Freeman

WINTER POPULATION DYNAMICS OF PHYTOPLANKTON IN COOS BAY, OREGON

by

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Dedication

I would like to dedicate this paper to my parents, Molly M. Freeman and Richard W. Freeman, without whose love and support I would have never reached this point.

I would also like to thank Dr. Paul P. Rudy, for his irreplaceable help, patience and understanding. Thanks also to the entire staff at the Oregon Institute of Marine Biology, especially Jean Hanna and Bob Ellis.

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Tables and Graphs

This study is concerned with the early winter (October, November, December) dynamics of phytoplankton populations in the South Slough of the Coos Bay estuary. A student study, conducted at the Oregon Institute of Marine Biology in July and August 1973 established the size, location and make-up of the phytoplankton population present during the summer months. It is hoped that this study, when combined with the findings of the OIMB summer study, will lead to the formulation of a summer-fall-winter trend in the phytoplankton populations in the South Slough.

Coos Bay is located in Coos County, Oregon, about 200 miles south of the Columbia River and about 445 miles north of the San Francisco Bay. The Coos Bay watershed area encompasses about 820 square miles and consists primarily of coniferous forests. At mean high tide, the Coos Bay estuary, including the South Slough, contains approximately 10,500 acres, and is reduced to about 5,000 acres at mean low tide. The Coos Bay estuary, as far as salinity is concerned, varies from a partly mixed to a well mixed or vertically homogeneous estuary depending on the season and location within the estuary.

This study is primarily concerned with the phytoplankton population of the South Slough, which drains an area of approximately 26 square miles. Much of the South Slough is composed of marsh areas and extensive mud flats which lie exposed at low tides. Carex sp. and Distichlis sp. are the prominent marsh plants present.

The South Slough is connected to Coos Bay through a narrow channel 50-75 yards wide, deep enough to allow small fishing vessels to pass through. The channel leading into the South Slough is very near the mouth of Coos Bay, and there is a great influx of sea water at incoming tides. The salinity of the South Slough is therefore very near that of pure sea water, 33-35 ppt (o/oo), and varies seasonally with increased runoff.

Very little is known of the hydrography and physiography of the South Slough. It remains in a pristine condition in most of its upper reaches.

The annual freshwater runoff from South Slough drainage basin was estimated to be 98 cfs. The monthly values ranged from 6 cfs in August to 232 cfs in February. The annual average precipitation of 54.82 inches resulted in 42.58 equivalent inches of runoff. Harris, et al. (1979).

For the purposes of this study, the smaller South Slough estuary will be treated as a part of the greater Coos Bay estuary, with respect to hydrography and physiography.

Phytoplankton is a general class of organisms; those organisms which float and drift in the water layers. The phytoplankton is composed of an array of plant species, incapable of movement against the tides and currents, which contain chlorophyll and are thus able to perform photosynthesis. Part of the phytoplankton community is made up of the benthic forms, which by definition dwell primarily on the bottom of the estuary. The other part of the community

consists of the free floating forms, found in the upper parts of the water column, where light intensity and wavelength are adequate for their survival.

The most obvious and usually most numerous form of phytoplankton is the diatom. The diatoms are unicellular and possess a unique skeleton of silica and pectin, composed of two parts or valves, the hypotheca and epitheca. In one group of diatoms, referred to as the pennate forms, many species have a characteristic slit (raphe) through which the protoplasm may be in contact with the water. Raymont (1967). Most marine species belong to the centric group of diatoms that have no raphe, but show characteristic patterns of pores in the exoskeleton.

Within the valves, cytoplasm forms a lining surrounding a large vacuole filled with cell sap. The nucleus is usually central, with numerous chromatophores found throughout. The chromatophores contain a mixture of chlorophylls a and c, with several carotenoids, mainly β-carotene and α-xanthophyll, Raymont (1967), which absorb light at wavelengths different from the chlorophylls and consequently allow the organism to photosynthesize over a greater range of light wavelengths.

The range of size in diatoms is relatively large, with some approaching dimensions as great as 400 microns in diameter and 150 microns in length, while many species are as small as 10 microns or less. Part of this variation in size is due to the method of reproduction: at each cell

division, the valves separate, one going to each daughter cell, where both the hypotheca and epitheca from the original diatom form the epitheca for the daughter cells. With this method of reproduction, the average size of the individuals of a continually dividing population must decrease as division continues.

H.H. Gran has shown division rates for various diatom species to be considerably faster than one division per day. However, growth conditions in the ocean and estuary are hardly ever as favorable as those in culture, and a division rate of once every one or two days is probably nearer the maximum. Raymont (1967). Rates of division do vary from species to species, and will also depend on environmental conditions such as temperature, light, salinity, and available nutrients. In general, reproduction rates of phytoplankton decrease with decreasing temperature, while a critical level of light for a population "bloom" has been suggested by Riley (1967), and Castenholtz (1964) has shown the ability to use light in some species is regulated by the time of exposure and salinity. Pratt (1965) has concluded that the nutrients Silicon and Nitrogen regulate the maximum abundance and termination of the winter-spring phytoplankton bloom in Narragansett Bay.

With long periods of reproductive activity, the average size of the diatom cell will decrease rapidly. The restoration to maximum size is achieved by the formation of an auxospore, during which the cell throws off the old valves

and increase greatly in size. A membrane of pectin and silica is formed around the enlarging cytoplasm and new valves consistent with the increased size are formed.

Oils produced as an end product of the photosynthetic process are stored within the valves and may be useful in the control of bouyancy. Both salinity and temperature affect the specific gravity of seawater, and these two factors undoubtedly play a part in the sinking of phytoplankton. Raymont (1967).

The flushing rate of the estuary also plays a major role in the composition of the populations of phytoplankton within the estuary. The flushing rate is the period of time it takes the freshwater input to the estuary to replace the tidal volume, and is usually expressed in terms of river flow in a ratio to the volume of water in the area considered in conjunction with the ratio of fresh to salt water in the area. If S_o is the salinity of the water outside the estuary which is available for mixing, and S is the salinity at any point inside, the fresh water content is given by:

$$f = \frac{S_o - S}{S_o}$$

and the accumulated freshwater volume is then given by:

$$F = \int_{vol}^{\circ} f d(vol)$$

where the integration is carried out over the total volume.

