EFFECTS OF UNTREATED SEWAGE EFFLUENT ON THE ECOLOGY AND METABOLISM OF INTERTIDAL FLORA ON ROCKY SHORES ADJACENT TO SHORELINE-DISCHARGING SEWAGE OUTFALLS

by

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ABSTRACT

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An initial survey indicated that the response of the intertidal macroalgal community to the presence of sewage effluent could be related to the volume and means of discharge as well as the rate of dilution and dissemination of the sewage field. Species characteristic of the lower intertidal and upper subtidal regions were the ones most sensitive to the presence of sewage effluent. Thus, the continuous discharge of effluent at Clover Point has resulted in a depression of the *Phyllospadix* and red algal zones. The *Phyllospadix* population at Macaulay Point showed signs of recovery in 1972 following the cessation of discharge from the shoreline outfall in 1971. Only three species of macro-Phaeophyte algae were present intertidally at Macaulay Point in 1971. By the spring of 1972 six additional species of macro-Phaeophyte algae had established intertidal populations at that site; of these, five had significantly higher upper limits than corresponding populations at Clover Point. With the techniques employed, no significant differences in growth rate were apparent between test populations of *Laminaria groenlandica*, *Egregia menziesii* and *Nereocystis luetkeana* at Clover Point and control populations at Albert Head.

The freshwater component of sewage effluent was largely responsible for the significant depression of net photosynthesis of *Laminaria groenlandica* at high concentrations of effluent and tapwater. The

depression is believed due to the inability of the osmoregulatory mechanisms to cope with osmotic stress at low salinities. Some component of sewage effluent other than freshwater was active in further depressing the rate of net photosynthesis. The dark respiration rate of *Laminaria groenlandica* was generally unaffected by reduced salinity but was affected by reduced oxygen supply in effluent-diluted seawater.

An attempt was made to explain the upper limit depressions of whole zonal associations and of individual macro-Phaeophyte species, in terms of net production as controlled by temperature and salinity.

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PART I. INTRODUCTION

A. OBJECTIVE

This research project was initiated as a component of an environmental monitoring program in the marine receiving area for a trunk sewer discharging comminuted, but otherwise untreated, sanitary sewage. In May, 1970 the University of Victoria was authorized by the Capital Regional District of British Columbia to undertake such a monitoring program at the site of the extended Macaulay Point Outfall. The program was required by the Pollution Control Branch of British Columbia, the regulatory agency for such discharges.

The monitoring program had two main objectives: (1) to determine whether the environmental design criteria had been met, and (2) to determine if the discharge from the extended outfall had produced observable changes in the nearby marine ecosystem (Ellis, Littlepage and Drinnan, 1971). Initially routine water quality testing was implemented, but the program was later extended to include a series of special projects. One of these projects was a study of the shoreline effects of sewage effluent.

Furthermore, in July, 1971 the University was authorized by the Minister of Lands, Forests and Water Resources of the Province of British Columbia to "conduct applied research pertaining to a study of the accumulated effects of the Clover Point Sewer on the local marine ecosystem, including the shoreline" (Ellis and Littlepage, 1972).

Also in July, 1971, the University of Victoria was authorized by the Capital Regional District of British Columbia to undertake a monitoring program which was to incorporate "a review of the types and extent of the marine life in the intertidal zone" at the site of the Finnerty Cove Outfall (Drinnan, Ellis and Littlepage, 1971). Figure 1.1 indicates the location of the three outfalls.

The study of the effects of these three outfalls on the adjacent intertidal biota was designed and implemented as a single unit and formed the basis of the extended field work and experimentation which this thesis presents.

The research program was conducted in four major studies. The objective of the first study (Part III), conducted in the spring of 1971, was to determine if any major qualitative changes were evident in the structure and vertical distribution of the intertidal biotic communities adjacent to shoreline-discharging sewage outfalls. The most obviuos changes were apparent amongst the marine flora; further studies were therefore directed to this major group of intertidal organisms. Thus the initial comprehensive approach, considering both intertidal fauna and flora, was restricted to the latter. The second, third and fourth studies, conducted in the spring, summer and fall of 1972, respectively, were more quantitative in nature than the initial study.

The second study had several objectives which evolved directly from qualitative trends observed in the data of the initial study.

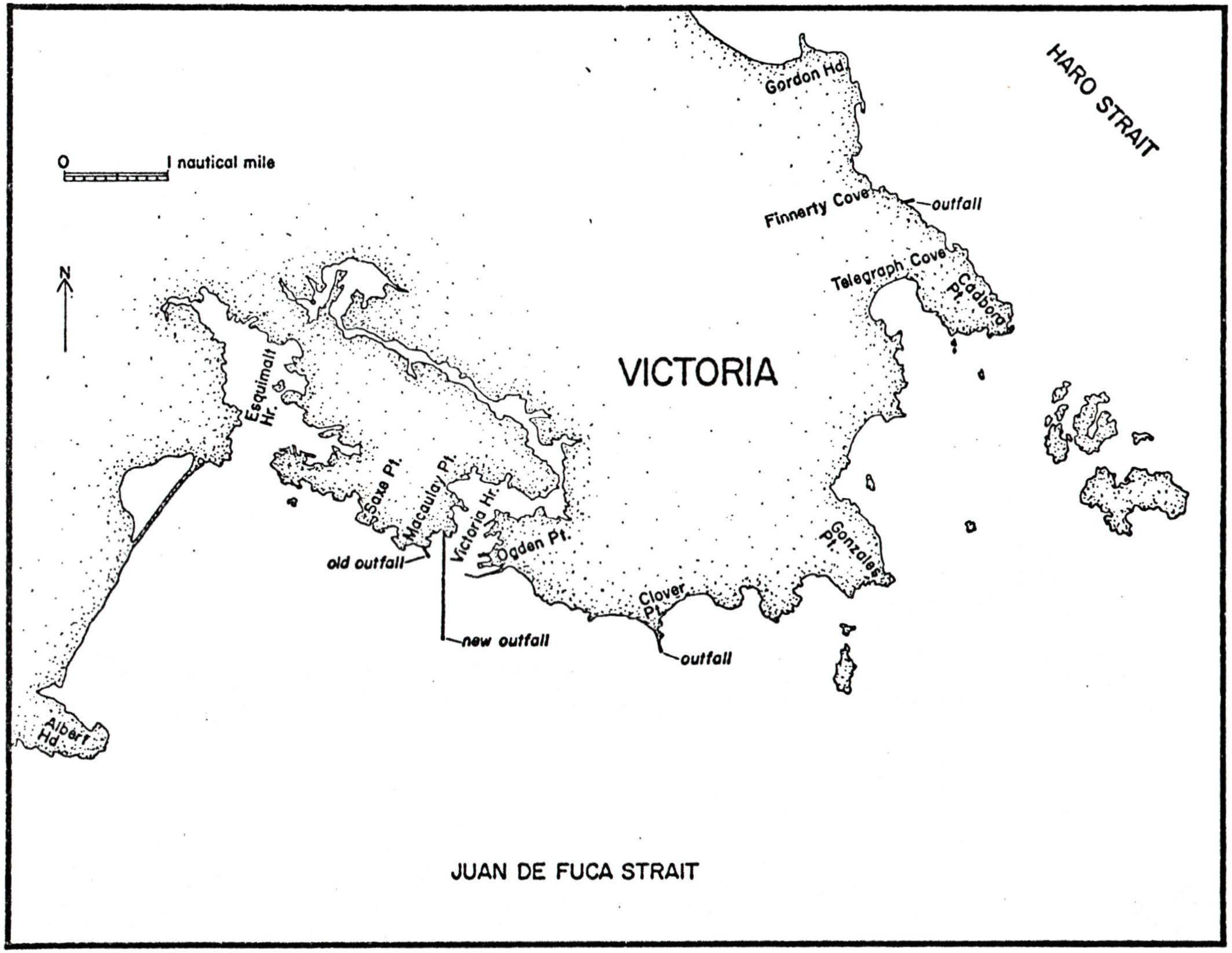

Figure 1.1. Location of Macaulay Point, Clover Point and Finnerty Cove outfalls.

The objectives of the second study included: (1) a comparison of the upper limit elevations of the *Phyllospadix* and red algal zones at Albert Head, Macaulay Point and Clover Point (Part IV), (2) an attempt to illustrate the re-establishment of intertidal populations of selected macro-Phaeophyte algae at Macaulay Point following the cessation of discharge from the shoreline outfall at that site (Part V), and (3) a comparison of the upper limit elevations of selected macro-Phaeophyte algae at Macaulay Point and Clover Point (Part V).

The third study was of the effects of ambient concentrations of sewage effluent on the *in situ* growth rates of three species of macro-Phaeophyte algae (Part VI).

The objective of the final study was to determine and compare the *in vitro* effects of the freshwater component and 'whole' sewage effluent on the net photosynthetic and dark respiration rates of *Laminaria groenlandica* Rosenvinge (Part VII).

B. REVIEW OF THE USE OF INTERTIDAL ALGAE TO MONITOR POLLUTION

Until recently, the emphasis on the analysis and monitoring of water quality has been on the physico-chemical properties of the receiving waters. However, at the present, specific biological indicators of pollution are being widely applied (Jamison, 1970). Stein and Denison (1967) consider the use of organisms for the assessment of pollution superior to physical and chemical determinations and maintain that physico-chemical measurements have little reality unless they are related to beneficial or detrimental responses exhibited at the organismic level. Moreover, indicator organisms represent conditions that have prevailed over a longer period of time than do specific physico-chemical measurements which can do no more than indicate conditions extant at the time of sampling. Stein and Denison also indicate that the use of single organisms (i.e., coliform bacteria) as indicators has frequently caused confusion leading to arbitrary conclusions, and therefore stress the need for approaches which take into account several different taxonomic groups. In addition, the indicator organisms of choice are those which are sessile, or move very little, and can not therefore actively avoid a pollutant.

At present there is a small but steadily increasing body of literature pertaining to the use of marine algae for the assessment of marine pollution. Macroscopic marine algae have a number of advantages as indicator organisms: (1) all species are attached and can not therefore avoid a pollutant, (2) they present a vast number of species representing three major phyla from which indicator species can be selected, and (3) most species have fairly extensive geographical ranges and can therefore be used to assess pollution effects over a broad area. Marine algae also provide species capable of showing a graded response proportional to the degree of concentration and the time of exposure to a pollutant and can therefore be used to assess subtle environmental changes affected by pollution.

Until recently, the intertidal macroalgae have not been utilized as monitors of marine pollution, perhaps because the relative severity and variability of the intertidal environment has been thought to be inappropriate for the detection and separation of man-induced environmental changes from those due to extremes of the normal environment. However, given proper attention to the normal variability of the intertidal flora and with careful selection of control sites, it would appear feasible to use intertidal marine algae as pollution monitors.

The intertidal zone itself offers many advantages as a study area, particularly ease of access during low tide periods. It is an aesthetically appealing environment of great ecological importance and a highly productive habitat which is not only the centre of life for its permanent inhabitants, but also serves as a nursery ground for many marine forms and contributes greatly to the productivity of the contiguous waters (Oglesby and Jamison, 1968).

The long term effects of marine pollution on macrophytic marine algae have been analyzed in two studies. Bellamy *et al.* (1967) have compiled species lists which allow comparison with records compiled in 1861 for an area of the north-east coast of England which has a marked pollution gradient. The algal flora was increasingly reduced with increasing pollution. Widdowson (1971a) has studied the changes in the intertidal flora of the Los Angeles area since the survey by E.Y. Dawson in 1956-59 and found a general and widespread reduction in species diversity which was attributed to human activity, including sewage pollution.

