067	-0.2227	0.0340	0.1688	-0.0461	-0.0630
A. japonica	-0.0122	-0.1526	-0.0002	-0.1000	0.3555	0.4295	-0.3483	-0.3673	0.0345	-0.2303
Nitzschia pungens var. atlantica	-0.3128	-0.2494	0.3272	-0.1714	0.2283	0.5213	-0.3444	-0.3697	-0.0271	-0.2115

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Table 4. (Continued)

	Biddulphia longicruris	Ceratulina pelagica	Thalassiosira pacifica	Diatoma elongatum var. tenue	Chaetoceros radicans	Thalassionema nitzschioides	Thalassiosira subtilis	Melosira moniliformis	Fragillaria pinnata	Plagiogramma van huerckii
Biddulphia longicruris	1.0000									
Ceratulina pelagica	-0.0193	1.0000								
Thalassiosira pacifica	0.0994	0.4184	1.0000							
Diatoma elongatum var. tenue	-0.2558	-0.0754	0.1622	1.0000						
Chaetoceros radicans	-0.0969	-0.0937	-0.2381	-0.0514	1.0000					
Thalassionema nitzschioides	-0.3332	-0.0401	0.2038	0.0739	0.1641	1.0000				
Thalassiosira subtilis	0.2830	-0.1475	-0.2859	-0.2531	-0.1588	-0.1954	1.0000			
Melosira moniliformis	0.5237	-0.1924	-0.0713	-0.1493	-0.0936	-0.3205	0.1380	1.0000		
Fragilaria pinnata	0.0436	-0.1609	0.0061	-0.2279	-0.0640	-0.0864	-0.0986	0.3500	1.0000	
Plagiogramma van huerckii	0.0099	0.4661	0.4006	-0.2306	-0.1158	0.1341	-0.0862	-0.1461	0.1775	1.0000
Thalassiosira no. 2	0.1552	-0.2260	-0.1984	-0.0843	0.0308	0.1541	0.1635	0.2264	0.2769	-0.0379
Chaetoceros compressus	-0.1150	-0.0982	-0.1077	-0.1552	0.0932	0.2898	0.2663	-0.1173	-0.2090	-0.1247
Gyrosigma fasciola	-0.0801	-0.0705	0.3644	-0.0309	-0.0074	0.4864	-0.1389	0.0818	0.4127	0.2786
Skeletonema costatum	-0.0908	-0.1785	-0.2718	-0.2035	0.3103	-0.0384	0.3777	-0.1308	-0.0923	-0.1137
Cyclotella meneghiana	0.1664	0.212	-0.0129	0.0148	-0.2406	-0.3208	-0.2679	0.3748	0.2888	-0.0409

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Table 4. (Continued)

	Biddulphia longicruris	Ceratulina pelagica	Thalassiosira pacifica	Diatoma elongatum var. tenue	Chaetoceros radicans	Thalassionema nitzschioides	Thalassiosira subtilis	Melosira moniliformis	Fragillaria pinnata	Plagiogramma van huerckii
Thalassiosira nordenskiöldii	-0.0901	0.1555	0.2069	-0.0133	0.0005	0.1114	-0.0820	-0.2132	-0.0165	0.3746
Synedra fasciculata	0.1972	0.0466	0.0640	-0.2230	0.1518	0.0114	-0.1388	0.2276	0.1760	0.2410
Bacteriastrum delicatulum	-0.1201	0.6674	0.4155	-0.0897	0.1135	0.3363	-0.2237	-0.2444	-0.2134	0.3611
Fragilaria capucinia	0.3693	-0.0704	-0.1614	-0.2350	-0.0416	-0.1781	0.4707	0.2034	0.0419	-0.1678
Chaetoceros cinctus	0.0754	-0.2436	-0.3387	-0.3100	0.0086	-0.0927	0.3927	0.1336	0.2540	0.0550
C. didymus	-0.0697	-0.1632	-0.4048	-0.2501	0.6788	0.0832	0.0694	-0.0978	-0.0650	-0.1411
Coscinodiscus excentricus	0.3454	-0.1412	-0.1755	-0.1771	0.2963	-0.1283	-0.0277	0.3549	0.0724	-0.1601
Nitzschia fundi	0.3078	0.1813	0.1560	-0.0868	-0.1917	-0.2140	-0.0731	0.4111	0.3042	0.2574
Melosira dubia	0.5344	-0.0626	0.1343	-0.2575	-0.1303	-0.2799	0.2036	0.5439	0.3768	-0.0556
Navicula gregaria	0.0417	-0.0381	0.0911	0.0490	-0.0876	-0.0521	-0.2132	0.2591	0.4524	0.1398
Melosira nummuloides	0.3552	-0.2073	-0.1082	-0.1771	-0.0960	-0.2347	0.0411	0.4670	0.3948	-0.1007
Asterionella kariana	-0.2463	0.4343	0.3403	0.0388	-0.0427	0.1980	-0.1533	-0.0944	0.1232	0.3829
A. formosa	-0.0436	-0.1027	0.0048	-0.0727	-0.0859	-0.0676	-0.1831	0.1855	0.0180	-0.0513
A. japonica	-0.0086	-0.1259	-0.3275	-0.2028	0.0614	-0.1404	0.4680	-0.0679	-0.1253	-0.0411
Nitzschia pungens var. atlantica	-0.0245	-0.1570	-0.3376	-0.1838	0.6195	0.0654	-0.0213	-0.0807	-0.0161	-0.0794

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Table 4. (Continued)

	Thalassiosira no. 2	Chaetoceros compressus	Gyrosigma fasciola	Skeletonema costatum	Cyclotella meneghiana	Thalassiosira nordenskiöldii	Synedra fasciculata	Bacteriastrum delicatulum	Fragilaria capucinia	Chaetoceros cinctus
Thalassiosira no. 2	1.0000									
Chaetoceros compressus	0.0152	1.0000								
Gyrosigma fasciola	0.3838	0.0099	1.0000							
Skeletonema costatum	0.0601	0.3883	-0.1948	1.0000						
Cyclotella meneghiana	-0.0021	-0.2929	0.0032	-0.3904	1.0000					
Thalassiosira nordenskiöldii	-0.1080	0.0705	0.0783	0.0570	-0.0510	1.0000				
Synedra fasciculata	0.1803	-0.1315	0.2111	-0.0475	0.0837	-0.0257	1.0000			
Bacteriastrum delicatulum	-0.1451	0.0017	0.2147	-0.1748	-0.1495	-0.0168	0.1058	1.0000		
Fragilaria capucinia	-0.0876	0.1566	-0.1462	0.2745	-0.0259	-0.1237	0.1096	-0.1661	1.0000	
Chaetoceros cinctus	0.3363	0.1075	0.0879	0.4865	-0.1720	-0.1420	0.1201	-0.1702	0.2621	1.0000
C. didymus	0.1787	0.3728	-0.1084	0.6528	-0.3016	-0.0477	0.1759	-0.0597	0.0696	0.2749
Coscinodiscus excentricus	0.1923	0.0150	0.0054	0.1424	0.0027	-0.1342	0.0930	-0.1692	0.0905	0.1698
Nitzschia fundi	-0.0155	-0.3631	0.0735	-0.3732	0.3776	-0.0540	0.2483	-0.0120	0.0267	-0.1493
Melosira dubia	0.0049	-0.1564	0.1038	-0.1825	0.0990	-0.0364	0.1543	-0.1788	0.2222	-0.0355
Navicula gregaria	0.2955	-0.1991	0.3801	-0.2218	0.3887	0.0161	0.1078	-0.1058	-0.0299	0.0644
Melosira nummuloides	0.1444	-0.2189	0.1082	-0.2299	0.4113	-0.1288	0.1844	-0.2077	0.1840	0.1274
Asteriorella kariana	-0.0210	-0.0042	0.3122	-0.0635	-0.1270	0.2763	0.0064	0.2920	-0.1706	0.0157
A. formosa	-0.2034	-0.0736	-0.1447	-0.2121	0.3849	-0.0593	0.0153	-0.0515	-0.1402	-0.2318
A. japonica	0.0384	0.3379	-0.1489	0.4497	-0.2905	0.1020	-0.1976	-0.0534	0.0639	0.3034
Nitzschia pungens var. atlantica	0.1721	0.1009	-0.1755	0.4876	-0.2813	-0.0566	0.1879	-0.1576	-0.0090	0.3142

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Table 4. (Continued)

	Chaetoceros didymus	Coscinodiscus excentricus	Nitzschia fundi	Melosira dubia	Navicula gregaria	Melosira nummuloides	Asterionella kariana	Asterionella formosa	Asterionella japonica	Nitzschia pungens var. atlantica
Chaetoceros didymus	1.0000									
Coscinodiscus excentricus	0.4030	1.0000								
Nitzschia fundi	-0.3070	-0.0521	1.0000							
Melosira dubia	-0.1385	0.2288	0.4242	1.0000						
Navicula gregaria	-0.2184	0.0514	0.2243	0.0160	1.0000					
Melosira nummuloides	-0.1520	0.2268	0.3406	0.3668	0.3334	1.0000				
Asterionella kariana	-0.1869	-0.2047	0.1046	-0.0476	0.1632	-0.1632	1.0000			
A. formosa	-0.1816	-0.1279	0.0889	0.1382	-0.0629	0.0576	-0.0845	1.0000		
A. japonica	0.3816	-0.0301	-0.1983	-0.0759	-0.1889	-0.1546	-0.0862	-0.0925	1.0000	
Nitzschia pungens var. atlantica	0.6990	0.3330	-0.2911	-0.1830	-0.1616	-0.1432	-0.1604	-0.1156	0.1828	1.0000

presence in the Yaquina Estuary is probably due to transport of coastal water by the tide.