If R is the rate of influx of fresh water, the flushing time, t, can be determined by:

$$t = \frac{F}{R}$$

where F is the total freshwater volume from above. The flushing number technique, used by Harris, et al. (1979) yielded extreme values of flushing numbers of 0.030 for February and 0.001 for August. Low values indicate very little stratification.

The tidal prism in the estuary is the difference in volume of the estuary due to the tidal highs and lows. Harris et al (1979) used three independent methods to estimate the volume of the tidal prism and obtained a value of 3.3×10^8 ft^3 for the South Slough. The classification of an estuary, with regard to salinity, is calculated as the ratio of river flow per tidal cycle to the tidal prism. When this ratio is 0.1 or less, the estuary is classified as well mixed. A ratio of 0.1 to 0.5 indicates a partly mixed system, and above 0.5 a highly stratified system. Dyer (1973). The ratio of freshwater volume per tide cycle to tidal prism, described by Harris et al (1979), gave extreme values of 3.05% for February and 0.09% for August.

The Coos Bay estuary is well mixed during the summer months, and changes to partly mixed during the winter, because of the increased river flow.

Salinities within the estuary range from 0 ppt (fresh water) in the uppermost reaches of the bay to greater than 30 ppt (sea water) at the mouth. The temperature varies seasonally, and averages 8° - 12° during the early winter (fig. 4).

The tides are caused by gravitational forces of the moon

and sun acting upon a rotating earth. The tide height reached for any day depends upon the moon-sun alignment. When the moon and sun are in line, their forces complement each other and an increased tide range results. A decreased range results, therefore, when the moon and sun are not in line (the first and last moon quarters). The tides follow a diurnal cycle, resulting in two high and two low tides within an approximate 24 hour period. The moon passes through a given meridian at mean intervals of 24 hours 50 minutes, called a Lunar Day, thus it passes a particular meridian 50 minutes later each day. Therefore each day the tides rise on an average 50 minutes later. The interval between the passing of the moon and the rise of the tides is constant for any given coastal position.

The position of the moon affects not only the time of the tides, but also the height and mass of the water involved in the tidal current, creating the higher high, lower low, lower high and higher low tides experienced within an approximate 24 hour period (24 hours 50 minutes).

MATERIALS AND METHODS

Surface plankton samples were taken during the daylight high and low slack tides on six days during the period beginning October 31, 1977 and ending on December 4, 1977. Two samples were taken, high and low tides on October 31, November 12, November 14, November 16, November 28, and December 4, 1977. A series of samples was also taken during

the 24 hour period of December 3-4, 1977. One sample was taken every three hours during the 24 hour period.

A total of 20 samples were taken, with eight samples composing the 24 hour series, and the remaining twelve composing the high-low population comparison.

The samples were collected by allowing 500 milliliter(ml) Erlenmeyer flasks to fill when submerged just below the surface of the water. The undiluted samples were treated in the laboratory with Lugol's Solution-Weigert's variation, in the proportions 1:2,000 or 0.05 ml per 100 ml of sample. Lugol's solution was added to act both as a preservative and a dye in the case of the clear silica valves of the diatoms.

The samples were filtered, using a standard suction apparatus, onto a 4.5×10^{-4} mm (0.45 micron) Millipore HA membrane filter. The filters chosen, from standard stock, were equipped with gridding for use as a counting aid. After filtering, the samples were allowed to dry in a Thermodyne hot plate oven. For handling, the filters were placed on glass microscope slides. A small amount of immersion oil was applied to the dried filter, which effectively cleared the filter for microscopic viewing and counting of the organisms present. The organisms were counted on American, Optical-Spencer compound microscopes.

A counting field on the slide was defined to have the dimensions 6.0 mm x 20.0 mm. Vertical sweeps, each 0.95 mm wide were used to scan and count every 2.0 mm across the

slide. The organism count was extrapolated to include the entire surface area of the filter.

Organisms were counted as single cells only, and in the case of chain type diatoms, individual cells within the chain were counted, rather than counting the chain as a solitary organism.

Organisms present were identified to genera only, due to the extreme difficulty of identification of species and the high magnification necessary to discern characteristic pore patterns, etc., needed for species identification.

RESULTS

The major genera identified included Coscinodiscus, Melosira, Skeletonema, Fragillaria, Thallasiosira, and Nitzschia. Other genera identified were Biddulphia and Grammatophora. Three other classifications were used in place of further identification: dinoflagellates, pennates, and stars (an unidentified organism).

Coscinodiscus sp. comprised the major portion of all samples taken, dominating the populations at both high and low tides. By individual count, Coscinodiscus sp. averaged 54.8% of the number of cells collected at low tides, and 74.6% at high tides. The range of percentages varied from 49.2 to 60.5% at low tide, and from 44.9 to 87.9% at high tide.

Melosira sp., second to Coscinodiscus in cell percentage per sample, comprised an average of 20.5% at low tides, and

only 1.8% at high tides, varying from 13.6 to 30.3% at low tides and from 0 to 3.9% at highs.

The remaining genera composed no greater than 29% (Fragillaria sp.) of any sample, and averaged between 1 and 10% in each sample.

Overall concentrations of cells per Liter (c/L) varied for an individual genera, between 10 c/L and 2,600 c/L; and between 300 c/L and 3,000 c/L for total cell concentrations.

Coscinodiscus also dominated the population samples taken at high tides during the 24 hour sampling, December 3-4, 1977. For the two high tides sampled, Coscinodiscus comprised 87% and 84% of the total cells per Liter, Melosira followed as above, comprising only 4% and 5% of the sample at the same tide.

Total cell concentrations during the 24 hour sampling period varied from 380 c/L to 1,000 c/L.

The physical results of the samplings, both raw cell counts and the relative per cent compositions of each genera are furnished in tables 1 through 3.