Oglesby and Jamison (1968) and Jamison (1970) have used the intertidal algal community to assess the short-term effects of industrial pollution in the Point Whitehorn-Cherry Point area of northwestern Washington. Dube (1970) has primarily used subtidal algal populations in his baseline studies of that same area.

On a more international scale, Golubic (1970) has reported the use of intertidal Cyanophyte mats as indicators of severe organic pollution in Yugoslavia. He also noted that increased pollution was indicated by the absence of the widely distributed and dominant *Cystoseira barbata* and by the presence of *Ulva lactuca* and *Codium tomentosum*. The numbers of *Cystoseira* decreased along a gradient of increasing pollution, ending with the total absence of this species, whereas *Codium* became more abundant with increased pollution. Bellan (1970), studying the effects of severe sewage pollution near Marseilles, found that the distribution of *Cystoseira stricta* could be used as an indicator of the effective geographical range of an effluent field. Burrows (1971) and Burrows and Phybus (1971) have studied the *in vitro* and *in situ* effects of polluted seawater on the growth of *Laminaria saccharina* in northeast England, and Hopkin and Kain (1971) have been testing the toxicity of various marine pollutants on *Laminaria hyperborea* at the L.M.B.C. Marine Biological Station at Port Erin on the Isle of Man. On the basis of these studies it is apparent that marine algae do have considerable potential for use in assessing the effects of marine pollution.

The intertidal zone is perhaps the best environment in which to assess the effects of pollutants which are discharged from shoreline outfalls, particularly those with a lower specific gravity than seawater (i.e., all freshwater-based effluents such as sewage and pulp mill effluents, and oils) and therefore influence the physico-chemical nature of the surface waters to a great extent. It is the surface waters which periodically cover the intertidal zone and, if these waters contain biologically active pollutants, it follows that it is the intertidal biota which will show the most marked responses.

C. REVIEW OF LOCAL INTERTIDAL SYNECOLOGICAL STUDIES

1. Greater Victoria Area

There is a surprising scarcity of published data pertaining to all aspects of intertidal biology in the Greater Victoria area. The earliest work available (Stephenson and Stephenson, 1961) had no previous counterpart. The Stephensons described the pattern of intertidal zonation and the vertical distribution of the dominant intertidal organisms in the vicinity of Finlayson Point on the southern coast of Victoria. The only other pertinent publication available (Widdowson, 1965) was a survey of the distribution of intertidal algae between Port Renfrew and Gordon Head, on the east coast of Victoria, with regard to salinity and tidal factors.

2. Juan de Fuca Strait, San Juan Archipelago and Puget Sound

Rigg and Miller (1949) published an account of the intertidal plant and animal zonation in the vicinity of Neah Bay near the western entrance of Juan de Fuca Strait. Muenscher (1915) has studied the algal associations of San Juan Island and the distribution of intertidal algae on Shaw Island (1916). In addition, Harlin (1969) has published a phycological survey of Steamboat Island in Puget Sound.

3. Queen Charlotte Strait and the Strait of Georgia (and adjacent inlets)

Scagel (1961) published a comprehensive study of the distribution of marine algae in Queen Charlotte Strait in relation to some physical oceanographic factors. Druehl (1967a) studied the vertical distributions of some marine algae as related to the estuarine conditions in Indian Arm. In addition, South (1968) has published a phycological survey of Gabriola Island which is located on the western side of the Strait of Georgia. An extensive survey of the intertidal and shallow subtidal algal communities in the Comox - Denman Island area, with particular reference to the distribution and abundance of carrageenin-containing Rhodophyte algae, is presently being accomplished (Austin, *et al.*, Reports 1971, 1972 and 1973).

PART II. THE INTERTIDAL AND OCEANOGRAPHIC ENVIRONMENT IN THE GREATER VICTORIA AREA

A. CAUSES OF INTERTIDAL ZONATION

The primary cause of intertidal zonation is the existence of an air-water interface creating vertical ecological gradients (Stephenson and Stephenson, 1949; and Zaneveld, 1969). In a hypothetical marine area with no tide and no wave action there would be a supralittoral and a sublittoral zone caused by gradients of moisture and light respectively. With wave action, but no tide, a littoral zone would be produced related to the amplitude of the waves. Therefore all the essentials of an intertidal zone could be produced without any tide (Stephenson and Stephenson, 1949). The effect of tidal action will therefore be to expand the gradients related to the air-water interface by producing a periodic vertical oscillation.

The factors directly influencing intertidal zonation are: exposure to wave action, impact of waves, strength of tidal currents, turbulence, duration of emersion and submersion, type of substrate, temperature, salinity, pH, oxygen concentration, availability of nutrients, quantity and quality of light, moving ice, the periodicity of these factors and competition (Zaneveld, 1969). Zonation usually results from the effects of several of these factors and the related gradients. However during a particular season, or during a certain stage in the life cycle of an organism one factor may become dominant. As Zaneveld states, "the width of the zone occupied by a certain species is a function of the degree of its tolerance to the combined effects of the ecological gradients acting together at a certain level and the possibility to adapt itself morphologically and physiologically to the induced environmental stresses." With increasing height in the littoral and supralittoral regions there is a decrease in the time of submergence, an increase in the time of desiccation and light intensity, and a steeper gradient for salinity, temperature and pH.

B. FACTORS INFLUENCING ZONATION AND DISTRIBUTION OF INTERTIDAL ALGAE IN THE GREATER VICTORIA AREA

The environment of the intertidal zone is very complex, involving both oceanographic and climatic factors and the interactions between them. In the following discussion of these factors in the Greater Victoria area, air temperature, total precipitation and hours of sunshine are considered as representative of climatic conditions; surface salinity and temperature as representative of oceanographic conditions; and tidal rhythms, currents and wind-driven wave action as factors which control the interaction of oceanographic and climatic factors.

The aim of the following description of the climatic and oceanographic environments is to provide an overall picture of the conditions extant within the Greater Victoria area. As much as possible, special reference is made to conditions in the areas studied during the field investigations discussed later in the text.

1. Climatic Factors

Meteorological data were obtained from weather stations closest to the field research sites on Albert Head, Macaulay Point, Clover Point, Telegraph Cove and in the vicinity of Finnerty Cove. Data from the Gonzales Heights weather station were used as representative of the climatic conditions at Macaulay Point and Clover Point; from William Head as representative of conditions at Albert Head; and from either Gordon Head or Saanichton as representative of conditions at Telegraph Cove and Finnerty Cove, on the east coast of Victoria. The data were analyzed in order to determine if any marked climatic gradients existed within the Greater Victoria area in 1971 and 1972, during the period of field research.

There was no marked gradient of either air temperature maxima or minima within the Greater Victoria area in 1971 and 1972 (Table 2.1). However, Saanichton had slightly higher temperature maxima during the months of June and July, and Gonzales Heights had slightly higher temperature minima during the winter months. Winter minimum temperatures are not low enough in this area to harm most common intertidal algae. Kanwisher (1966) has shown that several common north temperate intertidal algae can survive freezing for short periods with little deleterious effect. During the summer months, temperature maxima can be expected to affect intertidal algae through a combination of thermal stress (insolation) and by accelerating the rate of desiccation, particularly when coincident with low relative humidity and direct sunlight.

William Head experienced more total precipitation than Victoria proper in both 1971 and 1972 (Table 2.2), particularly during the winter months. There was less total precipitation at Gonzales Heights

Table 2.1. Mean monthly and annual temperatures ($^{\circ}F$) including mean maxima and mean minima for 1971 (a) and 1972 (b), as measured at Saanichton C.D.A., Gonzales Heights and William Head. (Annual Meteorological Summary and Long Term Records (Victoria), 1971 and 1972).

	1971 (a)												
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Saanichton C.D.A.													
Mean Maximum	43	46	47	55	61	61	73	74	64	55	48	40	56
Mean Minimum	32	35	33	39	45	47	52	54	48	42	39	31	41
Mean Temperature	38	40	40	47	53	54	62	64	56	49	43	35	48
Gonzales Heights													
Mean Maximum	43.0	45.9	49.7	55.9	61.4	64.6	68.0	67.8	64.8	57.2	48.8	45.5	56.1
Mean Minimum	35.7	36.8	38.9	42.7	46.8	50.0	52.2	52.4	50.4	46.4	41.0	38.4	44.3
Mean Temperature	39.4	41.4	44.3	49.3	54.1	57.3	60.1	60.1	57.6	51.8	44.9	41.9	50.2
William Head													
Mean Maximum	44	46	46	54	59	60	70	72	62	55	49	43	55
Mean Minimum	36	37	35	40	45	48	51	53	48	42	40	32	41
Mean Temperature	40	41	41	47	52	54	61	63	55	48	44	37	49
	1972 (b)												
Saanichton C.D.A.													
Mean Maximum	39	46	50	51	63	64	73	73	62	56	50	41	57
Mean Minimum	28	33	37	36	46	49	53	53	47	40	39	32	41
Mean Temperature	34	40	44	44	55	57	63	63	54	48	44	36	49
Gonzales Heights													
Mean Maximum	43	45.9	49.7	55.9	61.4	64.6	68.0	67.8	64.8	57.2	48.8	45.5	56.1
Mean Minimum	35.7	36.8	38.9	42.7	46.8	50.0	52.2	52.4	50.4	46.4	41.0	38.4	44.3
Mean Temperature	39.4	41.4	44.3	49.3	54.1	57.3	60.1	60.1	57.6	51.8	44.9	41.9	50.2
William Head													
Mean Maximum	41	45	50	51	64	65	70	71	60	55	49	42	55
Mean Minimum	29	35	36	35	43	44	51	52	47	42	41	35	41
Mean Temperature	35	40	43	43	53	55	61	61	53	48	45	39	48

Table 2.2. Monthly and annual total precipitation (inches) and days measurable for 1971 (a) and 1972 (b) as measured at Gordon Head, Gonzales Heights and William Head. (Annual Meteorological Summary and Long Term Records (Victoria), 1971 and 1972).

	1971 (a)												
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Gordon Head													
Total Precipitation	5.43	3.52	3.31	0.77	0.93	1.31	0.48	0.47	1.46	2.39	5.18	6.45	31.70
Days Measurable	22	15	18	7	8	10	4	2	9	12	19	20	146
Gonzales Heights													
Total Precipitation	4.63	2.76	2.80	0.58	0.59	0.80	0.52	0.57	1.72	2.38	4.19	5.31	26.85
Days Measurable	22	17	18	5	7	11	4	4	11	15	17	20	151
William Head													
Total Precipitation	8.03	3.70	4.64	0.90	0.97	1.40	0.39	0.39	2.08	4.02	6.42	8.33	41.27
Days Measurable	23	17	18	9	7	12	5	6	8	16	21	19	161
	1972 (b)												
Gordon Head													
Total Precipitation	6.45	6.55	4.96	1.76	0.16	1.12	1.47	1.02	2.04	1.11	1.62	8.01	36.27
Days Measurable	21	16	12	12	2	9	5	5	12	6	12	19	131
Gonzales Heights													
Total Precipitation	5.37	4.99	4.06	1.11	0.08	0.93	1.41	1.13	1.97	0.90	1.79	6.25	29.99
Days Measurable	23	19	15	14	2	9	6	3	11	8	17	21	148
William Head													
Total Precipitation	8.89	6.55	6.15	2.32	0.10	1.01	2.14	0.82	2.68	1.27	2.12	9.57	43.62
Days Measurable	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	24	151

than at Gordon Head, though it rained more frequently at the former site. Much of the precipitation carried by winds from southerly and and westerly directions is lost on the windward side of the Olympic Mountains of northern Washington and the lower mountains of southwestern Vancouver Island (Anon., 1972). The greater amount of precipitation at William Head is probably related to its more intimate geographical location relative to these mountains. Widdowson (1965) has stated, on the basis of meteorological data available to him, that the average annual rainfall in the area of Juan de Fuca Strait decreases in an easterly direction. Precipitation affects intertidal algae through its effect on desiccation and osmoregulation. Light precipitation may be beneficial by decreasing the rate of desiccation, but heavy rainfall will lead to osmotic stress by washing away the film of seawater adhering to algal thalli and replacing it with freshwater.