The results of the cluster analysis are presented in Table 5. These clusters can be spatially and temporally characterized as follows:

cluster A: upstream estuary in spring 1974

cluster B: upstream estuary during summer and fall 1974, and entire estuary in February 1975

cluster C: upstream estuary in spring 1975

cluster D: downstream estuary in spring 1974 and 1975

cluster E: downstream estuary in June 1974

cluster F: downstream estuary in summer 1974

cluster G: downstream estuary in September and November 1974

cluster H: downstream estuary in October 1974

cluster I: downstream estuary in early spring 1975

The upstream portion of the estuary was represented in three of the nine clusters. Of these three groups, one represented spring of 1974 and a second represented May 1975. The third cluster included upstream observations from summer and fall of 1974 and observations from throughout the estuary in February 1975. The six clusters associated with downstream samples represented smaller increments of time than those associated with upstream assemblages.

Table 5. Results of cluster analysis of 96 samples of planktonic diatoms relative to occurrences of 20 species. Symbols as explained in text.

Date	1H	1L	2H	2L	3H	3L	4H	4L
May 26, 1974	D	D	D	A	A	A	A	A
June 8	E	E	E	A	E	A	A	A
June 23	E	E	E	E	E	A	A	A
July 17	F	F	F	F	F	B	B	A
August 18	F	F	F	B	F	B	B	B
September 16	G	G	G	G	G	B	B	B
October 20	H	H	H	H	H	H	B	B
November 17	G	G	G	G	G	G	B	B
February 22, 1975	B	B	B	B	B	B	B	B
April 20	I	I	I	I	I	I	I	C
May 4	I	I	I	C	C	C	C	C
May 20	D	D	D	D	D	C	C	C

In the discriminant analysis of the nine groups determined by the cluster procedure, 73% of the total variance was accounted for in the first three canonical variables and 92% in the first five. A plot of the first canonical variable against the second canonical variable partitioned clusters H and G as discrete groups from other clusters (Fig. 22). These two clusters represented autumn samples from downstream areas of the river. Their distinct separation from the other clusters and from each other indicates a distoncinuity in the taxonomic structure of fall downstream assemblages and other observations. Clusters C, D and H (basically samples from spring 1975) were closely related groups that partitioned out from the other clusters, while exhibiting a degree of continuity among themselves. This suggests a succession of species which may be related to the transition from a homogeneous state of winter to a heterogeneous pattern of spatial distributions in summer. The remaining four clusters represented upstream (cluster A) and downstream (cluster E) observations of spring 1974, downstream samples of summer 1974 (cluster F) and the large cluster of upstream summer and fall assemblages along with winter collections (cluster B). The upstream assemblages of spring 1974 were central to the other three groups. A plot of the first canonical variable against the third canonical variable partitioned out the summer communities of the bay (cluster F) (Fig. 23). This projection away from clusters A, B and E reveals a

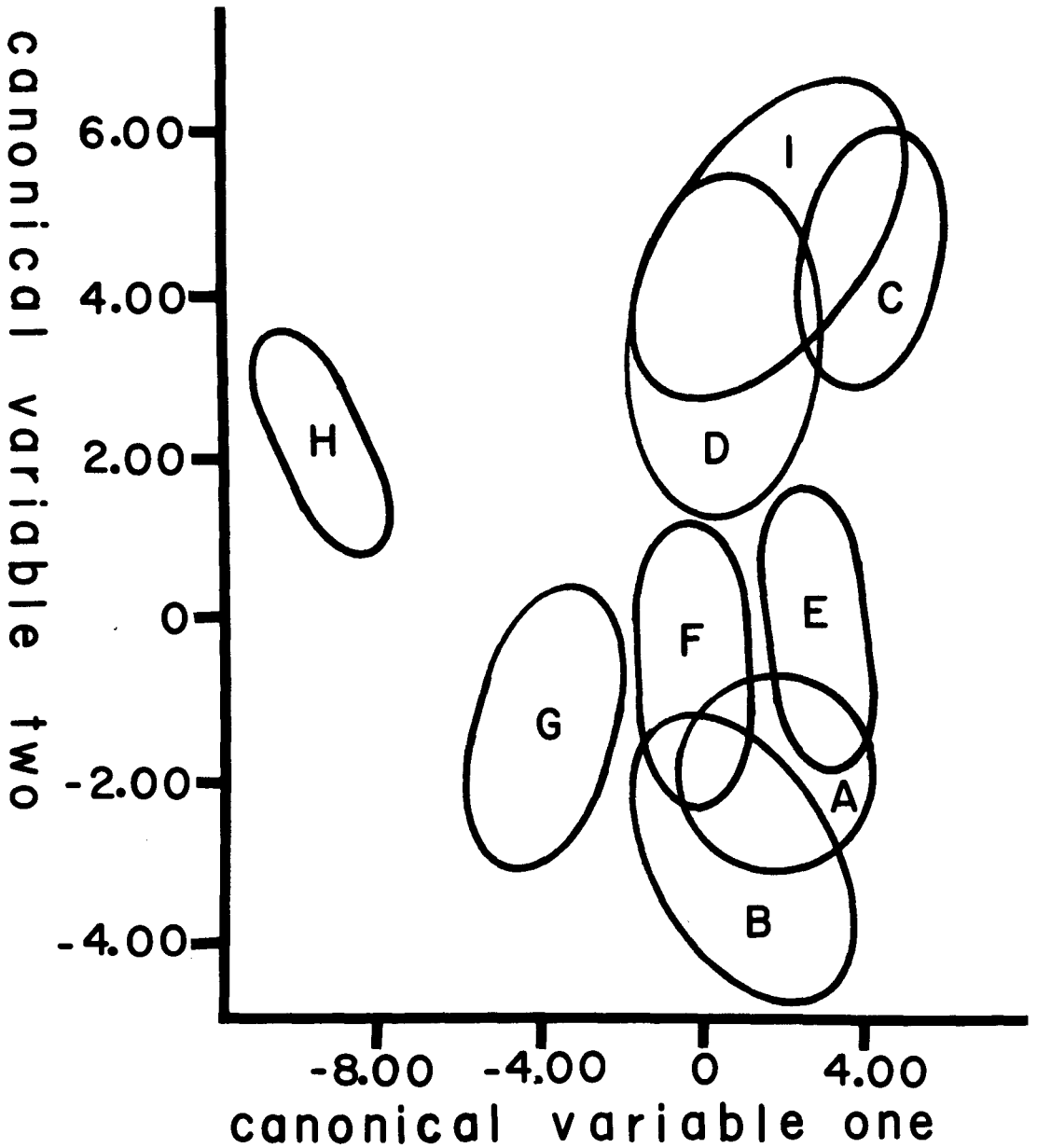

Figure 22. Plot of canonical variable one against canonical variable two of the discriminant analysis. Ellipses encircle points for individual clusters as indicated by letters. Letters correspond to clusters in Table 5.

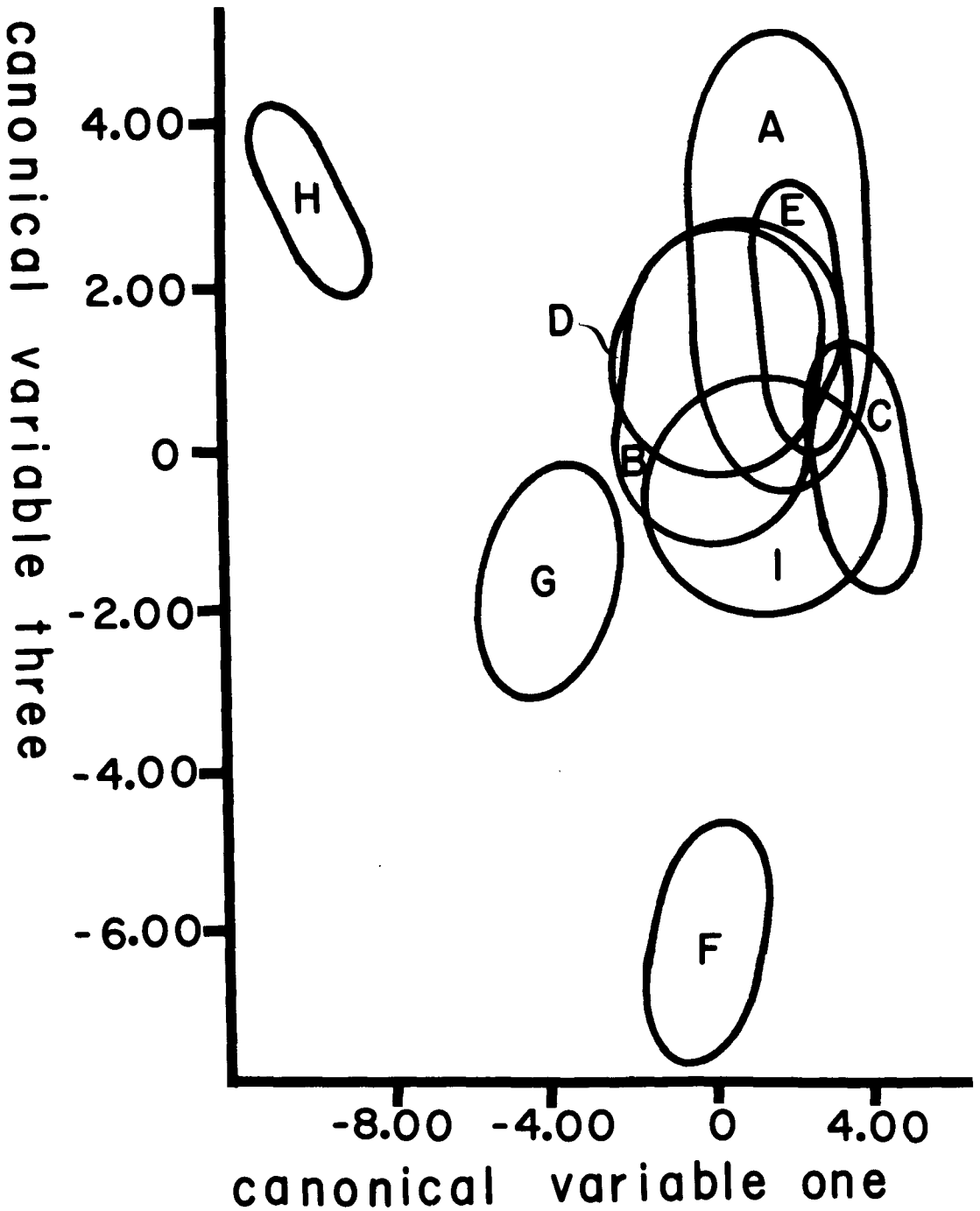

Figure 23. Plot of canonical variable one against canonical variable three of the discriminant analysis. Ellipses encircle points for individual clusters as indicated by letters. Letters correspond to clusters in Table 5.