Population and relative abundance comparisons, carried out in hope of finding distinct populations within the estuary were calculated using the Whittaker Percent Similarity Index (appendix). The results of these calculations are summarized in figure 3.

CONCLUSIONS

The OIMB student's study, summer 1973, found an upper

bay phytoplankton assemblage dominated by Skeletonema sp. and Melosira sp.; and a lower bay assemblage dominated by Chaetoceros, Skeletonema, and Thallasiosira. The samples taken during the twenty-four (24) hour period of December 3-4, 1977, show a distinct upper South Slough assemblage dominated by Melosira, Coscinodiscus, and Fragillaria. This dominance by Melosira, etc., during the early winter months of 1977 is interesting when compared with the results from summer 1973, In that study, Melosira and Coscinodiscus (that study was also confined to identification to genera only) each comprised less than five (5) percent of the samples. OIMB students (1973). As shown above, in the winter of 1977, Melosira and Coscinodiscus comprise up to thirty (30) percent and eighty-eight (88) percent respectively.

The population figures and composition suggested by the same should be viewed discerningly, as the figures were obtained using identification only to genus level, which may introduce an error into the actual population size and composition.

The major constituent of all samples was the genus Coscinodiscus, which is readily identified to that level by its characteristic valve. Species identification, however, has become increasingly complex, with a much greater level of magnification necessary than was readily available. Many species are now differentiated only by the number or pattern of pores in their exoskeleton.

As a result, the large percentage of Coscinodiscus present, which for the purposes of this study were counted as a single group, may be found to be comprised of a number of different species, perhaps composing entirely different upper and lower bay assemblages.

This possible error may also be reflected in the percent similarity computed, using Whittaker's Index. The large number of Coscinodiscus present in every sample almost immediately makes the populations sampled similar; when as shown above, the Coscinodiscus populations at high and low tides may be composed of completely different species, or a mixture of populations.

The Whittaker Percent Similarity Index also fails to take into account areas in the populations where a type of organism is represented in one population and not in the other. For the purposes of percent similarity, this difference in the populations is ignored (i.e. it contributes or subtracts nothing to the total percent similarity, despite evidencing a difference in the population). The similarity computed in this fashion is based solely on the percent composition of each population of organisms present in both populations.

Coscinodiscus is known to reach into the hundreds of microns in diameter, yet a majority of the organisms counted from the winter 1977 samples were on the order of 50 microns or less, with a substantial portion considerably smaller. This may be evidence of a continually dividing population,

with subsequent decrease in the average individual size, or evidence of preferential predation. In either of these cases, further evidence of one or the other would most likely have been observed. With a continually dividing population, some individuals will remain at the large original size, no individuals of such size were noted in the samples, and with predation, a number of predator zooplankton would also have been found in the samples, as no filtering other than through the membrane Millipore filter was performed.

The succession of dominance from Chaetoceros, Skeletonema, Thallasiosira, and Melosira during the summer in the Coos Bay estuary to Coscinodiscus and Melosira during the early winter should in no way be considered unique. Scott and Chadwick (1924) found after years of study in the Irish sea, that during the winter when the phytoplankton concentration is low, the populations are dominated by Coscinodiscus, and somewhat later by Biddulphia. The spring bloom was characterized by species of Chaetoceros together with Thallasiosira and Lauderia. Raymont (1967). Lillick (1940) studying phytoplankton in the Gulf of Maine found the winter flora to be dominated by Coscinodiscus, with the spring bloom consisting predominantly of Thallassiosira, which is succeeded by a sharp bloom of Chaetoceros. During the late summer Rhizosolenia and Skeletonema take over, followed again by the winter domination of Coscinodiscus. Raymont (1967).

In a strikingly similar study, Cassin and McLaughlin

(1972) found annual maxima in phytoplankton biomass to occur in summer; with minor peaks in January and May, dominated by the diatoms, particularly Centrales (Coscinodiscus, Actinodiscus, Chaetoceros, and Biddulphia). The winter community consisted mainly of Skeletonema costatum, Thallasiosira baltica, T. gravida, T. halina, Leptocylindrus sp., Rhizosolenia sp., Chaetoceros sp., and Asterionella japonica. Takahashi, et al. (1976), found Thallasiosira sp. and Chaetoceros sp. to be dominant in spring and summer populations in Saanich Inlet, B.C. Canada, with their numbers dropping off sharply in autumn. Smayda (1973) found Skeletonema costatum to be the dominant species in Narragansett Bay in the winter-spring bloom, and to usually be the initiating species in that bloom.

A number of natural factors play a major role in the size and composition of the phytoplankton community, including temperature, incident light, nutrient levels, available nutrients, and salinity. These factors may contribute independently or jointly in their effects on the population.

Gran (1929b) and Scott and Chadwick (1924) expressed the belief that temperature was the chief factor in the seasonal succession of phytoplankton. Raymont comments:

> Species succession would appear to be a very widespread phenomenon among phytoplankton. Although temperature, and to a lesser extent light intensity, and perhaps nutrient concentration may play a part in the changes, more subtle differences, particularly the biological history of the water, have an important role. Raymont (1967).

Phytoplankton cells respond to temperature by changing their rate of division and assimilation number. Both division rate and assimilation number increase with temperature until unfavorably high temperatures are reached. This is because metabolic rates, including the dark reaction rates of photosynthesis, are temperature dependent.

Phytoplankton also respond to temperature with a change in the composition of their cells. Skeletonema costatum cells increase photosynthetic enzymes and organic matter at low temperatures and double their carbon content per cell as temperature decreases from 20°C to 7°C. The increase in carbon per cell and carbon per unit chlorophyll a with decreasing temperature appears to be a characteristic of marine phytoplankton. Jørgenson (1968).

Since cell division and dark reaction rates of photosynthesis depend upon rates of enzymatic processes, an increase in amount of cellular enzymes per cell offsets to some extent the decrease of enzymatic activity with the decrease in temperature.