No comparative sunshine data was available within the Greater Victoria area, but monthly and annual data from the Gonzales Heights station are given in Table 2.3. It is to be expected that the number of hours of sunshine will be inversely related to the hours of cloud cover and, to some degree, to the amount of precipitation. It is therefore probable that the William Head area receives less sunlight than is experienced in Victoria proper. Widdowson (1965) has reported that the hours of sunshine increase in an easterly direction from Sooke. During periods of emersion, bright, direct sunlight will contribute to insolation stress and, when coincident with high air temperature, may lead to the bleaching of algal thalli.

Table 2.3. Duration of sunshine (hours), percentage of possible hours, numbers of days without sunshine and normal duration (hours) for each month and annually during 1971 (a) and 1972 (b), at Gonzales Heights. (Annual Meteorological Summary and Long Term Records (Victoria), 1971 and 1972).

		1971 (a) Sunshine		
Month	Duration in hours	Percentage of possible	No. of days without sunshine	Normal
Jan	42.6	16	15	70.0
Feb	91.9	32	8	96.7
March	143.2	39	2	146.3
Apr	180.9	44	1	210.5
May	293.3	62	0	275.0
Jun	182.2	38	1	276.8
July	358.4	74	1	337.0
Aug	330.6	75	0	298.4
Sept	202.4	54	4	208.4
Oct	150.3	45	5	140.7
Nov	60.2	22	9	80.9
Dec	42.0	16	16	65.8
Year	2078.0	47	62	2206.5
		1972 (b)		
Jan	61.5	23	12	70.0
Feb	102.4	36	5	96.7
March	112.0	30	6	146.3
Apr	182.8	45	0	210.5
May	280.5	60	0	275.0
Jun	219.6	46	1	276.8
July	380.3	79	2	337.0
Aug	336.9	76	1	298.4
Sept	195.1	52	2	208.4
Oct	186.9	56	3	140.7
Nov	98.1	35	5	80.9
Dec	52.1	20	16	65.8
Year	2208.2	49	53	2206.5

In brief summary then, it appears that no marked gradient of air temperature exists between the weather stations in the Greater Victoria area. The William Head area experienced more total precipitation and, conversely, probably received less sunlight than did Gonzales Heights and Gordon Head. The effect of this precipitation/sunlight gradient would however be minimal during the summer months when the amount of precipitation is least and at comparable levels at all three monitoring sites.

2. Oceanographic Factors

i. General Oceanographic Description of Juan de Fuca Strait

Juan de Fuca Strait has been described by Herlinveaux and Tully (1961) as a complex, deep positive estuary. The strait is divided into inner and outer parts by a sill extending south from Victoria. The inner strait is separated from the Strait of Georgia by the San Juan Archipelago.

Oceanic waters tend to intrude along the bottom of the strait during flood tides, then expand upward favouring the southern shore. Ebbing waters first appear in the middle of the strait, then expand down and across the strait favouring the northern shore. The ebb current is stronger at the surface and the flood current is stronger near the bottom (Herlinveaux, 1954).

The Fraser River discharge maintains a shallow brackish upper layer in the Strait of Georgia which tends persistently seaward through Juan de Fuca Strait due to the estuarine mechanism (Tully, 1958). Herlinveaux and Tully (1961) have described the tidal pump mechanism which drives the estuarine circulation. On ebbing tides the Strait of Georgia brackish surface layer passes through the San Juan Archipelago where it is mixed to near homogeneity with deeper, more saline layers by turbulent tidal currents. Thus, in the inner part of Juan de Fuca Strait there is little stratification. With the flooding tide part of this mixed water is carried back through the passes between the Gulf Islands and eventually sinks below the brackish surface layer in the Strait of Georgia. On the next ebbing tide, part of the mixed water of the inner Strait of Juan de Fuca escapes seaward in the upper zone of the outer part of the strait where it creates a new stratification by overriding a deeper layer of oceanic water. With flooding tides the bottom waters of the Outer Strait ride up and flow over the sill and are then contained in the Inner Basin when the flood tide turns to ebb. This oceanic water is then incorporated with the mixed waters of the Inner Strait.

Thus there is a net flow of low salinity surface waters from the Strait of Georgia which is replaced by waters of higher salinity formed as a result of turbulent mixing in the narrow channels of the San Juan Archipelago and entrainment of oceanic waters in the inner part of Juan de Fuca Strait. As the surface layer of mixed waters formed in the inner part of Juan de Fuca Strait moves seaward, there is a steady increase in salinity due to entrainment of oceanic waters from the deep layer.

Herlinveaux and Tully (1961) noted that surface salinity maxima occurred in March and October; a marked minimum occurred in January and a broad minimum through June and July. The January minimum is primarily related to coastal rains and the June-July minimum is related to the seasonal maximum discharge from the Fraser River. The Fraser River supplies 70-75% of the freshwater in the Strait of Georgia-Juan de Fuca Strait system.

The stability and density structure of the water column throughout Juan de Fuca Strait is salinity dominated. During the summer the thermocline coincides with the halocline. In winter the waters are isothermal, or the surface waters may be colder than the deep waters; then the stability depends on the salinity structure alone.

ii. Surface Salinity and Temperature Distribution

The horizontal distributions of summer (June) and winter (November) surface salinities and temperatures in the Greater Victoria area are given in Figures 2.1 and 2.2, respectively. These figures are based on the Pacific Oceanographic Group Data Record (Anon., 1955) and are a modified version of those published by Widdowson (1965). The data shown in Figure 2.1 indicates that the surface salinities in Haro Strait north of Cadboro Point (Ten Mile Point) were 0.5-1.0°/oo lower than those in the waters bounded by Gonzales Point and Race Rocks. The lower surface salinities in Haro Strait are attributed to Fraser River discharge. The waters north of Cadboro Point were however isothermal with most of the water mass around Victoria.

The 9.0°C isotherm evident during the summer in the area between Trial Island and Ogden Point and extending a distance offshore (Figure 2.2) has interesting ecological implications. Herlinveaux

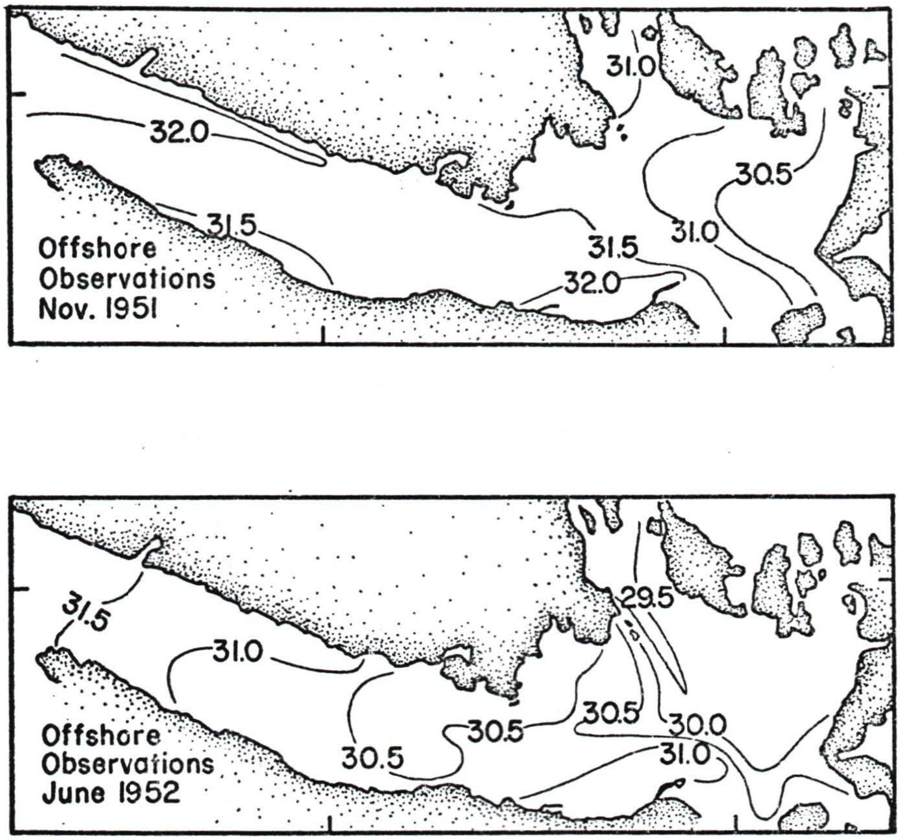

Figure 2.1. Horizontal distribution of summer (June) and winter (November) surface salinities in the Greater Victoria area. (Based on POG data Record, Anon., 1955; after Widdowson, 1965; modified).

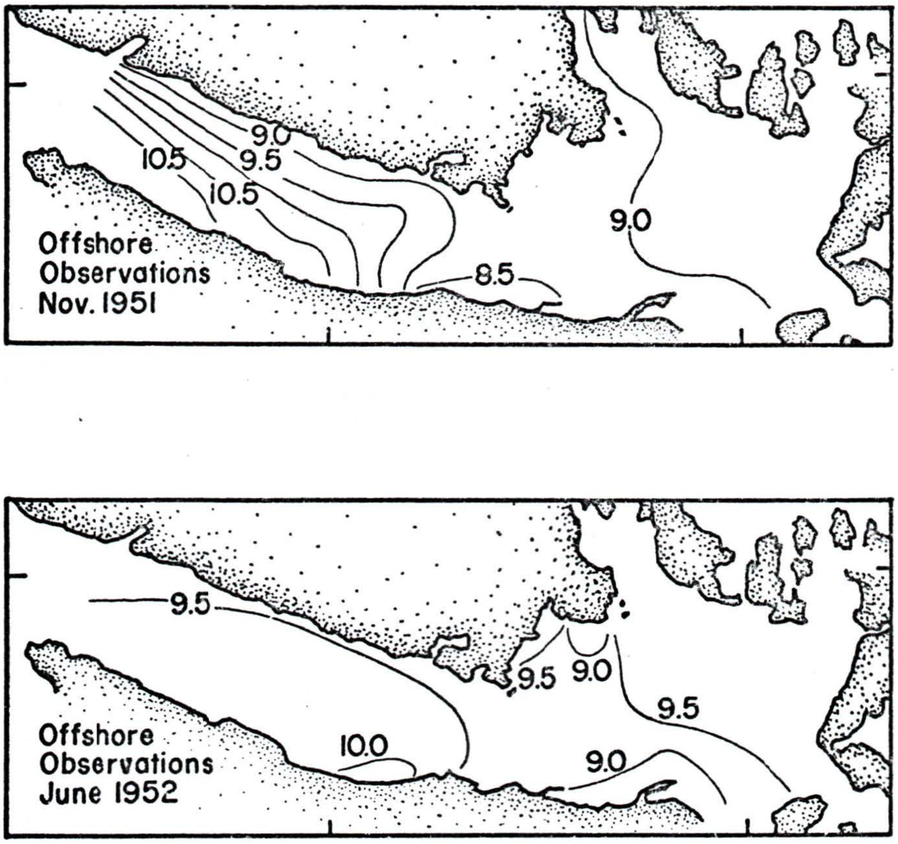

Figure 2.2. Horizontal distribution of summer (June) and winter (November) surface temperatures in the Greater Victoria area. (Based on POG Data Record, Anon., 1955; after Widdowson, 1965; modified).

and Tully (1961) also recorded a cooler water isotherm bounded by the same geographical localities. Herlinveaux (1957) has shown that, in summer, surface temperatures decrease during periods of maximum flow. He concluded that this effect was caused by mixing of the near surface and deeper waters, and that the mixing forces were dependent on the speed of tidal flow. This would then imply that the area bounded by this cooler isotherm is subject to tidal currents of greater magnitude than those in the areas south of Trial Island and between Esquimalt and William Head to the west.