degree of cohesiveness between these latter observations, emphasizing a continuous relationship between all spring assemblages and those of upstream areas in summer and fall throughout the estuary in winter. In contrast, a discontinuity between these assemblages (clusters A, B and E) and those of downstream areas in summer is indicated. A discriminant analysis of the environmental variables, ordered in terms of the nine sample clusters, indicated that 26 (27%) of the 96 observations were misclassified. Nine of these misplaced observations were in cluster A which spanned across summer, fall and winter months.

Distribution Relative to Environmental Variables

An analysis of environmental variables resulted in some relatively high correlations (Table 6). Rainfall showed significant correlations with the following factors: visible radiation (-), salinity (-), temperature (-), nitrate-nitrite concentration (-), phosphate concentration (+), the ratio of nitrate-nitrite to phosphate concentration (+), and tidal height (+). Visible radiation was highly correlated with salinity, and to a lesser degree with nitrate-nitrite concentration, and salinity and nitrate-nitrite concentration also were correlated. Temperature was negatively correlated with phosphate concentration and the ratio of nitrate-nitrite to phosphate concentrations, while displaying a positive correlation with silicate concentration.

Table 6. Matrix of correlations for ten environmental variables.

	Rainfall	Visible light	Salinity	Water temperature	Nitrate-nitrite concentration	Phosphate concentration	Silicate	Ratio of nitrate-nitrite to phosphate concentration	Tidal height	Chlorophyll *a*
Rainfall	1.0000									
Visible light	-0.4812	1.0000								
Salinity	-0.5168	0.9562	1.0000							
Water temperature	-0.5498	0.0396	0.1239	1.0000						
Nitrate-nitrite concentration	-0.6003	0.5037	0.5954	0.1112	1.0000					
Phosphate concentration	0.7196	-0.3571	-0.4824	-0.6502	-0.6168	1.0000				
Silicate	-0.4932	0.0788	0.1265	0.5272	0.1993	-0.4014	1.0000			
Ratio of nitrate-nitrite to phosphate concentration	0.5665	-0.1335	-0.2031	-0.5439	-0.4796	0.5668	-0.4531	1.0000		
Tidal height	0.5339	-0.2054	-0.2911	-0.5245	-0.3878	0.7151	-0.4197	0.3179	1.0000	
Chlorophyll *a*	0.0079	-0.1742	-0.1832	0.2194	-0.2102	0.0048	0.2326	-0.0346	0.0813	1.0000

Nitrate-nitrite concentration exhibited a negative correlation with the concentration of phosphate. The ratio of the concentrations of these two nutrients was negatively correlated with nitrate-nitrite and positively correlated with phosphate. Phosphate concentration also showed a high correlation with tidal height.

The canonical correlation of species and environmental data generated ten canonical variables. The percentages of variance extracted from the species and environmental observations by this analysis were 67% and 100%, respectively (Table 7). Redundancy in the species data given the environmental data was 40%. Nearly half of the variance extracted was accounted for by the first three canonical variables (41% for the species and 52% for the environment). The canonical correlation coefficients associated with these variables were 0.93, 0.89 and 0.84, respectively. In addition, the highest correlations between canonical variables and 17 of the 20 species were retained in the first three canonical variables.

Interpretation of results from the canonical correlation analysis to determine possible relationships between species and a particular environmental variable is based on examination of the correlations between the canonical variables and the original observations on the species and environmental factors. The first canonical variable has a high negative correlation with water temperature. Diatom species exhibiting a negative correlation with the first canonical variable, and

Table 7. Correlations of original observations on species and environmental factors to canonical variables one (CV1), two (CV2) and three (CV3), canonical correlation coeffieicnts (ϱ), proportion of variability associated with each variable of species and environmental data matrices (CVS and CVE), and redundancy of CVS given CVE.

Variables	CV1	CV2	CV3
Skeletonema costatum	-0.53	-0.10	-0.32
Chaetoceros socialis	-0.48	0.16	-0.21
C. debilis	-0.54	-0.20	-0.40
C. cinctus	-0.55	-0.28	-0.11
C. radicans	-0.25	-0.30	-0.13
C. subtilis	0.24	-0.00	0.83
?Cylindropyxis sp.	-0.13	0.09	0.53
Nitzschia fundi	0.13	-0.03	0.62
Amphiprora alata	0.83	-0.30	-0.29
Surirella ovata	0.82	-0.32	-0.08
Thalassiosira fluviatilis	0.51	0.24	-0.64
T. decipiens	-0.07	0.63	-0.48
T. pacifica	0.16	0.43	-0.03
T. nordenskiöldii	-0.15	0.53	0.03
Melosira sulcata	-0.52	-0.39	-0.04
M. dubia	-0.06	-0.06	0.21
M. moniliformis	0.07	-0.50	0.24
M. nummuloides	0.12	-0.42	0.23
Plagiogramma brockmanni	-0.39	0.23	0.11
P. van huerckii	-0.33	0.37	0.14
rainfall	0.33	-0.14	-0.26
incident visible radiation	0.35	0.71	0.24
salinity	0.27	0.77	0.26
water temperature	-0.89	0.32	-0.14
nitrate-nitrite concentration	-0.01	0.26	0.63
phosphate concentration	0.51	-0.48	-0.31
silicate concentration	-0.54	0.12	0.35
ratio of nitrate-nitrite to phosphate concentration	0.60	-0.05	-0.66
tidal height	0.45	-0.35	-0.21
chlorophyll a concentration	-0.21	0.02	-0.11
ϱ	0.93	0.87	0.84
% variability CVE	18.00	11.00	13.00
% variability CVE	22.00	17.00	13.00
Redundancy (CVS/CVE)	0.15	0.08	0.09

thus indicating a positive relationship with water temperature, were Melosira sulcata, Chaetoceros socialis, C. debilis, C. cintus and Skeletonema costatum. In contrast, Amphiprora alata, Surirella ovata and Thalassiosira fluviatilis exhibited a high positive correlation with the first canonical variable, demonstrating an inverse association to water temperature. The second canonical variable has a relatively high positive correlation with both visible radiation and salinity. These two factors had previously shown an extremely high correlation (0.96) of raw data values. Thalassiosira decipiens, T. pacifica and T. nordenskiöldii had a strong positive association with the second canonical variable, while Melosira moniliformis and M. nummuloides showed a negative correlation. Canonical variable three was positively associated with nitrate-nitrite concentration and negatively correlated with the ratio of nitrate-nitrite to phosphate concentrations. Species with positive correlations with canonical variable three were Chaetoceros subtilis, ?Cylindropyxis sp. and Nitzschia fundi. Negative correlations were observed with Thalassiosira decipiens and T. fluviatilis.

DISCUSSION

In an estuarine system, the initial distributions of planktonic organisms are determined by the mixing and scattering processes of continually shifting waters (currents and tides), while the taxonomic structure of the resulting assemblage is dependent on the survival and reproduction rates of the constituent species. Thus, the rate of succession (change in species composition) and the degree of dominance in assemblages of planktonic diatoms is a function of the hydrographic alteration of environmental conditions (Margalef, 1958). The structure and also the productivity of the autotrophic component of a plankton community is further regulated by the availability of light. Relationships between seasonal patterns of environmental properties and changes in phytoplanktonic assemblages have been investigated in estuaries and embayments in various areas of the world (Smayda, 1957; Braarud et al., 1958; Margalef, 1958, 1968; Pratt, 1959; Patten, 1962; Patten et al., 1963; Mulford, 1964; Taylor, 1966; Williams, 1966; Welch et al., 1972; Legendre, 1973). The general seasonal cycle of phytoplankton encountered in most of these areas involves a period of low productivity in winter caused by insufficient light for photosynthesis. Therefore, the spatial homogeneity and diversity of phytoplanktonic assemblages are expected to be maximum during this period, as increased mixing and turbulence within the

aquatic system tends to limit the ability of species to establish an equilibrium with a continually changing environment, thus minimizing dominance of species (Hutchinson, 1941, 1961). Biological inactivity and the death and decomposition of organisms during the winter allow for the accumulation of large nutrient pools. The gradual increase of sunlight in early spring, coupled with the presence of this large concentration of nutrients, is considered the major factor for the initiation of spring "blooms" of certain phytoplanktonic species (Marshall and Orr, 1972, 1928, 1930; Sverdrup, 1953; Braarud et al., 1958; Ryther, 1956; Welch et al., 1972; Parsons and Takahashi, 1972; Sakshaug and Myklestad, 1973). The depletion of nutrients by metabolic processes, in addition to greater grazing pressure at this time, results in reduction and stabilization of phytoplanktonic populations. Unless upwelling occurs, nutrients become limiting and low levels persist throughout summer and fall. In some areas fall maxima related to mixing in the water column and decreases in zooplankton abundance are observed. The actual dynamics of the relationship between nutrients and phytoplanktonic populations involves complex processes of assimilation and metabolism (Pratt, 1950). The proper balance of nutrients and the concentrations at which various essential elements may be limiting is difficult to establish (Rice, 1953; Ketchum et al., 1958; Yentsch and Vaccaro, 1958; Thomas, 1966; Goering et al., 1970; Eppley et al., 1973). Rates of regeneration and

uptake, the existence of nutrient pools within cells, and other undetermined factors restrict the interpretation of nutrient-species data to rather broad relationships.