Figure 4 shows the high and low extremes for temperature and salinity over a nineteen (19) year period, at the same site from which the winter 1977 samples were taken. The temperature varies from a high of 15°C in July to a low of 8°C in October through April. This small variation in temperature over the year is not large enough to be the exclusive reason for the seasonal succession in Coos Bay, although it

does appear to be large enough to cause differing rates of division within the organisms and to cause increases in the amount of Carbon per cell and per unit chlorophyll.

Castenholtz (1964) found the growth of Fragillaria striatula and Synedra tabulata to be daylength dependent, and the doubling rates of these organisms were significantly lower during short days than during long days, both above and below the saturating light intensity. Melosira moniliformis showed less dependence on daylength, but was inhibited by high light intensities during 15 hour periods.

The rate of cell division is dependent upon the supply of photosynthetically produced carbon and is therefore light dependent. At very low light intensities, cellular carbon is used faster than it is produced. The rate of production is equal to its rate of use at the compensation intensity. Further increases in light intensity increase division until unfavorably high light intensities are reached or until some other factor becomes limiting. Rice and Ferguson (1975).

Phtoplankton adapt to changes in light intensity by changing the amounts of pigments or amounts of photosynthetic enzymes in the cells. Decreasing the chlorophyll a content of the cell increases the cell's resistance to extreme light intensities. As light intensity decreases, chlorophyll a concentration increases, and assimilation number and compensation level are reduced. These adaptive changes allow cells to utilize light of lower intensity than cells which have not been adapted. Rice and Ferguson (1975).

Riley (1967) suggested that the radiation level during the period from December to March was the most important factor in the onset of the winter phytoplankton bloom. He further suggested that the critical level for the initiation of the bloom is about 40 g-cal day^{-1}.

Assuming a thorough mixing of a column of water between the surface and a depth z, which may be the total depth of water in a shallow area, or may be a discontinuity layer which limits further downward mixing, the mean amount of light received by each cell will equal the mean amount of light $\bar{I}$ in the water column above depth z, which is given by:

$$\bar{I} = I_o/kz\ (1 - e^{-kz})$$

where k is the extinction coefficient and I_o is the incident radiation in g-cal/cm^{-2}/day^{-1}. Riley (1967).

This formula suggests that in some very shallow waters, growth may never be seriously limited by winter reduction in radiation.

Hitchcock and Smayda (1975) found that light intensity and available light greatly influenced phytoplankton winter growth in Narragansett Bay, contradicting previous studies: Pratt (1965) suggesting that a relaxation of grazing pressure determined the date of the winter bloom inception. In this particular study, the winter bloom was delayed 6 weeks past the usual date of its inception, until late January. The delay being attributed to subcritical light intensities in December.

The nutrient level in the estuary is the result of a number of modes of input. Fresh water runoff from the watershed area introduces nitrogen, phosphorus, and silicon, as well as trace amounts of other elements. There has been shown to exist in some estuaries, a salt wedge, which compensates for the net seaward movement of fresh water by moving inward below the surface, carrying detritus and nutrients brought up from deeper waters. Man's presence is also heavily felt in the estuary, with increased runoff from developed or disturbed natural areas, industrial effluents, heated water, nutrients from fertilized farmlands, as well as many toxic substances including pesticides.

Nutrients in the estuary are limiting factors in the growth of pytoplankton, which may be present at such low levels that no cell division occurs; as compared to a controlling factor such as temperature, which affects the rate at which phytoplankton utilize available energy supplies and nutrients. The concentration of a nutrient can be a limiting or a lethal factor to phytoplankton. In general only one nutrient will be limiting to cell division at any given time and this deficiency of a single essential element will prevent cell division. The concentration of a nutrient becomes limiting when it is low enough to preclude uptake at adequate rates for cell maintenance or high enough to be toxic. Nitrogen and Phosphorus tend to be the limiting nutrients in estuaries, as opposed to inorganic carbon, trace metals or

silicon. Rice and Ferguson (1975).

Figure 6 relates amounts of light, nitrogen, and phosphate to the phytoplankton population size throughout the yearly cycle. Clearly shown are the spring and fall maximums. With the spring bloom, the levels of N and P drop severely, perhaps allowing a different organism to dominate the population at that time. The summertime utilization of N and P keeps their levels low, gradually climbing with the onset of winter and lower population levels, with increased flow into the estuary of fresh water supplies and greater nutrient supplies from increased runoff. The high levels of light in the summer months do not appear to aid the phytoplankton populations in growth, as they are limited in this situation by nutrient levels. The thermocline established during the summer prevents nutrients from being drawn up from the bottom, and thus the plankton is unable to use all the incident light.

Maddux and Jones (1964) working with Nitzschia closterium and Tetraselmis sp. demonstrated that these organisms have a lower optimum light intensity when grown at lower levels of nitrate and phosphate. Nitzschia was shown to increase its optimum temperature for growth when cultured at high nutrient and light intensity levels from 16 to 23°C. In experiments with increasing light intensity, at lower concentrations of nitrate and phosphate the organisms were particularly susceptible to the increased light.

Grazing has been shown to have marked effects on the

overall size of the phytoplankton community, and can be considered to have an effect on the average size of the diatoms composing the community. Pratt (1965) hypothesized that grazing was responsible for the initiation of the winter-spring bloom of phytoplankton in Narragansett Bay.

The curves for phytoplankton concentrations are paralleled (with a short lag or delay) by the curves for the concentrations of zooplankton, most notably copepods.

The summer 1973 dominant organisms were largely chain type (i.e. Skeletonema, Thallasiosira, and Chaetoceros), and it is possible that this may play a major role in the winter survival of the organisms. It has been suggested by Gran that certain modifications in chain type organisms found in the Northern Atlantic, such as Chaetoceros decipiens, aid in the organism's flotation and thus aid winter survival. Gran has shown that these organisms actually modify the thickness of their cell wall, the stoutness of the setae, and the size of the interstitial spaces. These modifications, presumably for flotation, offer a mechanism for adjusting to the different densities that occur with the seasonal variations in the water temperature.