3. Tides

The essential feature which the tide imposes on the shore is the alternation of periods of submersion and emersion. The duration of submersion or emersion at any given level on the shore is controlled by both the period and the amplitude of the tide. The tidal period is in turn controlled by the type of tide. In the Greater Victoria area the tide is of the mixed, mainly diurnal type with marked inequalities in the time and heights of successive high or low waters (Canadian Tide and Current Tables, Vol. 5, 1972). The tide at Finnerty Cove has a slightly greater semi-diurnal component than the tide at Victoria Harbour. There is a gradient of increasing tidal amplitude from west to east with respect to the range of large tides. Thus at William Head the range of a large tide is 8.9 ft., while in Esquimalt and Victoria Harbours the range is 9.3 ft. and at Finnerty Cove the range is 9.8 ft. The slight increase in amplitude in Esquimalt and Victoria Harbours over that at William Head is probably related to the relative constriction of these water bodies and is probably not evident to the same extent along the open south coasts of Esquimalt and Victoria (pers. comm., Mr. W. Rapatz, Canadian Hydrographic Service, Tidal Surveys, Victoria). The increase in tidal amplitude at Finnerty Cove is related to the general elevation of mean sea level to the east of Victoria.

Doty (1946) has shown that a correlation exists between the vertical ranges of many intertidal algae and sudden sharp increases in the duration of maximum continuous emersion with small changes in elevation. His work was however based on mixed, mainly semi-diurnal tides and it is therefore questionable whether his theory of critical tidal factors will apply to other types of tides. Widdowson (1965) believes that the tidal factors relating to lower high waters (LHW) and higher low waters (HLW) are probably unreal when dealing with mainly diurnal tides such as are experienced at Victoria.

In Figure 2.3 the pattern of intertidal zonation at Finnerty Cove, which has a more prominent semi-diurnal component than the tide at Victoria Harbour, is related to the hours of maximum continuous emersion and submersion and various tidal factors considered as useful in describing zonation by several authors (Doty, 1946; Stephenson and Stephenson, 1961; and Widdowson, 1965). It is apparent that certain features of the maximum continuous emersion and submersion curves are related to several components of the zonation pattern evident at Finnerty Cove, particularly to the upper limits of the *Fucus* and the red algal zones. No causative relationship is however implied. The

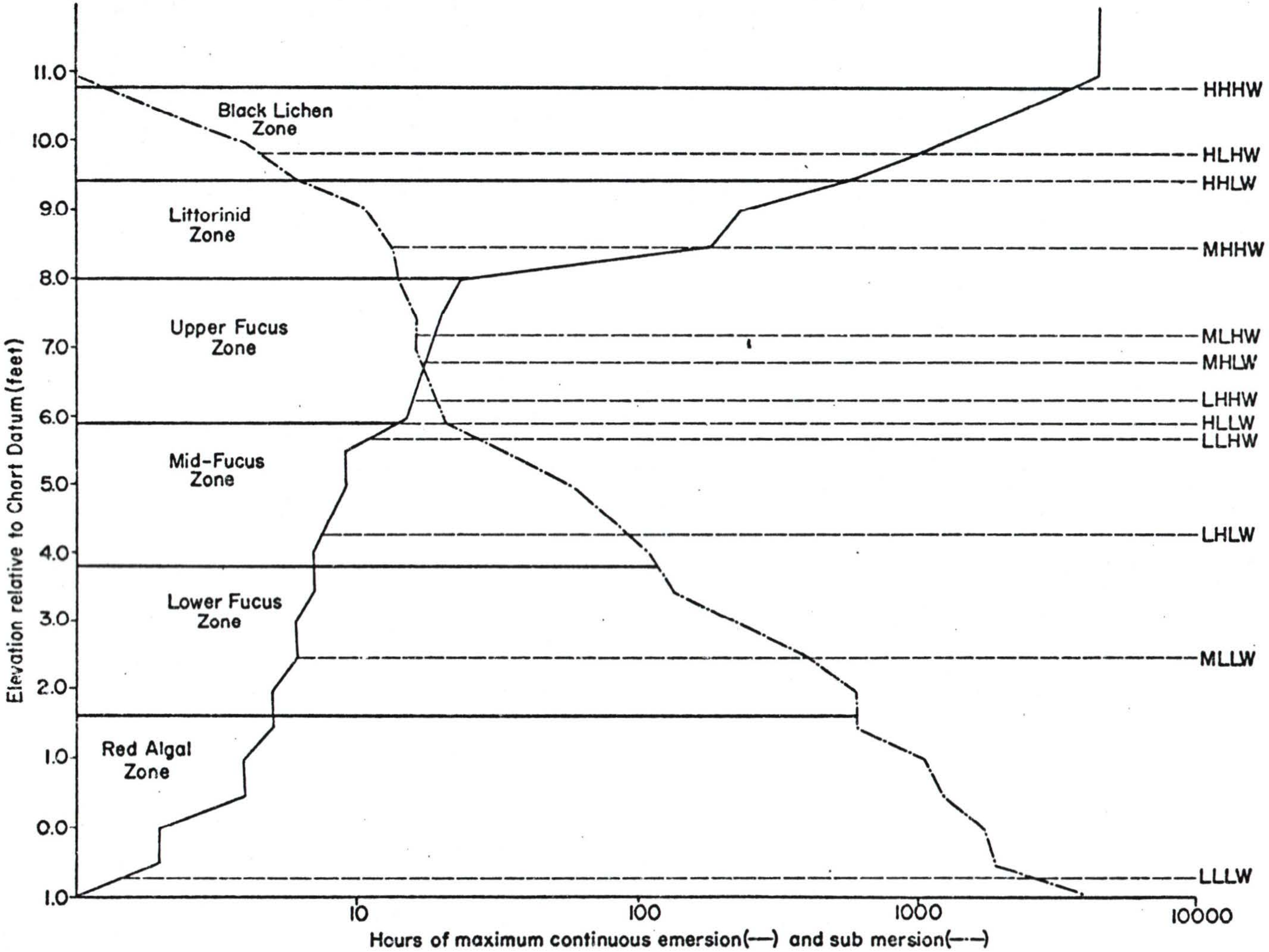

Figure 2.3. Pattern of intertidal zonation at Finnerty Cove as related to hours of maximum continuous emersion and submersion and various tidal factors. (Based on six months data from the Finnerty Cove Tide Gauge; March-August, 1972).

maximum continuous emersion and submersion curves and the elevation of the tidal factors (i.e., MHHW) are based on observations over a six month period (March through August, 1972) from the Finnerty Cove tide gauge. Zonal elevations are those recorded in 1971.

Since Finnerty Cove has the greatest tidal amplitude within the Greater Victoria area, the elevation of the high tides will be successively lower at Victoria and Esquimalt Harbours and at William Head; conversely, the elevation of the low tides will be slightly higher at these sites than at Finnerty Cove.

The datum used as the reference point in calculating the heights of high and low waters is peculiar to each locality and is subjectively defined as "a plane below which the tide will seldom fall" (Anon., 1972). Therefore the relative elevation of the zero tide level will be the same at each tide monitoring station. However, the absolute range of the tide at Finnerty Cove will still be 0.9 ft. greater than at William Head and approximately 0.5 ft. greater than on the south coast of Victoria proper. While such a difference in tidal range is not expected to be effective in causing gross changes in the pattern of intertidal zonation, it may cause minor changes in the relative elevation of the biotic subzones.

In all local areas, winter low tides occur at night and the spring and summer low tides occur in the daylight hours.

4. Currents

i. Tidal Currents

There have been several nearshore and offshore current surveys in this area, largely in the last decade. Data from these surveys will be discussed with respect to the general pattern and velocity of flow, and with particular reference to the manner in which these factors will influence the dispersion of sewage effluent from shoreline outfalls.

A general description of the tidal current flow patterns in the approaches to Victoria has been published by Herlinveaux and Tully (1961) (Figure 2.4). The flood tide flow is mainly confined to the southern half of Juan de Fuca Strait and an eddy is formed in the approaches to Victoria. This is an area of strong streams and tide rips, though less violent during the flood then during the ebb tide. With the ebbing tide, waters from the San Juan Channels issue as jets accompanied by violent rip tides in the inner strait. A convergence zone is formed near Victoria which moves southward as the seaward flow develops. Again, back eddies and violent rips are formed in the approaches to Victoria.

Associated Engineering Services Ltd. (1971) performed a drift pole current survey along the east Victoria coastline specifically to determine the rate and direction of dispersal from the Finnerty Cove Outfall. Their findings indicate that when the flood current flowing in a northeasterly direction through Baynes Channel meets the main Haro Strait current, the flow is pushed easterly away from the shoreline; backeddies are then formed causing a predominantly southern current close to the shoreline. On occasion, poles released near slack water or during a weakly flooding tide did move towards the shoreline. The ebbing current moved southerly through Haro Strait