The primary factor regulating both the hydrography of the Yaquina River and also the quality and quantity of visible radiation in the local area was the seasonal pattern of rainfall. In spring, summer and fall of 1974 rainfall was minimal and light intensities were high, physical properties of the estuary included relatively warm water temperatures, low turbidity, homogeneous mixing of the water column and the presence of a net non-tidal seaward drift, rather than distinct upstream and downstream currents (Burt and McAllister, 1959). This pattern of water movement tended to establish a definite horizontal gradient of physical and chemical properties. Temperatures were generally cooler in the bay and increased at successive upstream stations, while salinity and nutrients exhibited highest concentrations at high tide in downstream areas and lowest values at upstream stations (Figs. 4, 5, 6, 7 and 8). Characteristics of the river during this period also may have been partially affected by the occurrence of upwelling along the coast. In winter, a period of heavy rainfall and low light intensities, the hydrography of the Yaquina River was altered by a large inflow of fresh water from land drainage. This runoff carried a relatively high concentration of nitrogen and silica which had been leached from the soils of the river

valley. The input of fresh water diluted the brackish and marine waters of the estuary and decreased the overall salinity of the system. The high freshwater discharge apparently enhanced the transport of bottom sediments in a downstream direction, thereby increasing turbidity and in turn, inhibiting the penetration of light. Furthermore, the fresh water did not mix completely with marine water. and differences in density resulted in flow of low salinity runoff water at the surface, while ocean water carried in by the tide remained along the bottom. These processes established a vertical gradient of salinity and temperature and minimized the horizontal gradient of these properties at any given depth. Therefore, the chemical and physical properties were more similar between stations during the winter months than at other seasons.

Throughout the year, tide-related shifting of waters had a distinct effect on the assemblages of planktonic diatoms collected at fixed geographic points along the estuary. The D_{hk} values and cluster analysis indicated that assemblages collected at 1H, 1L, 2H, 2L and 3H were usually similar in taxonomic structure and species composition (Fig. 20, Table 5). This group of samples, representing the downstream portion of the estuary, consistently exhibited a relatively large difference from collections at 3L, 4H and 4L (upstream areas). There was some overlap observed between these two groups when 3L occasionally was more similar to the downstream samples, or 2L was

most closely associated with 3L, 4H and 4L. Obviously, the height of the tide on a given collection series, as well as seasonal hydrographic patterns, will affect the lateral movements of water. These processes apparently accounted for the variable association of collections at stations 2 and 3 with either upstream or downstream assemblages. Observations recorded in this area of the estuary were also the largest ranges of salinity and temperature, both within a tidal cycle and throughout the year. These results identified this portion of the estuary as the major transition zone between marine and freshwater habitats. This discontinuity was also observed by Manske (1968), while studying the distribution of Foraminifera in Yaquina Bay, and by Frolander et al. (1973), during investigations on the seasonal cycles of zooplankton in the estuary.

Salt concentrations and temperatures are important factors determining distributional patterns of diatom species (Patrick and Reimer, 1966; McIntire and Overton, 1971). It is evident that the structure of planktonic diatom assemblages in the Yaquina Estuary was closely related to location along horizontal gradients of temperature and salinity, and that, the magnitude of difference between upstream and downstream assemblages is directly related to seasonal hydrographic patterns affecting these properties. If one assumes that the relative location of organisms whose movements are primarily controlled by hydrographical processes will delineate the

shifting and mixing of water masses within the estuary, then these observations at fixed locations may be considered as indices to the gross horizontal displacement of planktonic diatom assemblages by tidal action. Moreover, the results of this study revealed broad seasonal patterns of spatial homogeneity (or heterogeneity) of communities within the system.

During spring, summer and fall, the differences between upstream and downstream diatom floras were most pronounced and appeared to be largely dependent on the introduction of species from either the marine or freshwater extremities of the estuary. The initial observations and highest concentrations of marine genera, such as Ceratulina, Bacteriastrum, Chaetoceros, Plagiogramma and Thalassiosira were recorded at downstream stations, usually at high tide. These taxa demonstrated a gradual decrease of dominance from the bay to upstream areas. Fresh- and brackish-water species, such as those of Diatoma, Surirella and Amphiprora were initially and most frequently encountered at stations 3 and 4 on the low tide. The plankton communities of spring, summer and fall exhibited a continual succession of dominant species and were characterized by low diversity and high redundancy as the relative abundance of one or several taxa increased disproportionately to the remaining species. The existence of a horizontal gradient of temperature and salinity apparently served to restrict the spatial distributions of organisms,

accentuating the marine and freshwater influence on species composition. This was further emphasized by the small niche breadth values calculated during this period (Table 3).

In winter, the similarity between upstream and downstream areas was at its maximum. MacArthur's difference measure indicated a relatively low degree of difference among all samples, although the least similarity was still observed between samples from stations 1 and 4. The establishment of a net downstream flow along the surface of the estuary increased the transport, and subsequently mixed the planktonic species throughout the upper layers of the system. As the penetration of light was largely inhibited by low intensities of incident radiation and the high turbidity of the estuarine waters at this time, phytoplankton probably did not survive in the bottom waters where salinity was relatively high. Thus, the phytoplankton communities of the estuary in winter were characterized primarily by the occurrence of brackish and freshwater forms which were carried from upstream regions throughout the estuary. The deterioration of horizontal gradients and apparent homogeneity of surface waters resulted in the broader spatial distribution of imported species. An additional effect of winter hydrography was to increase the concentration of attached brackish and freshwater diatoms in the plankton assemblages. These forms were apparently dislodged from their natural habitats by the relatively high energy input from

winter fluviatile processes. The overall effects of winter conditions were expressed in the high diversity and low redundancy of communities and the increased niche breadth values of many species (Tables 1 and 3).

Without additional data from coastal and upstream areas, it is not possible to determine whether the increased abundance of a taxon and its subsequent occurrence throughout the estuary originated from an invasion by populations from adjacent waters or was initiated by response to the prevailing estuarine environment. The former case would have involved the passive transport of cells by currents and tides into the estuary. A similar contention was proposed by Zimmerman (1972) and Frolander et al. (1973) relative to the seasonal abundance of zooplankton in the estuary. It is feasible that large phytoplanktonic communities in nearshore and upstream areas could sustain continued losses in this manner during periods of high productivity or entire small populations could be carried and dispersed into the river and bay. The increase in the relative abundance of a taxon may also be attributed to either increased reproduction of that taxon or decreased reproduction of other taxa within the estuary. Thus, as species richness was determined by transport of cells via water currents and tides, species equitability would be dependent on tolerance, preference or inability of an organism to adapt to the peculiarities of a brackish water system. As data obtained in this

study were expressed as relative abundance, the actual productivity and consequently the viability of specific taxa in the estuary was unknown. An examination of fresh samples indicated that the diatoms contained healthy-looking (pigmented) chloroplasts. The cells were alive, but it does not necessarily follow that they were capable of photosynthesis. If cells remained metabolically active within the estuary, they assumed the normal role of primary producers in the ecosystem. In the event that conditions in the estuary inhibited the metabolism of a group of organisms, production may cease. However, these cells are still available to grazing animals, and for a short time they continue to supply energy to higher trophic levels.

Rates of seasonal succession, differences in species composition, and the spatial distributions of populations were revealed by calculation of MacArthur's difference measure and application of the cluster and discriminant analyses (Table 5, Figs. 21, 22 and 23). The results of these statistical procedures clearly exemplified the differences in taxonomic structure of downstream and upstream communities during the spring, summer and fall and indicated the freshwater orientation of assemblages throughout the estuary in the winter. The partitioning of upstream stations into three clusters and downstream stations into six, emphasized the more rapid succession of different species which was observed in the bay area. Throughout spring, summer and fall downstream communities exhibited a series of

changes in dominant taxa. The large majority of these were oceanic and neritic species of the genera Thalassiosira and Chaetoceros, emphasizing the marine influence on the downstream flora of this period. The corresponding upstream assemblages at this time displayed relatively rapid changes in spring, associated with bloom occurrences of Amphiprora alata, Surirella ovata, Diatoma elongatum var. tenue and Thalassiosira fluviatilis. These species represent neritic and freshwater forms which are known to prefer waters of low salinity (Hendey, 1964; Patrick and Reimer, 1966). Changes in upstream communities in the summer and fall were relatively slow, perhaps indicative of stabilization of water properties due to lack of land drainage in this area at this time.