The chain type nature of these organisms may subject them to a greater chance of being carried out of the estuary and its protection in the winter, when the increased river flow partially stratifies the water column, creating a salt wedge. Under the conditions of a salt wedge, there is a net flow of fresh water out of the estuary, which floats on top of the

heavier, more saline water. To replace the flow of outward bound water, there is a net movement of salt water inward, below the surface of the estuary. The large chain organisms are more likely to be picked up and floated outward with the flow of fresh water, while the centric diatoms sink to a greater degree and are carried inward on the salt wedge. This phenomenon is relatively minor in effect when compared to the effect of varying reproduction rates and grazing.

A number of physical factors have been introduced which may influence the size and composition of the phytoplankton community and its seasonal succession within the estuary. Each may play an individual role, such as a limiting nutrient, or may work in conjunction with another to hinder or accelerate planktonic growth.

It has also been shown that the individual organisms adapt to varying conditions to which they are exposed, in apparent attempts to maximize growth under any set of conditions. The overall yearly success of such adaptations may be measured by the presence of the organism in the estuary the year around. The extent to which such individuals compose the population is a reflection of the success of their adaptations.

The interplay of the physical factors in the estuary, the phytoplankton's ability to adapt to varying conditions, and the basic requirements of the individual organisms (which may vary greatly from species to species, in terms of light and nutrients) for growth and reproduction, results in the

seasonal succession of pytoplankton seen to exist in the Coos Bay estuary. No one factor may be said to be responsible for the yearly succession, but rather, all contribute to the overall set of conditions responsible for the succession.

PHYTOPLANKTON CELLS PER LITER

GENERA	10/31		11/12		11/14		11/16		11/28		12/4	
	low	high	low	high	low	high	low	high	low	high	low	high
MELOSIRA	200		645	25	475	10	295	40	355	30	70	15
COSCINODISCUS	685	465	1605	1015	1740	1475	705	2665	575	395	265	335
SKELETONEMA	10		10	15	40	60	35	50	10			5
FRAGILLARIA	10		120	30	40	120		30	70	255	55	
NITZSCHIA	170	30	70	30	120	10	45	20			20	
THALLASSOSIRA	90	30	100	55	120	50	110	30	50	100	20	15
BIDDULPHIA	10	20			40	10	10		50			
GRAMMATOPHORA	10				10	20					20	
PENNATE			120	70	140	20	10	20	80	10	35	
DINOFLAGELLATE	110	60		60	120	150	20	110	30	30	15	
STAR	40			45	30	30	20	60		10	15	15
TOTAL	1335	605	2670	1345	2875	1955	1250	3035	1170	880	515	385

Table 1

PHYTOPLANKTON CELLS PER LITER(24 Hr. Series)

GENERA	11:30AM	2:30PM	5:30PM	8:30PM	11:30PM	2:30AM	5:30AM	8:30AM	11:30AM
MELOSIRA	70	142	15	198	163	213	21	208	367
COSCINODISCUS	265	269	335	605	255	184	319	337	417
SKELETONEMA			5	10				50	20
FRAGILLARIA	55	21		218	57	7		10	40
NITZSCHIA	20	35		10	21	21	7	10	80
THALLASSIOSIRA	20	7	15		7			20	
BIDDULPHIA									10
GRAMMATOPHORA	20								
PENNATE	35								
DINOFLAGELLATE	15			10			7		
STAR	15	21	15			7	28	10	20
TOTAL	515	495	385	1051	503	432	382	645	954

Table 2

PHYTOPLANKTON PERCENT COMPOSITION

	10/31		11/12		11/14		11/16		11/28		12/04	
	low	high	low	high	low	high	low	high	low	high	low	high
Melosira	14.9		24.1	1.8	16.5	0.5	23.6	1.3	30.3	3.4	13.6	3.9
Coscinodiscus	51.3	77.0	60.2	75.6	60.5	75.5	56.4	87.9	49.2	44.9	51.4	27.0
Skeletonema	0.7		0.4	1.1	1.4	3.1	2.8	1.6	0.8			1.3
Fragillaria	0.7		4.5	2.2	1.4	6.1		1.0	6.0	29.0	10.7	
Nitzschia	12.7	4.9	2.6	2.2	4.2	0.5	3.6	0.6			3.9	
Thalassiothrix	6.8	4.9	3.7	4.1	4.2	2.5	8.8	1.0	4.3	11.4	3.9	3.9
Biddulphia	0.7	3.3			1.4	0.5	0.8	0.3		5.7		
Grammatophora	0.7				0.3	1.0					3.9	
Pennate			4.5	5.2	4.9	1.0	0.8	0.6	6.8	1.1	6.8	
Dinoflagellate	8.3	9.9		4.5	4.2	7.8	1.6	3.6	2.6	3.4	2.9	
Unidentified	3.0			3.3	1.0	1.5	1.6	2.1		1.1	2.9	3.9
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100