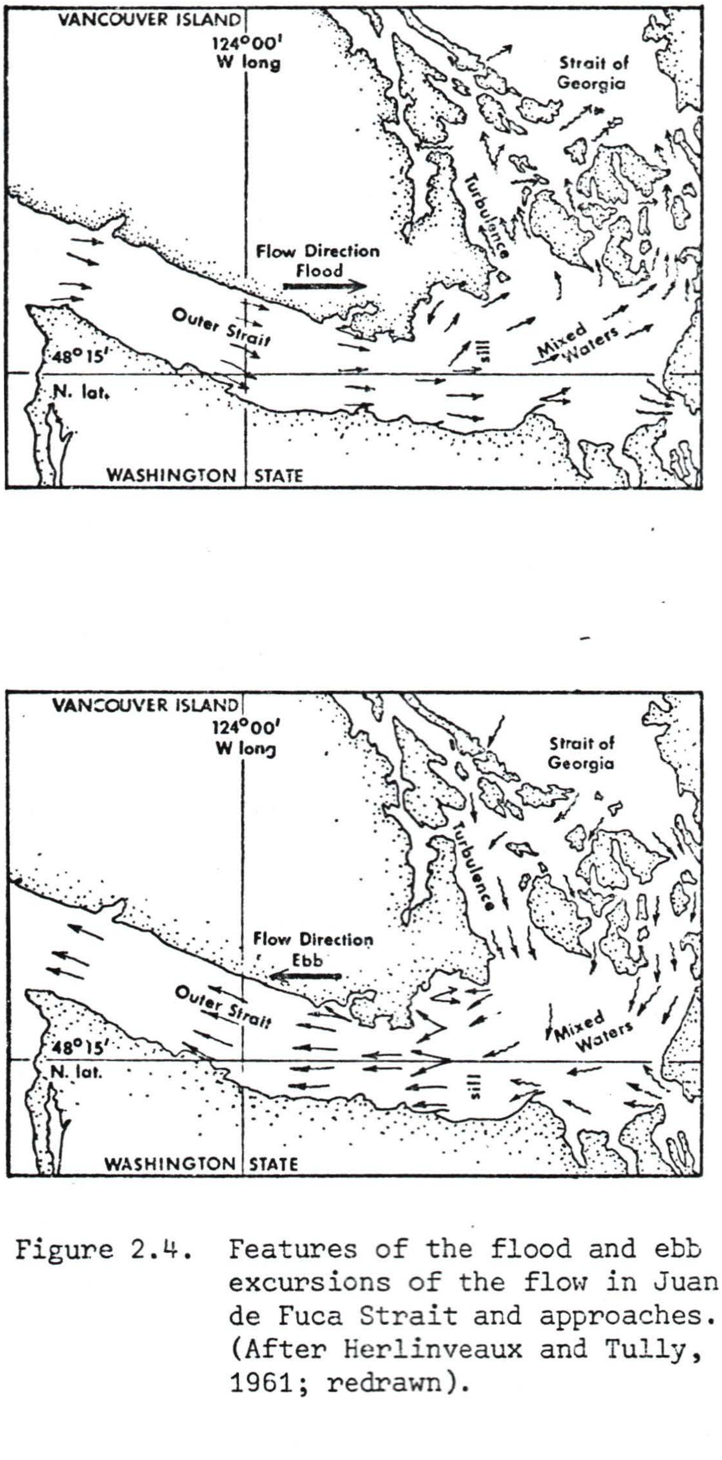

Figure 2.4. Features of the flood and ebb excursions of the flow in Juan de Fuca Strait and approaches. (After Herlinveaux and Tully, 1961; redrawn).

and the study area and then split to pass outside of Chatham Island and through Baynes Channel. It appears possible therefore that effluent from the Finnerty Cove Outfall may appear in a diluted form onshore during slack water periods and, on occasion, during weakly flooding tides. This was supported by turbidity profiling studies conducted independently in 1971 (Drinnan, Ellis and Littlepage, 1971).

Drift pole studies carried out in 1965 (Associated Engineering Services Ltd., 1966) provide the basis for the following description of tidal current flow in the large embayment south of Esquimalt and Victoria. On the flood tide a main stream current flows northeast with its inner limit on a line from Bentinck Island off Rocky Point to the south of Trial Island. The main current reaches a velocity of 2-3 knots. North of the main stream, in the broad triangular basin, the current is reduced until it is forced by headlands into anticlockwise eddy currents. As the flood turns to ebb and the current reverses to a southwesterly direction, there appears to be a general sweep shoreward. On the ebb tide the pattern is similar but in the opposite direction; that is, the eddy currents flow in a clockwise manner as do the currents sweeping shoreward as the ebb tide weakens.

A large gyre is formed north of Albert Head which alternately flows in a clockwise and an anticlockwise direction, depending on the state of the tide. During the flood tide nearshore currents move along the Esquimalt and south Victoria coasts in an easterly direction, but reverse and flow to the west during the ebb tide. The data available indicate that the currents are of higher velocity and more turbulent off Clover Point than off Macaulay Point. This would then lead to relatively faster rate of dispersal and dilution of sewage effluent in the Clover Point area than in the Macaulay Point area.

ii. Wind-Induced Surface Currents

Onshore winds will also affect the dispersal of sewage effluent from shoreline outfalls. Wind blowing over the surface of water imparts a current in the upper layers which is in the direction of the wind and is proportional to the wind velocity (Associated Engineering Services Ltd., 1970). During the summer months, winds with a southerly component are very frequent and relatively strong (Table 2.4) and are known to cause a shoreward drift of surface waters particularly during slack water periods and when tidal currents are of low velocity (Associated Engineering Services Ltd., 1970). Such onshore winds would cause an accumulation of sewage effluent around shoreline-discharging outfalls on the south coast of Victoria. However, increased wave turbulence would also produce a degree of vertical mixing. Therefore the absolute effect of onshore winds on effluent dispersal would also depend on the depth and volume of the freshwater layer formed by the outfall.

5. Wave Exposure

Wave exposure is the major factor which modifies the effective wetting level of the tides. Lewis (1964) considers wave action as the single most important factor determining shore populations and influencing their distributions. The degree of wave action in a locality depends on its geographical location, or aspect, relative to the

Table 2.4. Percentage frequency and average speed (mph) of winds in each direction for each month, and annually, during 1971 (a) and 1972 (b) at Gonzales Heights. (Annual Meteorological Summary and Long Term Records (Victoria), 1971 and 1972).

	Percentage frequency from each direction									Average speed m.p.h. from each direction							
MONTH	NORTH	N.E.	EAST	S.E.	SOUTH	S.W.	WEST	N.W.	CALM	NORTH	N.E.	EAST	S.E.	SOUTH	S.W.	WEST	N.W.
									1971 (a)								
Jan	19	9	7	12	9	16	24	3	3	11.0	7.4	8.0	12.3	11.0	21.5	20.2	6.7
Feb	26	14	11	6	6	9	22	3	3	9.7	6.5	6.9	11.7	10.4	15.5	18.3	7.3
Mar	13	8	3	18	7	17	25	3	2	10.2	7.9	11.1	21.3	9.6	19.0	16.3	6.8
Apr	14	13	8	7	8	17	29	2	4	10.6	7.4	7.5	13.1	8.3	11.4	15.4	6.9
May	9	5	4	3	11	30	32	2	5	8.2	7.5	7.2	12.8	6.9	10.4	16.2	6.3
Jun	4	6	7	4	11	34	28	1	6	5.9	5.3	5.2	6.8	8.8	11.2	13.5	7.0
Jul	4	8	5	3	10	39	21	1	10	5.7	6.2	4.3	4.1	5.9	11.4	11.8	3.7
Aug	4	4	4	4	13	38	22	1	11	6.0	5.8	6.0	6.1	7.6	11.8	12.1	5.9
Sept	16	12	7	4	10	18	20	2	11	11.5	8.9	5.9	6.6	7.4	9.7	11.4	5.2
Oct	15	9	10	13	11	12	19	3	8	9.5	8.0	8.4	11.5	8.8	10.6	15.7	6.8
Nov	19	10	19	20	6	6	14	2	5	8.5	6.7	9.5	16.0	10.0	13.4	16.3	6.4
Dec	29	8	12	16	6	6	16	4	3	10.0	8.9	13.3	18.1	9.2	14.7	15.9	6.7
Year	14	9	8	9	9	20	23	2	6	8.9	7.2	7.8	11.7	8.7	13.4	15.3	6.3
									1972 (b)								
Jan	18	17	7	11	7	12	23	3	3	9.8	13.1	6.1	11.3	10.8	23.2	20.7	8.0
Feb	23	15	12	8	8	11	22	1	1	8.5	8.2	6.9	9.8	7.1	16.1	19.7	4.8
Mar	16	11	17	7	9	14	20	2	4	8.0	6.5	8.9	9.5	6.6	13.4	16.4	4.3
Apr	13	6	9	8	7	17	38	2	*	10.0	6.9	7.2	14.8	8.8	15.2	16.3	7.8
May	15	4	3	2	11	32	28	2	4	9.3	6.2	4.9	4.7	7.2	10.4	12.1	3.9
Jun	5	4	3	2	12	39	30	*	5	7.7	6.2	4.3	5.0	7.1	11.0	14.0	3.0
Jul	12	11	5	3	10	36	19	2	4	9.1	7.1	5.6	5.1	8.1	12.7	13.3	3.6
Aug	7	8	6	3	11	38	23	3	1	6.1	5.6	3.8	4.7	6.2	9.8	10.2	3.5
Sept	15	12	7	7	11	21	25	2	1	8.4	6.6	7.4	11.5	7.1	10.6	13.2	5.5
Oct	27	22	8	4	9	10	15	5	1	8.4	7.8	4.9	5.7	6.2	8.2	13.1	4.7
Nov	27	13	20	17	5	7	10	1	*	10.8	6.8	8.4	15.5	8.5	7.6	13.6	3.1
Dec	19	25	18	16	5	5	10	2	*	8.8	17.2	9.2	15.5	10.9	16.1	15.6	5.5
Year	16	12	10	7	9	20	22	2	2	8.7	8.2	6.5	9.4	7.9	12.9	14.9	4.8

prevailing winds and the surrounding sea areas. Since waves are generally caused by wind, their size is primarily determined by the uninterrupted distance, or fetch, over which the wind can blow across water. The major factor which complicates the effect of wave action is the topography (slope and texture) of the shore. Thus both the frequency and strength of incoming waves and the shoreline topography must be considered in determining the degree of exposure. In general, as the frequency and strength of wave action increases there is a general impoverishment of flora and fauna, an upward displacement of the zonation of species without breaking the stratification, the appearance of marine species in the supralittoral and the appearance of sublittoral species in the eulittoral (Lewis, 1964 and Gurjanova, 1968).

Directional frequency and average wind speed data from the Gonzales Heights station for 1971 and 1972 are presented in Table 2.4. During the winter (October through March) winds blowing out of Juan de Fuca Strait (N, NE, E, SE) occur more than 50% of the time. Inward blowing winds (S, SW, W) predominate during the summer (April through September). The inward blowing winds, whenever they occur, are always stronger than the outward blowing winds.

The Finnerty Cove and Telegraph Cove areas will be much less exposed than the other study areas at Clover Point, Macaulay Point and Albert Head since the strongest winds (S, SW, W) blow offshore in these areas. In addition, gales from the southeast, which occur frequently in winter, will generate waves which will run more or less parallel to the shoreline in these areas with a subsequent decrease in the mechanical force imparted by gale-generated waves breaking on the shore. The Clover Point shoreline will be the most wave exposed of the areas studied. Because of its geographical location, Clover Point will receive wave action from all directions but the north. Macaulay Point and Albert Head should receive about the same degree of wave action but will be less exposed than Clover Point due to the relatively shorter fetchs to the west of these areas.

6. Summary of Environmental Data

Of the climatic factors considered, only the complex of total precipitation and sunshine appeared to show any gradient within the Greater Victoria area. Areas to the west of Victoria proper receive more precipitation and probably less sunlight, particularly during the winter. It is considered unlikely that this gradient would in itself produce significant changes in the structure and distribution of intertidal algal communities.

The slightly lower salinity of the surface waters of Haro Strait are not expected to affect the pattern of intertidal zonation but may influence the horizontal distribution of individual species (Widdowson, 1965). Surface water temperatures in the Greater Victoria area are sufficiently isothermal to pose no barrier to the distribution of algal species. Both surface salinity and temperature are indicative of the current structure in this area.

The similarity of tide types within the study area precludes the possibility of major changes in the intertidal communities which might be attributed to differences in tidal period. Minor changes in the elevation of biotic subzones may however be caused by the increase in tidal amplitude from west to east.

Tidal and wind-induced currents may have some effect on the structure of the intertidal algal communities adjacent to shoreline-discharging sewage outfalls with respect to their capacity to alter the rate of dispersal of discharged effluent. Effluent from the Finnerty Cove Outfall will be expected to arrive onshore in a diluted form under conditions when a slack tide period or a weakly flowing flood tide coincides with onshore winds. The rapid and turbulent tidal currents off Clover Point will accomodate a more rapid dilution and dispersal of effluent from that site then is expected at Macaulay Point which appears to be swept by currents of lower velocity. Onshore winds are expected to cause an accumulation of effluent along the shorelines at both these sites.