Spatial and temporal discontinuities and continua of assemblages are schematically represented in Figures 22 and 23. The discriminant analysis identified downstream assemblages of summer (cluster I) and fall (clusters B and F) as discrete communities. Their separation from downstream winter and spring assemblages and all of the upstream observations again emphasized the strong marine influence on the diatom flora of the estuary during this time. In contrast, the community structure of assemblages encountered in other seasons was more dependent on regulation by fresh and brackish waters. The contiguous clusters containing observations from throughout the estuary in spring of 1975 (clusters D, G and H) indicated the

gradual succession of species in time and space. It is of particular interest that samples from corresponding dates of 1974 were included in cluster H. This represented a degree of repetition in community structure and the recurrence of certain taxa. The reiteration of patterns in spring samples was also indicated by comparisons of diversity indices, and degree of redundancy and by computation of D_{hk} values (Table 1, Fig. 21). These results suggested that the dynamics of phytoplankton in the Yaquina Estuary may be cyclic, and at least some aspects of the diatom component of the plankton communities may be predictable.

It is widely accepted that individuals of the same species are physiologically similar in terms of metabolic requirements and responses to external conditions (Margalef, 1961; Patrick and Reimber, 1966). In this respect, the determination of the evenness component within the taxonomic structure of the planktonic diatom flora is closely associated with the environmental factors which regulate the growth and reproduction of a given species. Abundances recorded on a percentage basis are then a function of a taxon's ability, relative to other species present, to adapt to and survive in a particular set of environmental conditions. The increased dominance of various species at different points in time or space may be partially attributed to the existence of variable abilities for survival under existing external conditions for growth and reproduction (Patrick and

Reimer, 1966). Therefore, increase or decrease in relative abundance values does not necessarily imply an increase or decrease in the actual numbers of cells present. As a result, the co-occurrence of large relative abundance values for several species or similar patterns of seasonal change would indicate parity of ecological properties among those taxa. Throughout the analysis of the data obtained in this study, several groups of species exhibited statistical affinities associated with their patterns of occurrence within the estuary.

Amphiprora alata and Surirella ovata were the most closely associated taxa encountered throughout the year (Figs. 19 and 20). These two species exhibited nearly identical patterns of occurrence and relative abundance, although S. ovata had a wider yearly distribution based on niche breadth values (Table 3). These two taxa increased in relative abundance during the winter and became dominant in upstream assemblages in early May. This pattern of occurrence may be related to water temperature as indicated by the canonical correlation analysis (Table 7). The increased relative abundance of Thalassiosira fluviatilis was also related to low water temperatures. These three spring taxa are neritic diatoms which prefer low salinities (Hendy, 1964). Their distributions were correlated with Diatoma elongatum var. tenue, another spring dominant in upstream areas. This latter species is a freshwater taxon which tends to favor

slightly brackish water (Patrick and Reimer, 1966). The results of the analysis suggested that flowering of diatoms at upstream stations in spring, when availability of light and nutrients is not limiting, is restricted by the ability of a species to reproduce at low water temperatures.

In several cases, species of the same genera had similar patterns of occurrence and simultaneous maxima of relative abundance. This phenomenon was observed in Chaetoceros, Plagiogramma, Melosira and Thalassiosira, suggesting very close resemblance between growth requirements and response of species in these genera. Species of Chaetoceros and Thalassiosira displayed an interesting pattern of staggered maxima during summer and fall and simultaneous peak abundances in the spring (Figs. 15 and 18). Species of Chaetoceros tended to exhibit a more positive relationship to water temperature, while taxa of Thalassiosira were more closely associated with salinity and available light (Table 7). The high correlation between these environmental factors implies a large degree of similarity in the environmental growth requirements of taxa of Chaetoceros and Thalassiosira. These data also suggested a competitive interaction for nutrients between species of these two genera during the summer and fall, as in spring, a period of maximum nutrient concentration and non-limiting intensities of light, simultaneous increases in relative abundance occurred.

Species of Melosira exhibited largest relative abundance values in the winter. This pattern is manifested by a negative relationship between these species, especially M. moniliformis and M. nummuloides, and the environmental factors of light and salinity. Due to minimized biological activity associated with the reduction of incident radiation and the freshwater influx of high nutrient waters in the winter months, taxa expected to be dominant at this time of year are organisms capable of growth and reproduction at relatively low levels of light intensity and low salinities. In the estuary, the more abundant winter taxa, Amphiprora alata, Fragilaria pinnata, Gyrosigma fasciola, Melosira sulcata and Surirella ovata, were apparently better adapted for these conditions than the large majority of diatoms present. The combined factors of low light levels and low salinities during winter appear to serve as major determinants of the equitability (REDI) factor related to the diversity of species within a community. The slower rate of species succession observed at this time may also be related to the small number of species capable of cell division in the winter environment.

In addition to the availability of light and nutrients, the population size and relative abundance of a species is as dependent upon modification by grazing as upon reproduction and growth associated with the environmental conditions (Fleming, 1939; Buchanan and Lighthart, 1973). This is especially important when one considers the

effect of selective grazing within a diatom community (Fleming, 1939). During the winter months zooplankton populations tend to be rather low due to life cycle habits, so that grazing exerts little or no pressure on phytoplankton assemblages at this time (Heinrich, 1962; Takahashi and Parsons, 1973). A previous study in Yaquina Bay has established the strong possibility of regulation of species composition and equitability in phytoplanktonic assemblages by selective grazing behavior during spring (Deason, 1975). As grazing by zooplankters in the estuary would be at a projected maximum during the spring and summer months, this environmental pressure may be associated with the rapid succession of species observed in downstream areas at this time. However, further studies monitoring the seasonal effects of grazing are required, along with physiological investigations of species in order to most accurately assess and interpret the dynamics of the phytoplanktonic communities of the Yaquina Estuary.

A large majority of the attached diatoms previously reported from the Yaquina Estuary were encountered in the plankton samples analyzed for the present study (McIntire and Overton, 1971; Main, 1973; Main and McIntire, 1973; Riznyck, 1974). Many of these were represented by a small number of individuals, while others such as Synedra fasciculata, Melosira sulcata, Melosira moniliformis, Melosira nummuloides, Thalassionema nitzschiodes, Cyclotella meneghiana, Plagiogramma brockmanni, P. vanhuerckii, Surirella

ovata, were relatively abundant taxa in the water column. The total number of diatom species encountered in the plankton samples exceeded those of attached community studies by over 100. The degree of overlap observed between the planktonic and attached diatoms emphasized the incorporation of attached taxa into the plankton assemblages. The patterns of species diversity observed for the attached assemblages were in direct contrast to those established for the plankton communities (McIntire and Overton, 1971; Main, 1973; Main and McIntire, 1973). Attached communities tended to exhibit lower diversities and higher redundancies in winter, while these characteristics applied to the summer assemblages of planktonic diatoms. These discrepancies in community structure patterns accentuated the singularity of each type of habitat, in view of the fact that both were subjected to the same water properties within the estuary.

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APPENDIX

Appendix Table I. Diatom taxa identified in plankton samples from Yaquina Bay and Estuary, Oregon from May 1974 to May 1975. The taxa are listed in alphabetical order with their total abundance relative to the number of cells counted. (Each value under station heading is based on enumeration of approximately 6000 cells. Values under dates are based on enumeration of approximately 4000 cells.)

Species	Total no. cells observed	Stations								Collection dates											
		Low tide				High tide				1974								1975			
		1	2	3	4	1	2	3	4	May 26	June 8	June 23	July 17	Aug 18	Sept 16	Oct 20	Nov 17	Feb 22	Apr 20	May 4	May 20
Achnanthes brevipes Ag.	13	1		2		1	1	6	3		1			1		1	9	1			1
A. brevipes var. intermedia (Kutz.) Cl.	14		3			11						11					1	2			
A. cocconeiodes Riznyk	3		1				2						1	2							
A. deflexa Reim.	62			6	6	15		20	15									37			15
A. hauckiana Grun.	131	2	11	13	22	39	6	25	13	25	7	35	6	11	9	1	3	11	3		3
A. hauckiana var. rostrata Schulz.	27	6	2	8		3	2	4	2	1	2	6	5	3	1		1	5	1		2
A. kuwaitensis* Hendey	1								1						1						
A. lanceolata (Breb.) Grun.	71	4	11	15	19		2	12	8	3		2	1	4	1	1	4	47	3	3	2
A. lanceolata var. dubia* Grun.	1								1	1											
A. lanceolata var. haynaldii (Istu.-Schaarsch.) Cl.	4			1				3					1					3			
A. lemmeranii Hust.	6				5			1		5				1							
A. minutissima* Kutz.	4				4													4			
A. yaquinensis* McInt. & Reim.	1								1						1						
Achnanthes no. 14*	59				59													59			
Actinoptychus adriaticus var. balearica* Grun.	1	1																1			
A. senarius (Ehr.) Ralfs.	67	12	12	8	5	8	3	9	10	4	3	1	2	3	5	9	23	11	2	1	2
Amphipleura rutilans (Trent.) Cl.	51	1		1			47	1	1			48		1		1	2				
Amphiprora alata Kütz. (A.? paludosa Wm. Sm.)	2488	49	369	478	848	31	60	115	538	100	19	35	10	8	5	16	18	223	244	546	214
Amphora coffaeformis* Ag.	2				2									2							
A. exigua Greg.	21					19	2											18			
A. graeffi var. minor* Perag.	1					1												1			
A. laevis Greg.	2	1	1														1				1
A. lineolata Ehr.	14	8		1	1	3		1			2	2		1	1	1		2	2		3
A. ocellata* Donk.	1	1														1					
A. ovalis Kütz.	5		1	3										4						1	
A. ovalis var. pediculus* Kütz.	1			1													1				
A.? peragalli var. catalunica* Perag.	1					1						1									
A. proteus Greg	7	2				5				1	5		1								
A. sabyii Salah	6	3				3				2		3		1							
A. sublaevis* Hust.	1					1												1			
Amphora no. 1	6	3			1			2					1	1			1	1			
Amphora no. 2	6	1	1		1	2	1									1		2			3
Amphora no. 4	6		1			1	1		3					3		2				1	
Amphora no. 5	15	2	3	1		7			2		2	1			2		3	7			
Amphora no. 6	2		1	1								1						1			
Amphora no. 8	2		1						1						1			1			
Amphora no. 12*	1						1					1									
Amphora no. 13	3		1		2									2	1						
Amphora no. 14	10				3	1		3	1			2			3	1	2				
Amphora no. 16*	1	1													1						
Amphora no. 19	5			1	4					5											
Amphora no. 20	3	1						1	1			1				1		1			
Amphora no. 21	22					20	2					2						20			
Amphora no. 22	3			3									1	2							
Amphora no. 23*	1			1										1							