Table 3

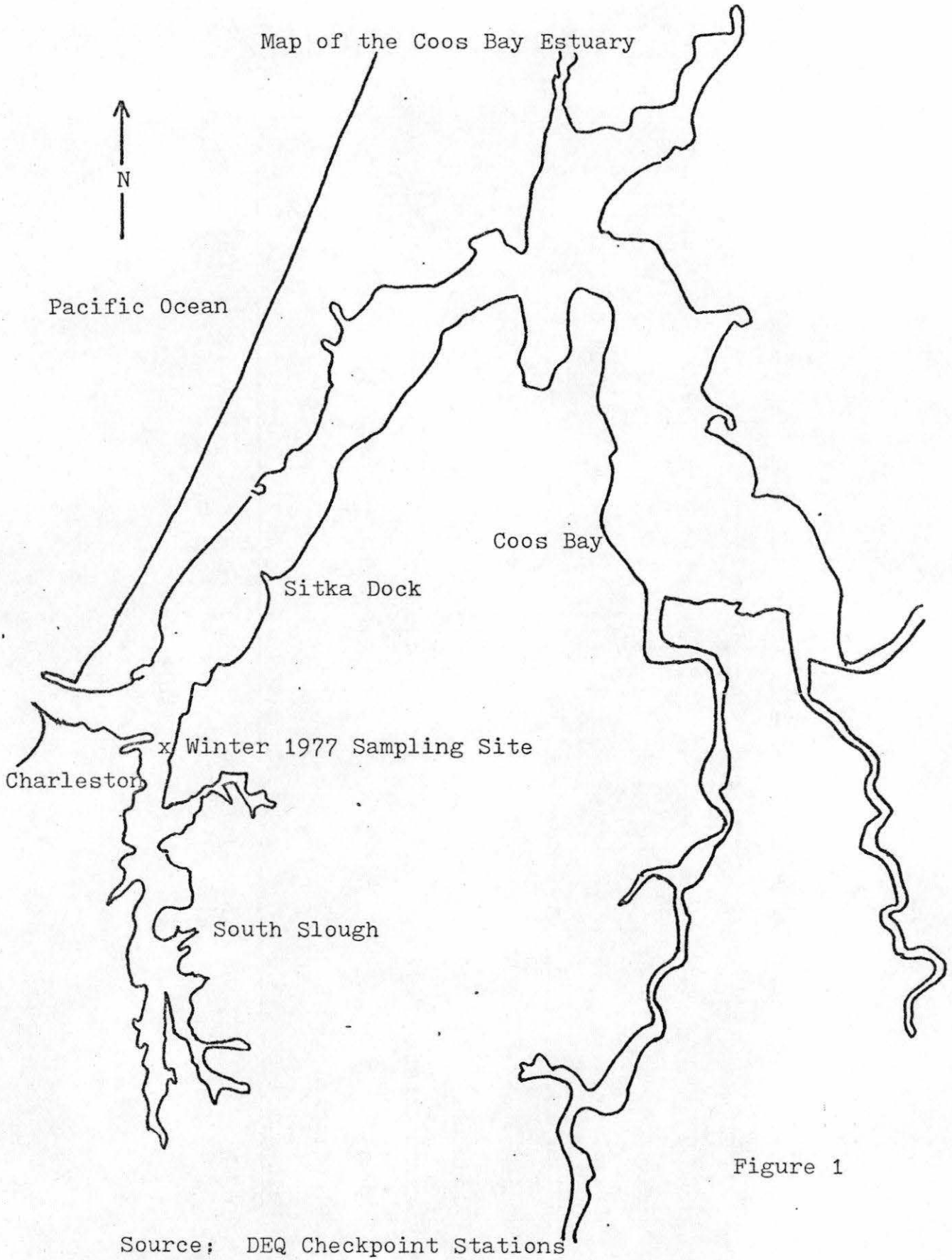


Figure 1

Source: DEQ Checkpoint Stations

TOTAL PHYTOPLANKTON

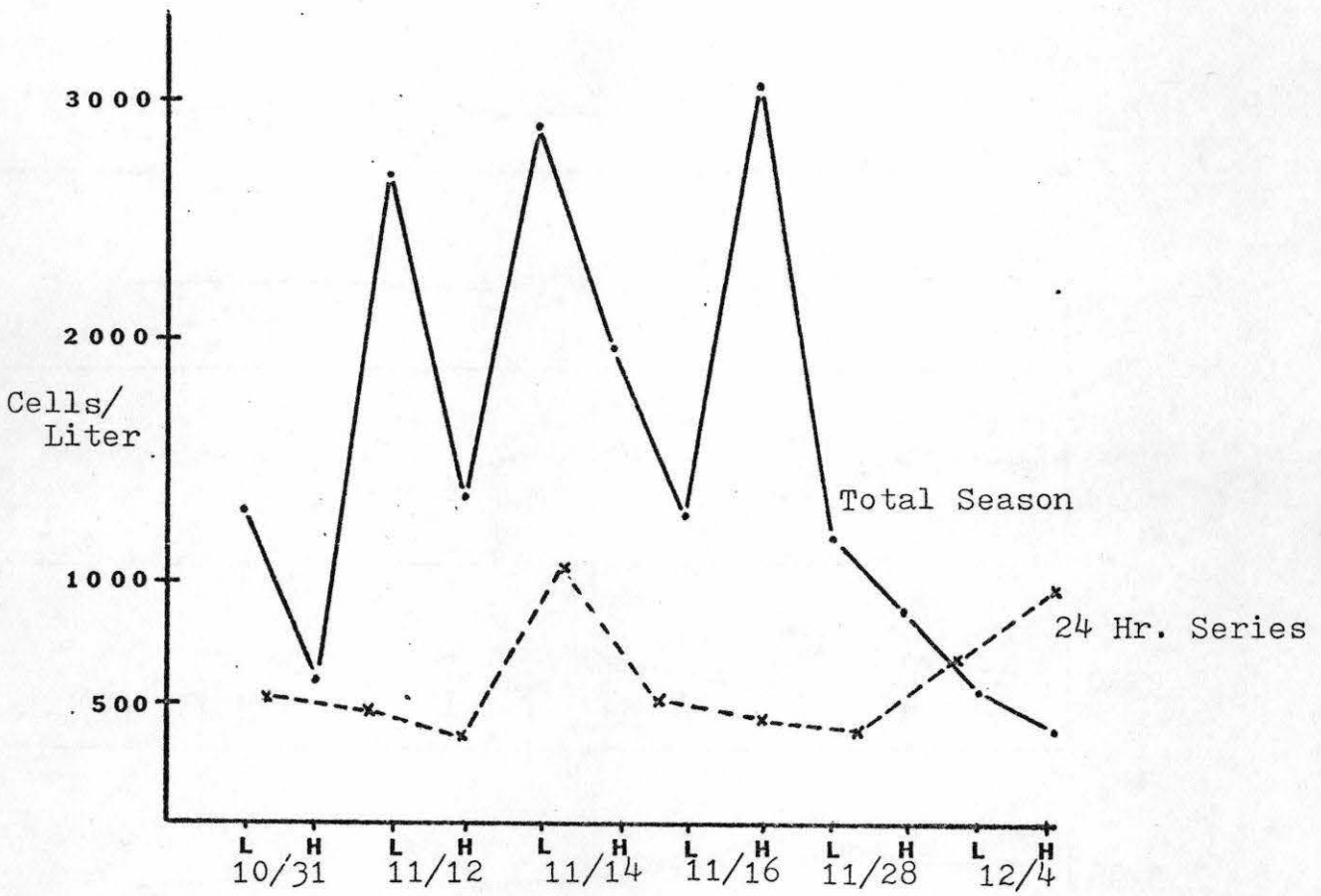


Figure 2

SOUTH SLOUGH ASSEMBLAGE DATA