Exposure to wave action appears to be the one natural component of the local intertidal environment which is sufficiently gradational within the Greater Victoria area to be possibly responsible for changes in the pattern of intertidal zonation and the vertical distribution of algal species. The Finnerty Cove-Telegraph Cove areas, on the east coast of Victoria, are the most sheltered of the study areas from the strongest prevailing winds; Clover Point, on the south coast of Victoria, is the most exposed of the study areas. Albert Head and Macaulay Point are less exposed than Clover Point, but are more exposed than the Finnerty Cove-Telegraph Cove areas.

C. SHORELINE WATER QUALITY

The Macaulay Point Outfall Monitoring Program was established and water quality sampling was commenced at a number of offshore and onshore stations in May, 1970. Of twelve parameters measured during the monitoring program, the following eight were considered as "gross sewage field indicators" (Balch, Marles, Ellis and Littlepage, 1972): nitrite, phosphate, total coliforms, fecal coliforms, secchi depth, forel colour, salinity and temperature. Dissolved oxygen, nitrate, silicate and chlorophyll *a* concentrations were found not to be significantly affected by the shoreline discharge of sewage effluent from the old Macaulay Point and Clover Point outfalls. In the following discussion only the water quality data from the seven onshore stations (Figure 2.5) will be considered as it is the inshore water mass which will influence the intertidal biota. Data plotted in Figures 2.6-2.13 indicate the measured values of the seven "gross sewage field indicators" at S3 (Macaulay Point) and S6 (Clover Point) but give the mean and range of the other shoreline stations (S1, S2, S4, W6, and S5). The vertical dotted line in each figure separates the block of data collected while the old Macaulay Point Outfall was operational from that collected after cessation of discharge from that outfall. Each figure includes data collected between May, 1970 and October, 1972.

Surface temperatures have shown a normal seasonal cycle with winter minima of 6-7°C and summer maxima of 11-14°C (Figure 2.6). The mean onshore temperatures were approximately one degree higher

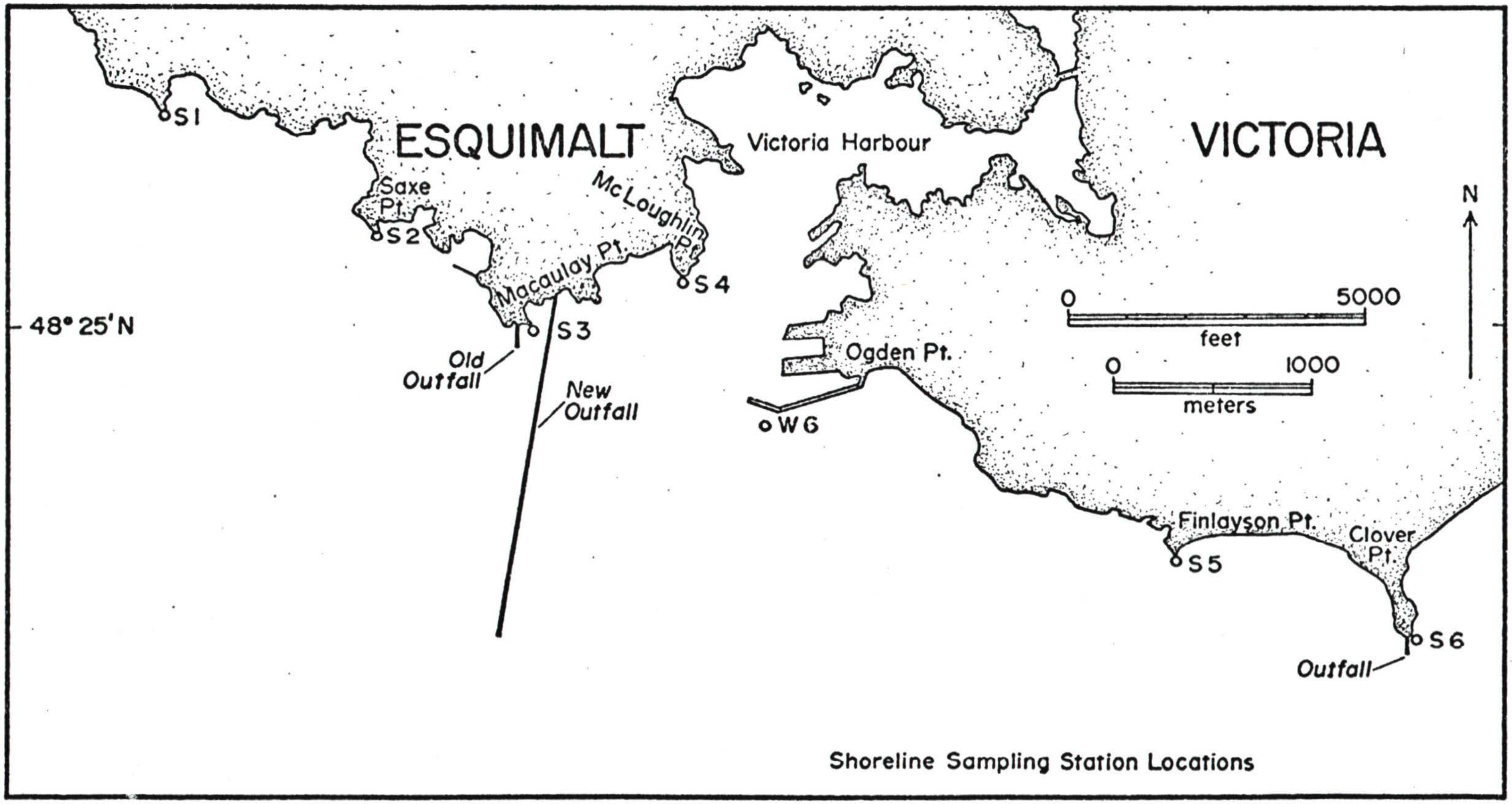

Figure 2.5. Location of shoreline water quality sampling stations.

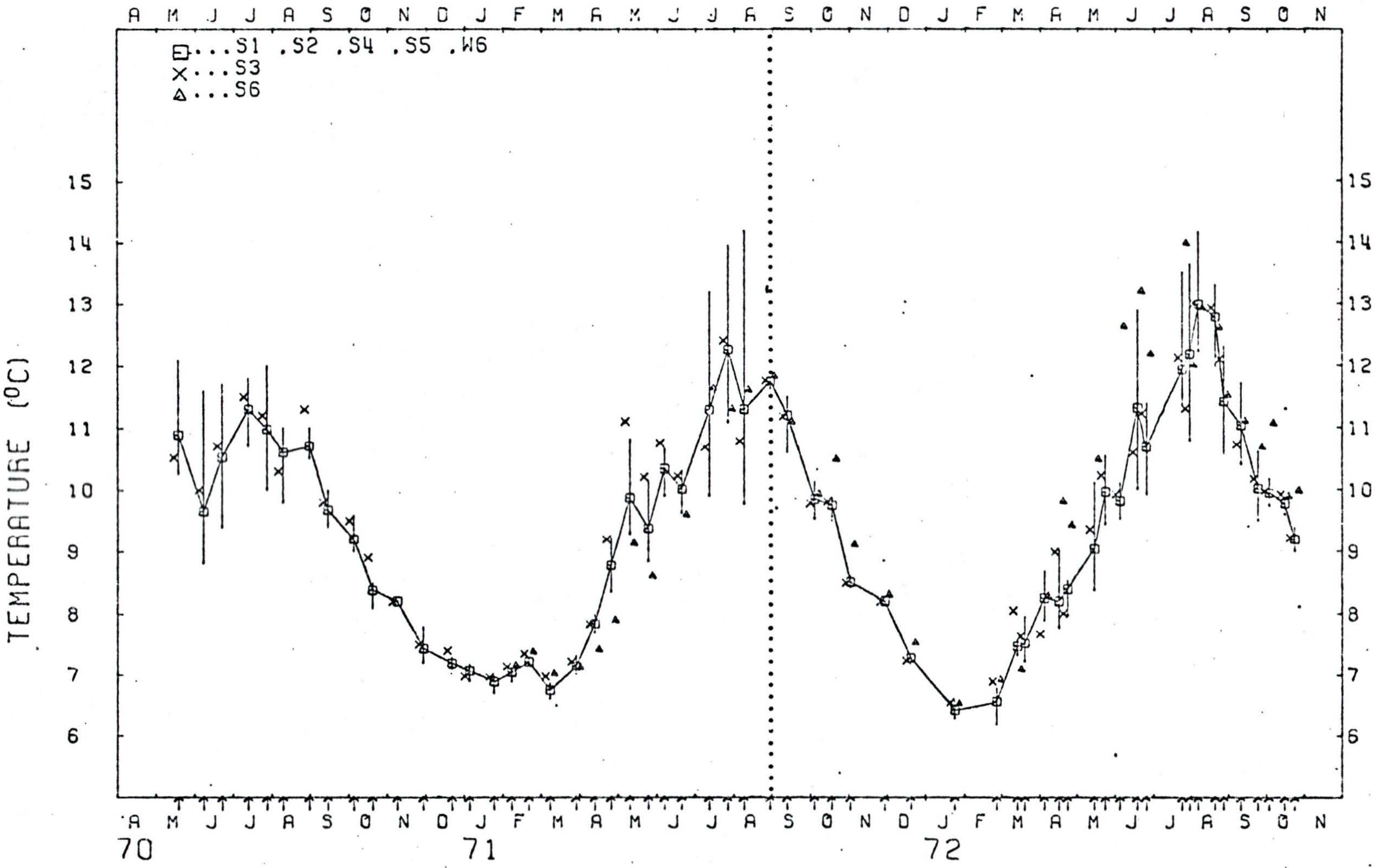

Figure 2.6. Surface temperature values (computer-drawn time series). Measured values at S3 and S6 and the mean and range at the other shoreline stations are plotted. Arrows on X axis denote sampling dates. The dotted line indicates the date of cessation of discharge from the Macaulay Point shoreline outfall (August, 1971).

than offshore temperatures during the February-July warming period but were isothermal with the offshore waters during the August-January cooling period. Both S3 and S6 had higher temperatures than the other shoreline stations, but the temperature at S3 returned to a background value after cessation of discharge from the shoreline outfall at Macaulay Point. The elevation of surface temperature at Clover Point is especially significant in terms of the lower surface temperature of the receiving waters in that area (pages 19 and 20).

Surface salinities indicated a seasonal trend in accord with that reported by Herlinveaux and Tully (1961) (Figure 2.7). The lowest salinities were recorded in January-February and in the period from June through August, with the highest salinities occurring in September and October. Salinities at onshore and offshore stations were the same. Salinity depressions of 1-1.5^{o}/oo were common at both S3 and S6 with depressions between 2 and 4^{o}/oo being evident at both stations. Ellis and Littlepage (1971) have reported a salinity depression of 10^{o}/oo at Clover Point, but this depression was also evident at S5 (Finlayson Point). Surface salinities returned to normal at S3 following cessation of discharge there.

Nitrite concentrations varied seasonally with maximum values being recorded from August to October and minimum values in January (Figure 2.8). There was no consistent difference between the onshore and offshore stations. Nitrite values at S3 and S6 were elevated high above those recorded at the other shoreline stations, with values at S3 dropping to background levels after the cessation of discharge from the shoreline outfall.