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Appendix Table I. (Continued)

Species	Total no. cells observed	Stations								Collection dates											
		Low tide				High tide				1974								1975			
		1	2	3	4	1	2	3	4	May 26	June 8	June 23	July 17	Aug 18	Sept 16	Oct 20	Nov 17	Feb 22	Apr 20	May 4	May 20
Amphora no. 24*	1								1						1						
Amphora no. 25	68	17	17	3	3	5	9	11	4					1	1	21	45	1	1		
Amphora no. 26	7					5	2											6			1
Anaulus balticus* Simon.	2										2										
Asterionella formosa Hass.	194		5	61	45		2	9	21	1	56	119	6					2	4		6
A. japonica Cl.	179	36	33	7	1	21	20	30	11				22	10	125	10	11				1
A. kariana Grun.	210	34	21			75	30	50		36	36	11	38	4	5			21	20	11	28
Asteromphalus hepactis*(Bréb.) Ralfs.	1	1															1				
Aulacodiscus brownei Norm. ex Pritch.	59	12	6	6	1	8	3	22	1	22	4	8	1	4	2		12	4			2
Bacillaria paxillifer (O.F. Mull) Hendey	42	5	6	2	3			1	25			1		5	3	5	9	19			
Bacteriastrum delicatulum Cl.	304	73	10	2		57	125	48	1	216	4		20					1	15	3	57
Biddulphia aurita (Lyngb.) Bréb. and Godey	56	13	8		2	11	9	9	4	2	6	2		3	7	7		6	6		13
B. longicruris Grev.	1189	16	311	253	160	8	6	39		29	23	78	88	418	226	204	99	16	1	3	9
B. longicruris var. hyalina* (Schröd.) Cupp	7							7			7										
Caloneis westii (Wm. Sm.) Hendey	4								4							1	3				
Camplyodiscus fastuosus* Ehr.	2								2									2			
Camplyosira cymbellaeformis* (A. S.) Grun.	2	2									2										
Ceratulina pelagica (Cl.) Hendey	952	112	29			408	325	76	3	896	48	1	1	2	3				1	1	
Chaetoceros cinctus Gran.	285	61	30	18	8	46	63	49	10		1		64	31	50	10	69	52	8	1	3
C. compressus Lauder	410	38	64	3	3	121	112	63	6		25			3	137	32	8		198		7
C. constrictus Gran.	167	53	18			19	58	19											158		9
C. debilis Cl.	2836	504	370	130	27	517	635	560	105		12		8	10	1100	995	144	19	475	60	25
C. decipiens Cl.	80	25	2			8	29	16		35	5			5	12		12		10	1	
C. didymus Ehr.	284	61	70	11	3	80	36	35	8	1					47	190	45	4	9		8
C. gracilis Schütt	6	1	1			1								1				2	3		
C. laciniosus Schutt.	75	9				36	4	19	7						26	38		5		6	
C. lorenzianus Grun.	97	40	11			7	3	33				3			12	57	20	2	3		
C. radicans Schütt	720	91	58	28	1	210	145	132	6	5	3					604	11	5	1	8	83
C. seiracanthus* Gran.	16						16					16									
C. socialis Lauder	3267	459	249	27	5	534	589	416	51	40		25	1295	385	164	173	39	3	111	36	61
C. subsecundus (Grun.) Hust.	106	27	14	1		32	35	5			11	11	2	31	6				33	12	
C. subtilis Cl.	4105	16	272	1224	1402	15	12	69	1095	592	918	713	808	375	100	74	77	22		3	4
C. vistulae Apstein	9	2	6						1								8		1		
Cocconeis californica* Grun.	1		1							1											
C. costata Greg.	26	1		3		1	21			2	1	21				1			1		
C. diminuta Part.	4				2			1	1	4											
C. ? disculus* (Schum.) Cl.	1	1																			1
C. fluviatilis Wall.	12		9	2					1	1							11				
C. placentula Ehr.	18					1	4	8	5									17			1
C. placentula var. lineata (Ehr.) V. H.	38	8	5	7	6	4	6	2									4	34			
C. scutellum Ehr.	51	10	8	8	8	5	3	6	3	7	7	1	2	1		3	16	6		2	3
C. scutellum var. parva* (Grun.) Cl.	1		1											1							
Coreothron hystrix Hensen	4	1		2				1							3					1	
Coscinodiscus angstii var. granulomarginata* Gran.	1					1										1					

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Appendix Table I. (Continued)

Species	Total no. cells observed	Stations								Collection dates											
		Low tide				High tide				1974								1975			
		1	2	3	4	1	2	3	4	May 26	June 8	June 23	July 17	Aug 18	Sept 16	Oct 20	Nov 17	Feb 22	Apr 20	May 4	May 20
Coscinodiscus excentricus Ehr.	270	7	2	11	94	6	5	4	91					1	1	242	19	7			
C. excentricus var. fasiculata* Hust.	1				1											1					
C. lineatus Ehr.	16	2	4	1		1	1	2	5	4			2	1			8	1			
C. marginatus* Ehr.	1		1								1										
C. moelleri* A. S.	1							1				1									
C. nitidus Greg.	3				1	1	1							1			1	1			
C. sublineatus Grun.	26	6	5	2	2	2	3	4	2	6	2	3	4	1	3	3	2	1	1		
Coscinodiscus no. 1	20	10	2		8					11							8	1			
Coscinodiscus no. 2*	1				1					1											
Coscinodiscus no. 3*	2							2		2											
Coscinodiscus no. 4*	1								1	1											
Coscinodiscus no. 5	10	8	1		1					1								9			
Cyclotella kutzingiana Thw.	13		1	1	11					7		6									
C. meneghiana Kütz.	357	15	29	54	167	11	23	19	39	99	114	32	14	10	2	5	13	101	5	9	4
C. stelligera* Cl. & Grun.	2	2										2									
?Cylindropysis sp. Hendey	5890	781	1026	829	701	396	264	757	1018	689	808	1156	621	406	794	41	407	391	121	44	477
Cylindrotheca gracilis (Bréb.) Grun.	9	1				2		4	2		4	3	1		1			1			
Cymbella naviculaeformis* Aver.	1								1									1			
C. tumida (Breb.) V. H.	9	1	3	1	3			1				1						8			
C. ventricosa Kütz.	14			4	5	1			4	1								10	2		1
Denticula subtilis Grun.	5			2					3					3							
Denticula no. 1*	1					1						1									
Diatoma elongatum var. tenue (Ag.) Kutz.	794	79	87	108	83	7	138	196	240	64	14							3	144	653	168
D. hiemale var. mesodon (Ehr.) Grun.	41	3	5	4	2	2	8	11	6			1		1				35		3	1
D. tenue* Ag.	2					2								2							
D. vulgare* Bory	2		2															2			
Diploeis bombus* Ehr.	1							1				1									
D. didyma (Ehr.) Cl.	9	3	1		1	4						5					4				
D. incurvata (Greg.) Cl.	6					3	2		1		1						1	3			1
D. interrupta (Kutz.) Cl.	4	1		1		2				1								3			
D. littoralis* (Donk.) Cl.	1					1						1									
D. smithi (Breb. ex Wm. Sm.) Cl.	9			1		4	1	1	2	1	1							7			
Ditylum brightwellii* (West) Grun. ex V. H.	1						1									1					
Epithemia turgida (Ehr.) Kutz.	12	3	3	1			2	2		2							1	6	1		1
Eucampia cornuta* (Cl.) Grun.	2	2														2					
E. zoodiacus* Ehr.	1					1												1			
Eunotia pectinalis var. recta* A. Mayer ex Patr.	1				1													1			
E. perpusilla Grun.	3			1				2							1			2			
Eunotia no. 1*	1			1						1											
Fragilaria capucina Desm.	297	52	68	5	18	43	1	31	79	4			32	163	23	22	27	21	2		
F. construens (Ehr.) Grun.	2							2		1	1										
F. construens var. subsalina* Hust.	5						5			5											
F. cylindrus* Grun.	1								1	1											
F. pinnata Ehr.	489	95	63	62	43	86	43	58	38	8	41	46	34	23	12	19	35	238	5	4	24
F. striatula var. californica Grun.	74	25	7	17		14	9		2			11				4	19	40			

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Appendix Table 1. (Continued)