24 Hr. Series Whittaker percent similarity

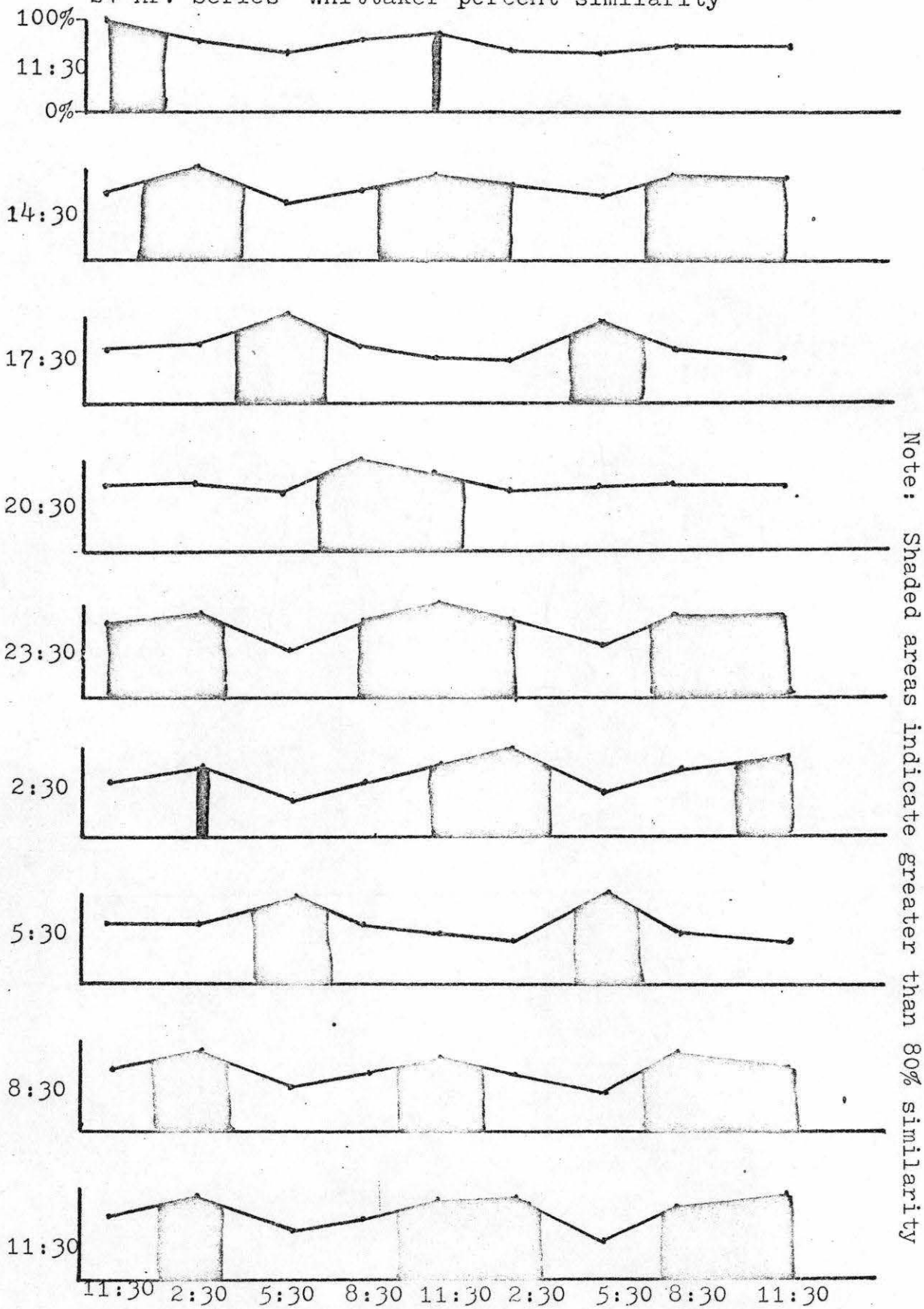


Figure 3

Seasonal Variation in Temperature and Salinity
(High and Low Extremes over a 19 year period)