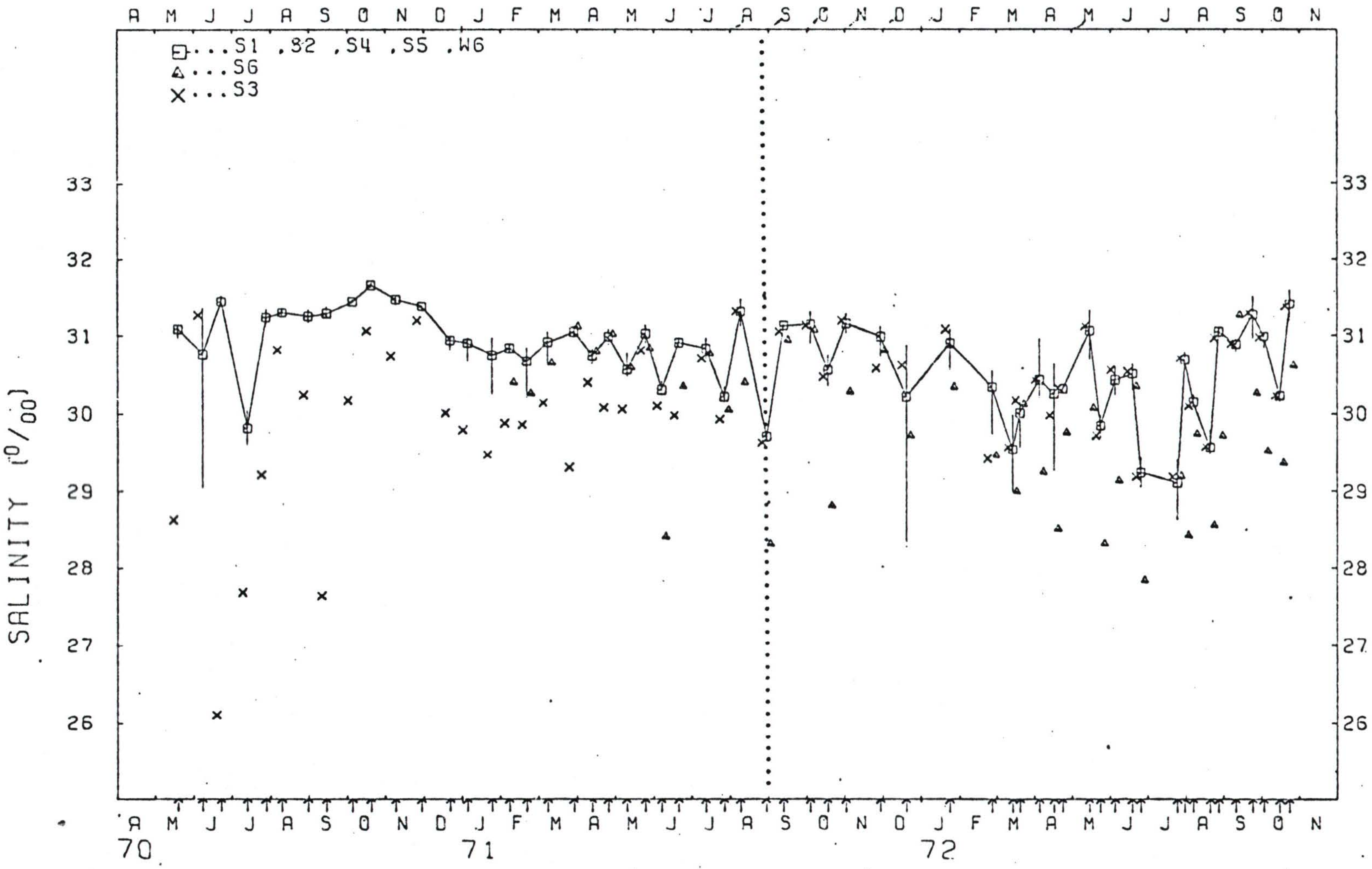

Figure 2.7. Surface salinity values (computer-drawn time series). Measured values at S3 and S6 and the mean and range at the other shoreline stations are plotted. Arrows on X axis denote sampling dates. The dotted line indicates the date of cessation of discharge from the Macaulay Point shoreline outfall (August, 1971).

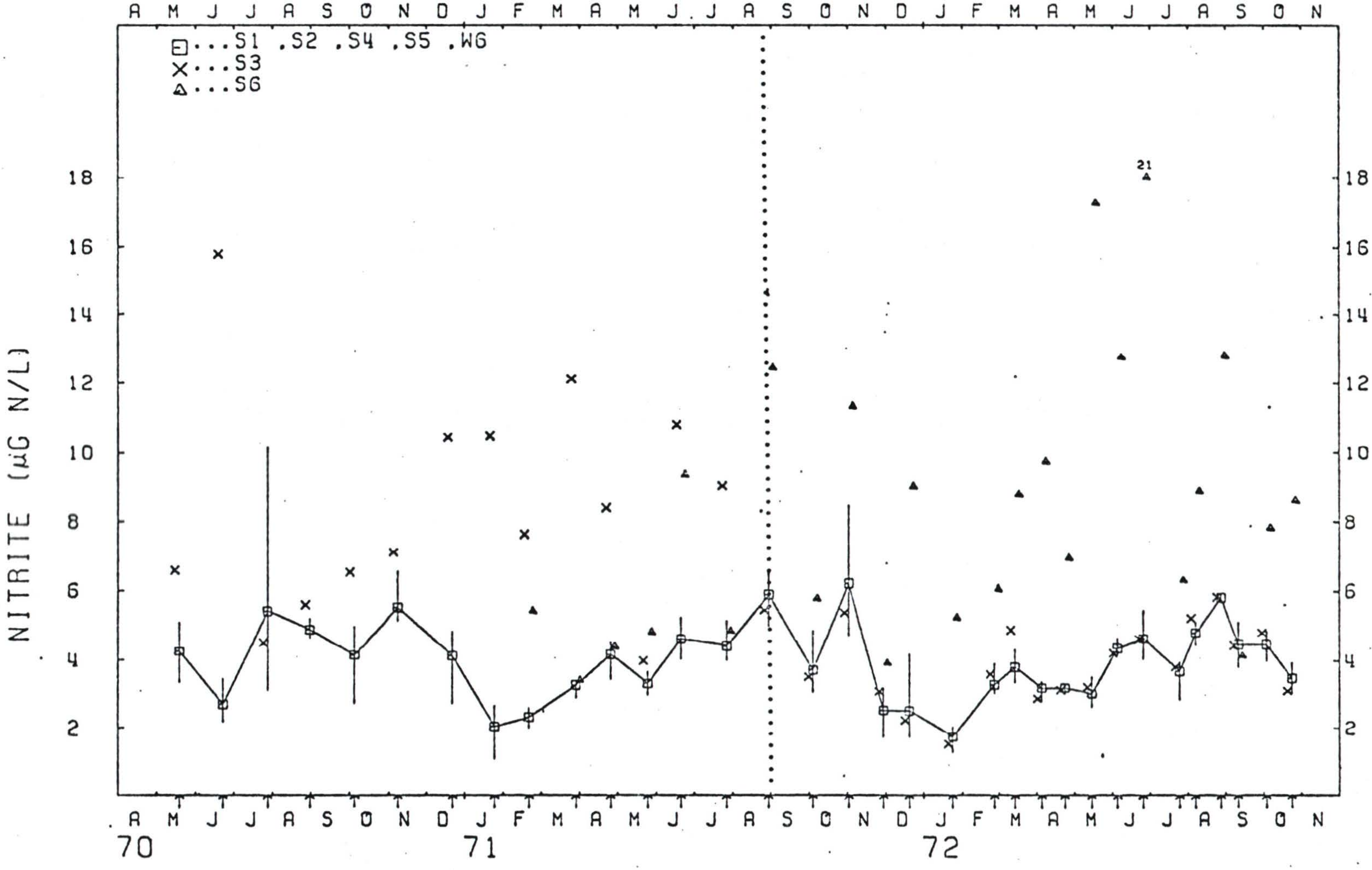

Figure 2.8. Surface nitrite values (computer-drawn time series). Measured values at S3 and S6 and the mean and range at the other shoreline stations are plotted. Arrows on X axis denote sampling dates. The dotted line indicates the date of cessation of discharge from the Macaulay Point shoreline outfall (August, 1971).

The seasonal cycle of phosphate concentration was not strongly developed although minima did occur in summer and maxima in winter (Figure 2.9). Except for S3 and S6, the shoreline and offshore stations had similar phosphate concentrations. Phosphate concentrations were greatly elevated at the two shoreline outfall sites, but the level dropped to background levels following cessation of discharge at S3.

The number of total coliform bacteria decreased during the summer months (Figure 2.10). The reasons for the summer decline of coliform bacteria have been reviewed by Bernard (1970). All shoreline stations other than S3 and S6 showed total coliform counts slightly greater than the accepted standard of 1000 MPN/100 ml. On three occasions the offshore stations also had counts in excess of the standard acceptable level. However, the counts at S3 and S6 were consistently several orders of magnitude higher than the acceptable public health standard. On occasion high counts were recorded at S3 even after cessation of the shoreline outfall.

Fecal coliforms are a more specific indicator of sewage pollution than are total coliforms since they are solely derived from the intestinal tracts of warm blooded animals. The data at hand showed no seasonal cycle of fecal coliform densities. The shoreline densities of fecal coliforms were generally higher than the offshore densities, while counts at S3 and S6 were several orders of magnitude higher than the rest of the shoreline stations (Figure 2.11). High counts of fecal coliforms were recorded at S3 on occasion subsequent to the cessation of discharge there.