Species	Total no. cells observed	Stations								Collection dates											
		Low tide				High tide				1974								1975			
		1	2	3	4	1	2	3	4	May 26	June 8	June 23	July 17	Aug 18	Sept 16	Oct	Nov 17	Feb 22	Apr 20	May 4	May 20
Fragilaria vaucheriae (Kütz.) Peters.	20	2		5	3	8	2											19	1		
Frickia lewisiana* (Grev.) Heiden	1				1												1				
Frustulia vulgaris Thw.	15	1	1	4	2	1	5		1									15			
Frustulia no. 2*	1							1		1											
Frustulia no. 3*	1								1	1											
Gomphonema angustatum (Kütz.) Rabh.	16	1		11	2	2					2	9					2	3			
G. montanum var. subclavatum Grun.	3			1				2										1			1
G. parvulum (Kutz.) Grun.	66	4	3	8	22	11	4	10	3						1			62		2	1
Grammatophora marina (Lyngb.) Kütz.	62	3	44	1	8	1	1	3	1	8	1	1				46	4	2			
G. oceanica Ehr.	5			1			4					1					2	2			
Gyrosigma articum* Cl.	1							1										1			
G. balticum (Ehr.) Rabh.	3							1	2			1						2			
G. eximium (Thw.) Boyer	9		6	1	1		1						1	1				5	2		
G. fasciola (Ehr.) Griff & Henfr.	403	106	39	23	12	91	81	33	23	12	16	30	14	12	8	11	16	149	47	17	73
G. glaciale Cl.	11	1	3	1			1	3	2							4	6	1			
G. nodiferum (Grun.) Rein.	74	3	10	9	5		2	42	3			4	1	9	6		3	19	3	1	28
G. peisonis (Grun.) Hust	85	3	8	29	8		1	21	15		1				3	48	20	1		2	
G. spencerii (Quek.) Griff. & Henfr.	11	1	1	1				1		4				7							
G. wansbeckii Cl.	5	1			1		1		2	1				4							
Gyrosigma no. 1	19		3	1	2		3	6	4				1				2	12	1	2	1
Gyrosigma no. 2	2			1			1			1								1			
Gyrosigma no. 3*	3			3													3				
Hannea arcus (Ehr.) Patr.	13	1	1		5	1	1	4			3	2	1					6		1	
Hantzschia amphioxys f. capitata* O. Müll.	3				3						3										
Hemiaulus hauckii* Grun. ex V.H.	2						2						2								
Leptocylindrus danicus Cl.	15	1				3		11											12		3
Licmophora gracilis (Ehr.) Grun.	37		9			1	19	10	1	11		17	2	7					3		
L. jurgensii var. dubia Grun.	8			1			1		6	7										1	
L. lyngbyei (Kutz.) Grun	5	1	1			2							1								
L. paradoxa (Lyng.) Ag.	4		2				1	1			1				1	1				1	
L. tincta* (Ag.) Grun.	8	8												8							
Mastogloia exigua Lewis	4					2		2										4			
M. smithii* Thw..	1				1												1				
Melosira dubia Kutz.	234	22	43	29	42	10	5	21	42	9	16	36	12	52	30	44	8	22			4
M. granulata (Ehr.) Ralfs.	102			9	20		41	12	20									102			
M. jurgensii* Ag.	2			2														2			
M. moniliformis (Mull.) Ag.	675	32	70	105	188	25	28	78	135	48	24	54	22	78	69	87	96	123	24	9	26
M. nummuloides (Dillw.) Ag.	213	14	14	48	37	9	13	15	63	3		24	48	35	4	10	21	59		3	6
M. sulcata (Ehr.) Kutz.	3536	368	608	596	228	290	450	546	413	100	82	192	120	222	101	406	1686	346	104	31	145
Meridion circulare (Grev.) Ag.	19			19														19			
Navicula abunda Hust.	40	14	7	3	2	5	2	3	4			7	2	12	5		4	3	2		5
N. admissa* Hust.	1				1												1				
N. agnita Hust.	12	2			1			9				6				1	1				4
N. arvensis Hust.	2		1	1						2											
N. auriculata Hust.	5	1	1				2		1	2				2		1					
N. cancellata Donk.	13	7			1	5				6	2				2			3			
N. cancellata var. ammophila* Grun.	1	1								1											

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Appendix Table I. (Continued)

Species	Total no. cells observed	Stations								Collection dates											
		Low tide				High tide				1974								1975			
		1	2	3	4	1	2	3	4	May 26	June 8	June 23	July 17	Aug 18	Sept 16	Oct 20	Nov 17	Feb 22	Apr 20	May 4	May 20
Navicula capitata* Ehr.	1			1									1								
N. cincta (Ehr.) Ralfs.	3			1		2				1		1	1								
N. clavata var. subconstricta Hust.	2		1			1								1				1			
N. commoides (Ag.) Perag.	5		1		1	1		2		1		1	1						2		
N. crucigera Wm. Sm.	7		2		1	1	3					1	1	1			2	1	1		
N. cryptocephala Kutz.	148	13	5	3	8	111	1	14	3	21	13	89	1		2		11	6		1	5
N. cryptocephala var. veneta (Kutz.) Grun.	21	9	2			6		1	3	2		7	1				1	10			
N. decussis* Østr.	1				1																
N. diserta W. Sm.	139	22	9	3		47	39	14	5			7		1				1	45	16	69
N. disecta Hust.	23	7	2	5	2			5		15		3					4	1			
N. diversistrata Hust.	2	1				1				1							1				
N. exigua* Greg. ex Grun.	1								1	1											
N. forcipata var. densestriata* A.S.	3					3						3									
N. granualata Bail.	2		2							1			1								
N. gregaria Donk.	224	14	15	39	20	57	6	42	21	9	18	18	5	1	3	3	13	112	14	6	22
N. grevelliana (Ag.) Cl.	5		1	1		2		1									2		1		2
N. halophila* (Grun.) Cl.	1								1	1											
N. minima Grun.	6	2	2	1		1				2							1	3			
N. mutica Kutz.	18	1	4	4	2	1		4	2	4				2				9	1	1	1
N. palpebralis Breb.	19	1	1		1	10	5		1					2				17			
N. patrickae Hust.	5				2			3							5						
N. peregrina (Ehr.) Kutz.	10	3	2	1		1	1	2		1	2						1	6			
N. phyllepta* Kg.	14								14	14											
N. pseudony Hust.	2	1			1					1									1		
N. pusilla W. Sm.	20		1	1		14	2	1	1			5		1	1			13			
N. rhynchocephala Kutz.	4	2	2															1	2	2	1
N. scopolorum Breb.	2		1					1				1							1		
N. seminulum* Grun.	1				1												1				
N. tripunctata* Bory	1					1							1								
N. vaucheriae* Peters.	3			3										3							
N. viridula Kutz.	4				2	1	1					1								3	
N. viridula var. avenacea (Breb. ex Grun.) V.H.	70	2	4	17	23	4	1	7	12	1	4		1	2	1			49	1	8	3
Navicula no. 2	53	15	7	3	4	22	2			2		24			22		5				
Navicula no. 4*	1	1										1									
Navicula no. 5	8		1			7					6	1						1			
Navicula no. 19	2		1				1					1		1							
Navicula no. 37	10			1	1	8						6					2	2			
Navicula no. 45*	1	1								1											
Navicula no. 46*	6					6						6									
Navicula no. 47*	3							3											3		
Nitzschia acicularis* W. Sm.	1				1											1					
N. aequeorea Hust.	2			2										1	1						
N. aerophila Hust.	3	1			1				1			1		1	1						
N. angularis W. Sm.	6	2	1	1					2				1	2		1	2				
N. apiculata (Greg.) Grun.	3					3						2						1			

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Appendix Table I. (Continued)

Species	Total no. cells observed	Stations								Collection dates											
		Low tide				High tide				1974								1975			
		1	2	3	4	1	2	3	4	May 26	June 8	June 23	July 17	Aug 18	Sept 16	Oct 20	Nov 17	Feb 22	Apr 20	May 4	May 20
Nitzschia clausii* Hantz.	8				8					8											
N. closterium (Ehr.) W. Sm.	26	2	5	1		3	14	1									1	18	5		
N. delicatissima Cl.	35	5	1			3	22	1							35						
N. dissipata Kütz.	10		2	4	4									1		2		7			
N. dissipata var. media* (Hantz.) Grun.	4				4					4											
N. dubia W. Sm.	11		1		6		3		1									1	2	5	3
N. filiformis (W. Sm.) Hust.	14	1	2	2	3		1	5					1	4	1			2	2	1	3
N. fonticola Grun.	3			1	2					1		1			1						
N. frustulum (Kutz.) Grun.	26		6	2			13	4	1						2	1	1	14	2	1	5
N. frustulum var. perminuta Grun.	25	2	3		1				19			2	3	5	1			14			
N. frustulum var. perpusilla (Rabh.) Grun.	110	12	19	4	15	9	13	9	20	22	1	9	13		1			56			
N. frustulum var. subsalina* Hust.	2				2												2				
N. fundi Chlon.	267	34	31	40	55	20	6	28	53	84	49	27	29	18	14	4	13	19	1	2	12
N. granulata* Grun.	1							1			1										
N. hungarica Grun.	19		3	2	2	2		1	9					3	4	3	2	4			3
N. hybrida Hust.	18	2	2	2	7	1	1		3	2				2	2	3	1	5		3	
N. hybridaeformis Hust.	14			1	7	5		1			3				1			3		8	
N. incrustans Grun.	49	5	4	13	4	3	3	11	6					1	2		12	13	16	1	4
N. lanceolata* W. Sm.	1	1															1				
N. latens Hust.	27	6		2		8	4	5	3	4				7	5	8	1	1	1		1
N. linearis W. Sm.	5			2					3									5			
N. longissima Ralfs.	22	4	4	1	1	4	1	2	5		1	1	5		4	5	2	2			2
N. marginulata Grun.	3							2	1	3											
N. obtusa* W. Sm.	2							2										2			
N. pacifica Cupp	31		3			3	20						5			18	8				
N. palea (Kutz.) W. Sm.	2			1					1	1			1								
N. paradoxa Gmel.	10				3	6	1						1	3			6				
N. pseudohybrida Hust.	51	10	8	12	2	13	1	1	4			3	2	1		5	19	21			
N. punctata (W. Sm.) Grun.	9	1	3	1	2			1	1						3		2	2	1		1
N. punctata var. coarcta Grun.	7		1	1	2		2	1	1				1				2	3	1		
N. pungens var. atlantica Cl.	168	50	33	9	2	23	33	18					3		2	91	67		5		
N. recta* Hantz.	1						1					1									
N. romana Grun.	2			1	1					1								1			
N. seriata* Cl.	6							6							6						
N. sigma (Kutz.) W. Sm.	26		2	4	3	5	5	2	5			3				3	4	11	4		1
N. sigma var. intercedens* Grun.	1	1								1											
N. sigma var. sigmatella* Grun.	3				3									3							
N. socialis Greg.	43	3	1	16	19	4		2		1	2	1	18		2	17	2				2
N. stagnorum* Rabh.	1							1										1			
N. subhybrida Hust.	57	11	3	7	26		1	5	4		3	2	4	6			14	22	4		2
N. sublinearis Hust.	2							1	1	1								1			
N. tarda Hust.	2	1		1						1								1			
N. tryblionella Hantz.	6	1			4			1			1			1			1	3			
N. tryblionella var. debilis (Arn.) A. Mayer	51	1	1	3	18	5	4	4	15	1	3	1	1				1	29	4	6	5
N. tryblionella var. levidensis (W. Sm.) Grun.	11		1		3		1	3	3	1		1					1	7		1	