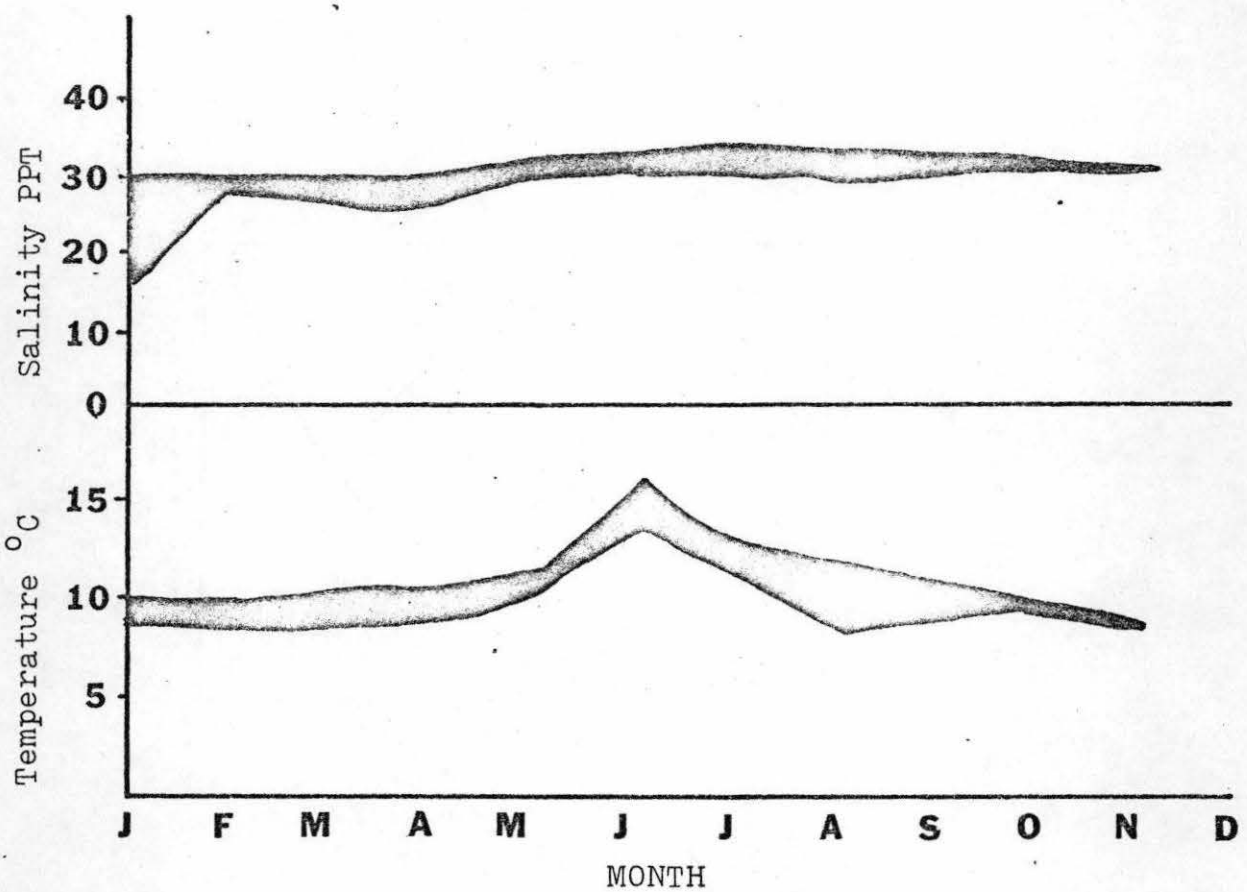
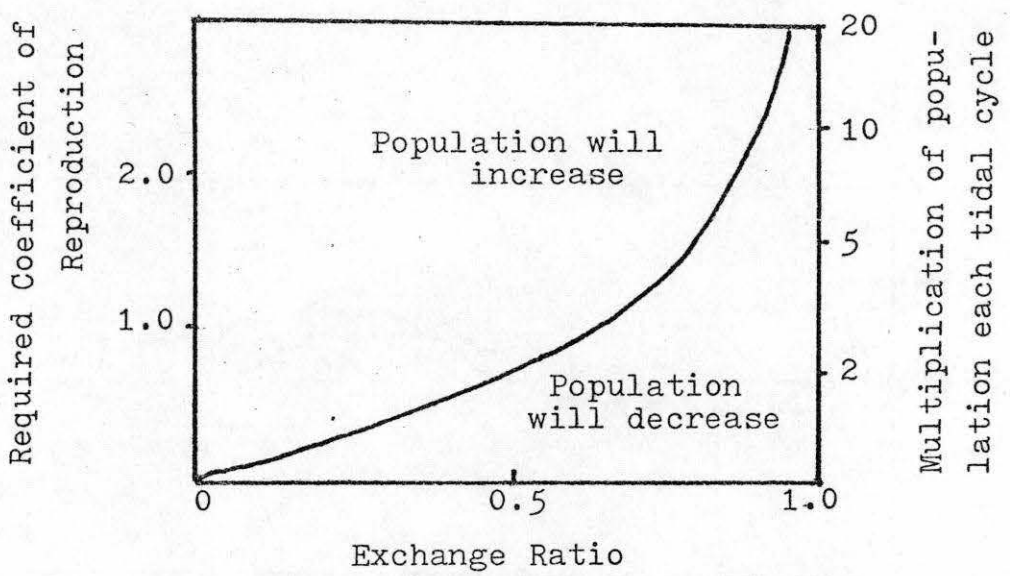


Figure 4

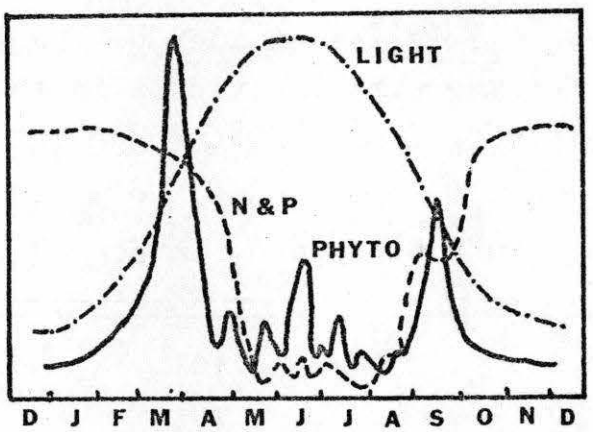
Reproduction vs. Exchange Ratio



Source: E.J. Perkins. p. 75

Figure 5

Seasonal Relationships Between
Phytoplankton, Light, and Nutrients



Diagrammatic representation of the seasonal cycles in light, nitrate and phosphate, and phytoplankton in a typical northern temperate sea.

Figure 6

Source: Raymont. p. 194

Appendix

The Whittaker Percent Similarity Index.

The percent similarity index is used to determine the degree of similarity between two populations. The percentage composition of individuals for each population must be calculated, and then may be applied to the formula:

$$P.S. = \sum L(P_1, P_2) \qquad P_1, P_2 = \text{Percent in } P_1, P_2$$

where $L(P_1, P_2)$ is the smaller of the two percentage figures for the same individual in the populations being compared.

ex.

organism	num. in pop. 1	num, in pop. 2	P_1	P_2	L
A	20	10	20	20	20
B	30	10	30	40	30
C	50	20	50	40	40
	100	50			90

The calculated percent similarity for the above example is 90%.

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