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Appendix Table I. (Continued)

Species	Total no. cells observed	Stations								Collection dates											
		Low tide				High tide				1974								1975			
		1	2	3	4	1	2	3	4	May 26	June 8	June 23	July 17	Aug 18	Sept 16	Oct 20	Nov 17	Feb 22	Apr 20	May 4	May 20
Nitzschia tryblionella var. victoriae Grun.	22	2	5	6	6			2	1	4			2	1				11			
Nitzschia no. 9	2	1						1										1			1
Nitzschia no. 10*	1							1										1			
Nitzschia no. 14*	1				1													1			
Nitzschia no. 15*	1						1														1
Nitzschia no. 32	14			2		9		3				12	2								
Nitzschia no. 34*	1							1				1									
Nitzschia no. 36*	1	1								1											
Nitzschia no. 37*	1							1		1											
Nitzschia no. 38	3	2						1		1		1		1							
Nitzschia no. 39	2			1					1	1		1									
Nitzschia no. 40*	1		1								1										
Nitzschia no. 41*	1					1						1									
Nitzschia no. 42	2			2									1				1				
Nitzschia no. 43*	1		1											1							
Nitzschia no. 44	6				1	1		1	3					2				4			
Nitzschia no. 45*	1				1										1						
Nitzschia no. 46*	1				1												1				
Nitzschia no. 47*	1				1												1				
Opephora marina (Greg.) Petit	7					6			1				1					6			
Pinnularia interrupta* W. Sm.	1	1																1			
P. mesogongyla* Ehr.	1			1														1			
Pinnularia no. 1*	1				1												1				
Pinnularia no. 3	5			2		3										1		4			
Plagiogramma brockmanni Hust.	1537	333	235	80	16	175	299	326	74	111	290	417	108	89	76	9	138	128	36	5	131
P. van heurckii Grun.	450	159	52	21	6	85	68	54	7	59	147	50	49	11	12		31	17	5	1	70
Pleurosigma affine Grun.	5	4				1				5											
P. afinne var. normanni Ralfs.	20	7	1		1	2	4	3	2			11	2	3			3	1			
P. angulatum W. Sm.	20	1			2	1	11	4	1		3						14	1			2
P. angulatum var. aestuarii* (Bréb.) V.H.	1					1												1			
P. decorum* W. Sm.	3		3														3				
P. intermedium* W. Sm.	1	1															1				
P. normanii* Ralfs.	1							1								1					
P. salinarum Grun.	4				1			1	1					3		1					
P. wansbeckii* Donk.	1	1								1											
Pleurosigma no. 2*	1			1									1								
Pleurosigma no. 3*	1								1						1						
Raphoneis amphiceros Ehr.	127	32	22	8		15	24	23	3	9	11	12	8	7	8	3	31	22	7	1	8
R. psammicola Riznyk	51	14	7	4	4	7	9	4	2	6	2		3	3	1		14	15	2	2	3
Raphoneis no. 5	7		2		2		1	1	1	1				2	1	1	2				
Raphoneis no. 6*	1		1															1			
Rhicosphenia curvata (Kutz.) Grun.	65	2	9	13	13	4	1	8	15				1	1	3			53	2	3	2
R. marina (W. Sm.) M. Schm.	8				4			4			2			4				2			
Rhizosolenia alata Brightw.	62	1	2			21	30	7	1		2		53		1		4		2		
R. delicatula Cl.	15	2				7		6							15						
R. semispina Hensen	9		1	1		2	4	1					2		1		3		3		
R. setigera* Brightw.	2		2														2				

(Continued on next page)

Appendix Table I. (Continued)

Species	Total no. cells observed	Stations								Collection dates											
		Low tide				High tide				1974								1975			
		1	2	3	4	1	2	3	4	May 26	June 8	June 23	July 17	Aug 18	Sept 16	Oct 20	Nov 17	Feb 22	Apr 20	May 4	May 20
Rhicosphenia stolterfothii Perag.	11	2	5			2		2									10				1
Rhopalodia musculus O. Mull.	25	3	1			12	4	2	3			2		3		1	1	18			
Skeletonema costatum Grev.	370	103	51	34	4	63	137	35	6		2		12	36	160	94	25	1	35	3	2
Stauroneis agrestes* Peters.	1								1									1			
S. constricta* (W. Sm.) Cl.	1							1													1
S. phoenicenteron* Ehr.	1		1															1			
Stephanodiscus no. 1*	1						1											1			
Stephanopyxis nipponica* Gran & Yendo	2						2					2									
S. turris Grev.	5	2	2				1										5				
Surirella apiculata W. Sm.	17	1	4	3	3		1	1	4							2		15			
S. gemma Ehr.	11	3	1	2	3			1	1							2	5	2		1	1
S. ovata Kütz.	2457	71	227	307	993	91	154	178	435	285	68	53	36	34	20	33	43	369	272	866	378
S. striatula* Turp.	1				1					1											
Synedra delicatissima* W. Sm.	1					1												1			
S. fasciculata	329	50	74	22	21	42	46	45	29	27	15	57	25	18	6	52	60	29	10	4	26
S. fasciculata var. truncata (Ag.) Kutz.	63	2	6	1	5	6	8	32	1	2		8		2	1	1	5	5	10	26	1
S. radians* Kütz.	1				1													1			
S. socia Wall.	11			1		4		4	2	1		4						6			
S. ulna Nitz.	15	1	2	6	4				2			5		3			3	4			
S. ulna var. danica* (Kutz.) V.H.	1				1					1											
Tabellaria fenestrata Kutz.	8	1		1	6								1	1			3	3			
T. flocculosa Kutz.	9	1	4	1				2	1						1			4			4
Thalassionema nitzschioides Grun.	717	145	38	5		274	187	58	10	12	15	10	9	8		6	34	16	312	63	152
Thalassiosira aestevalis Gran & Angst	76	16	5	9	6	12	15	6	7	18	1	5	4	1		3	3	1	9	6	25
T. decipiens (Grun.) Joerg.	3402	547	300	155	28	774	752	560	282	37	231	217	201	815	45	28	59	64	783	754	164
T. fluviatilis Hust.	1326	142	177	431	42	57	58	266	152		9	9	8	2	2		2	2	360	531	400
T. nordenskiöldii Cl.	350	25	3	3		165	114	32	6	1	154	73	5		14	8		1	94		
T. pacifica Gran & Angst	919	214	339	69	74	136	116	104	81	210	161	114	71	45	13	56	9	13	122	46	66
T. rotula Meun.	12	4	4			4							4								
T. subtilis (Østf.) Gran.	712	187	92	51	25	60	88	116	93					462	223	5	15	3	1		3
Thalassiosira no. 1	150	38	18	12	2	29	29	21	1						56	65	29				
Thalassiosira no. 2	449	59	29	78	96	43	48	29	54						180	12	83	99	17	23	22
Thalassiosira no. 3 (decipiens + pacifica)	158	42	42	9	6	10	20	29	8	1	22	20	14	11	2	5	6	4	28	37	10
Thalassiosira no. 4 (decipiens + aestivallis)*	1		1											1							
Thalassiosira no. 5 (decipiens + fluviatilis)*	1		1										1								
Thalassiosira no. 6 (decipiens + nordenskioldii)	2	1							1						1					1	
Thalassiothrix frauenfeldii Grun.	6		1	1	4					1		4	1								
Triceratium alternans Bailey	4	2				2						1	1								
Unknown 1	23	4				10	3	3	3			12			4	4	3				
Unknown 2	8		2	2			2	1	1					1	1	1	4	1			
Unknown 3	27	7	7	3	5	4			1						4		12	10		1	
Unknown 5	2	1	1														1	1			
Unknown 6*	2						2										2				

*Species record in one sample only.