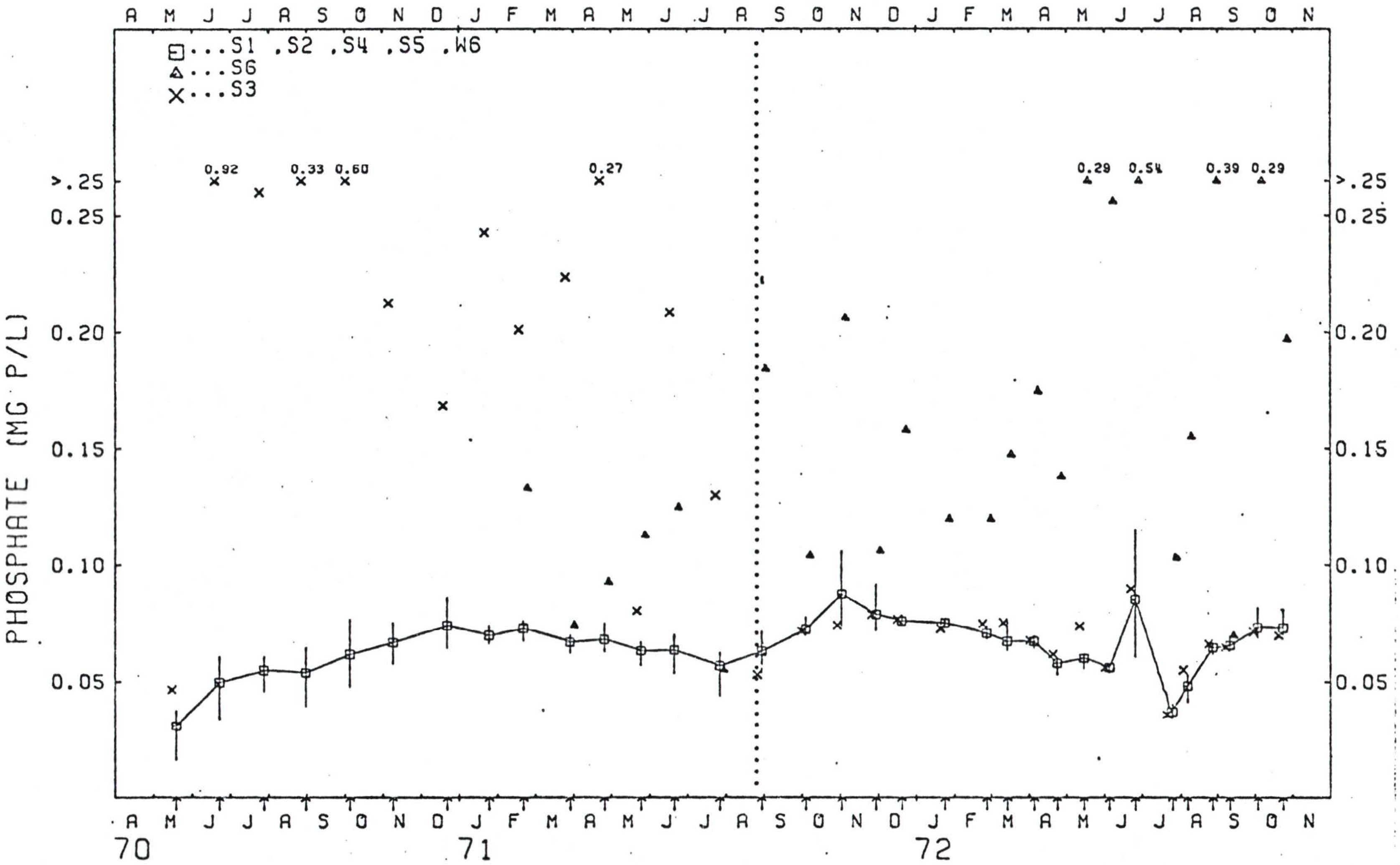

Figure 2.9. Surface phosphate values (computer-drawn time series). Measured values at S3 and S6 and the mean and range at the other shoreline stations are plotted. Arrows on X axis denote sampling dates. The dotted line indicates the date of cessation of discharge from the Macaulay Point shoreline outfall (August, 1971).

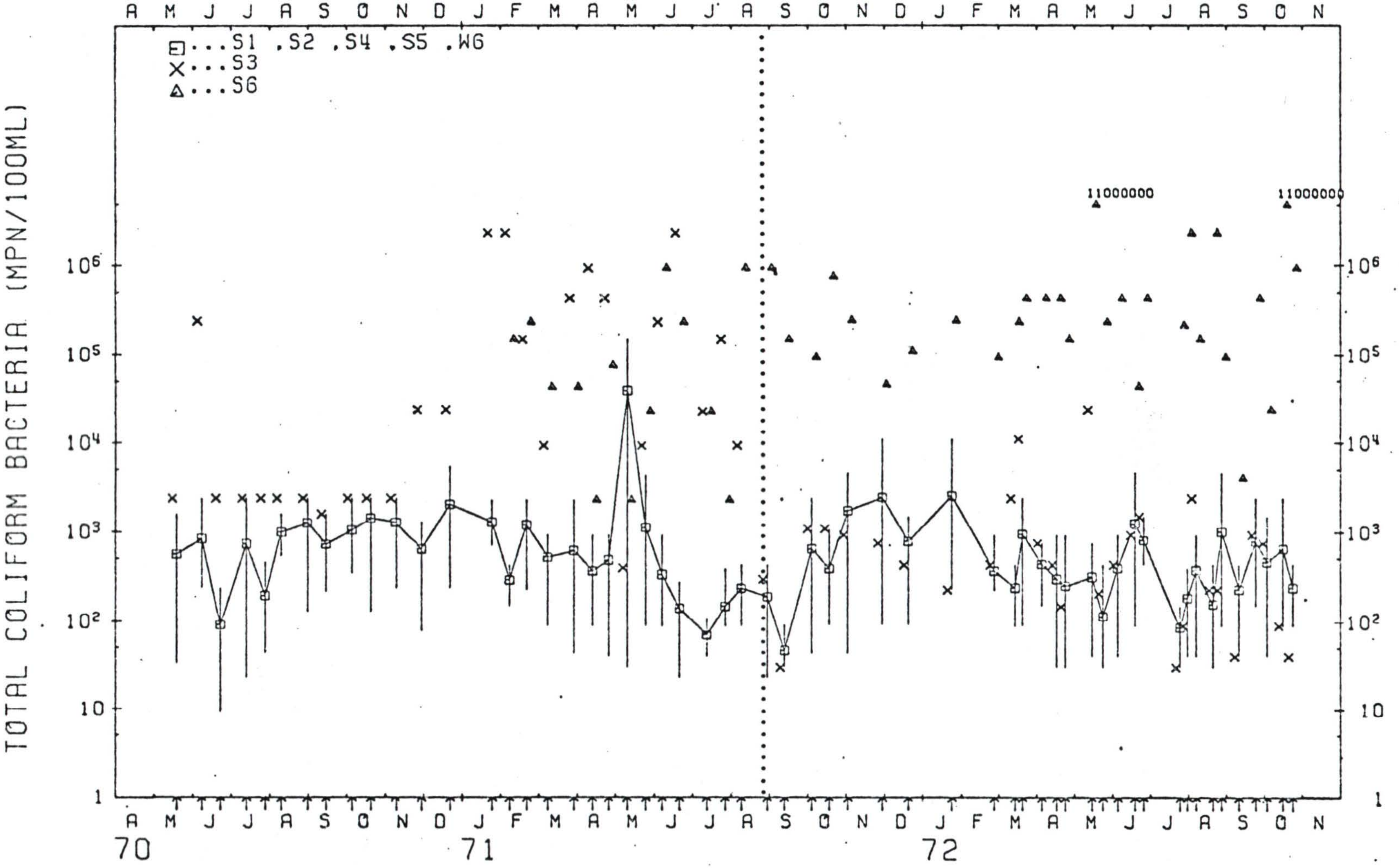

Figure 2.10. Total coliform bacteria values (computer-drawn time series). Measured values at S3 and S6 and the mean and range at the other shoreline stations are plotted. Arrows on X axis denote sampling dates. The dotted line indicates the date of cessation of discharge from the Macaulay Point shoreline outfall (August, 1971).

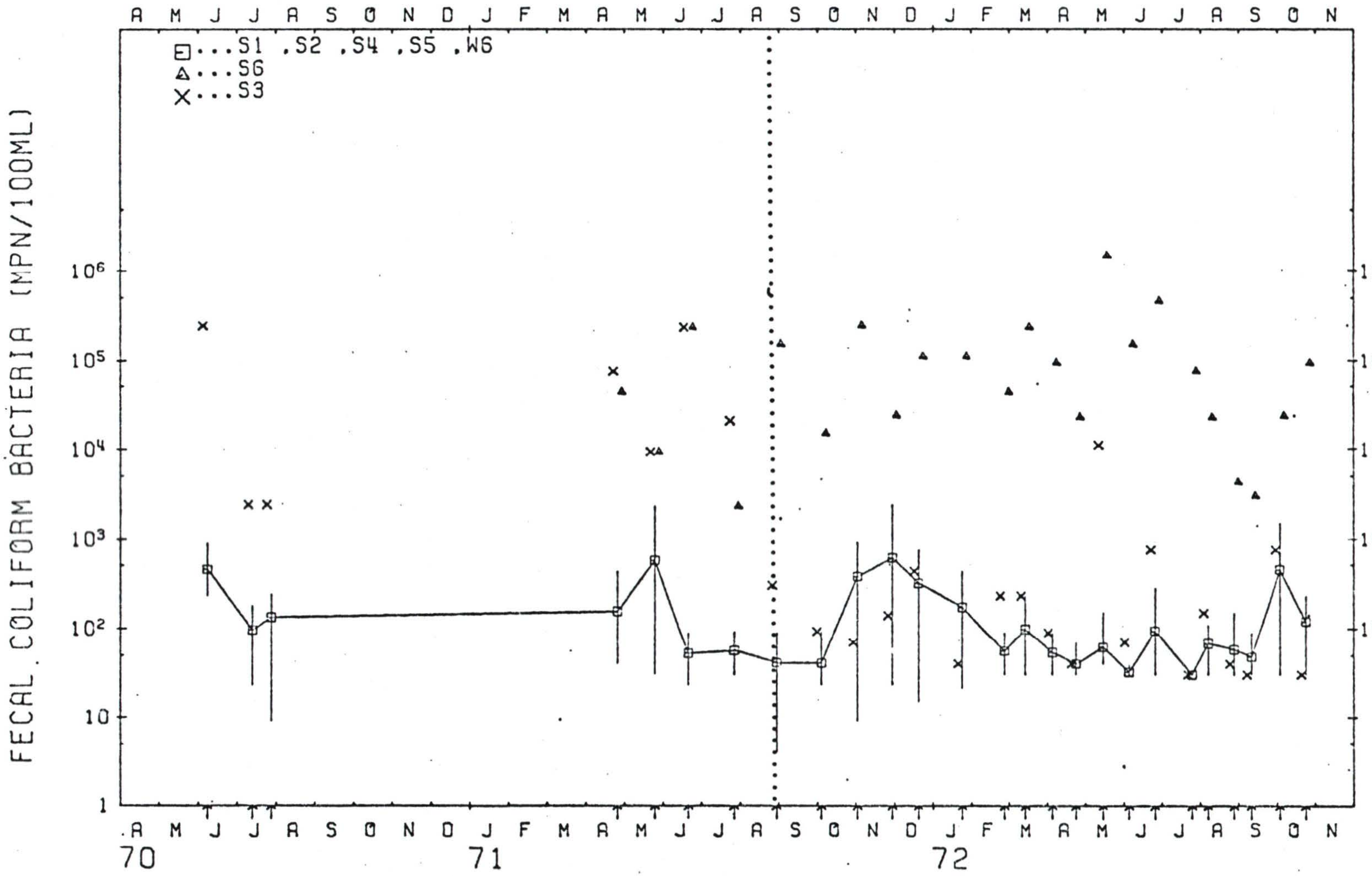

Figure 2.11. Fecal coliform bacteria values (computer-drawn time series). Measured values at S3 and S6 and the mean and range at the other shoreline stations are plotted. Arrows on X axis denote sampling dates. The dotted line indicates the date of cessation of discharge from the Macaulay Point shoreline outfall (August, 1971).

Turbidity, as measured by the Secchi disc method, showed a yearly minimum in the fall at both shoreline and offshore stations (Figure 2.12). However, offshore stations were consistently less turbid than the shoreline stations. Extreme turbidity at S3 and S6 has been attributed to the presence of sewage effluent at these stations. Turbidity decreased to background levels at S3 after the cessation of discharge of the shoreline outfall.

The Forel colour scale, like the Secchi depth is used to monitor the visual characteristics of water. High Forel values (greens and browns) denote the presence of organic and/or inorganic suspended materials; low values (blues) denote clean oceanic waters. There is no well developed seasonal cycle of Forel values but higher values tended to occur during the summers and low values in the winters (Figure 2.13). Shoreline values tended to be higher than offshore values, and values at S3 and S6 were consistently greater than 12 (brown). Values at S3 returned to near normal following the cessation of discharge from the shoreline outfall.

Very little data was collected at shoreline stations during the tenure of the Finnerty Cove Outfall Monitoring Program. The location of the shoreline sampling stations is given in Figure 2.14. The data collected are given in Table 2.5 (water quality parameters) and Table 2.6 (total and fecal coliforms in water and sludge total and fecal coliforms). The data available would indicate that there is no significant change in water quality along the length of shoreline from Telegraph Cove to Finnerty Cove. On the basis of offshore water

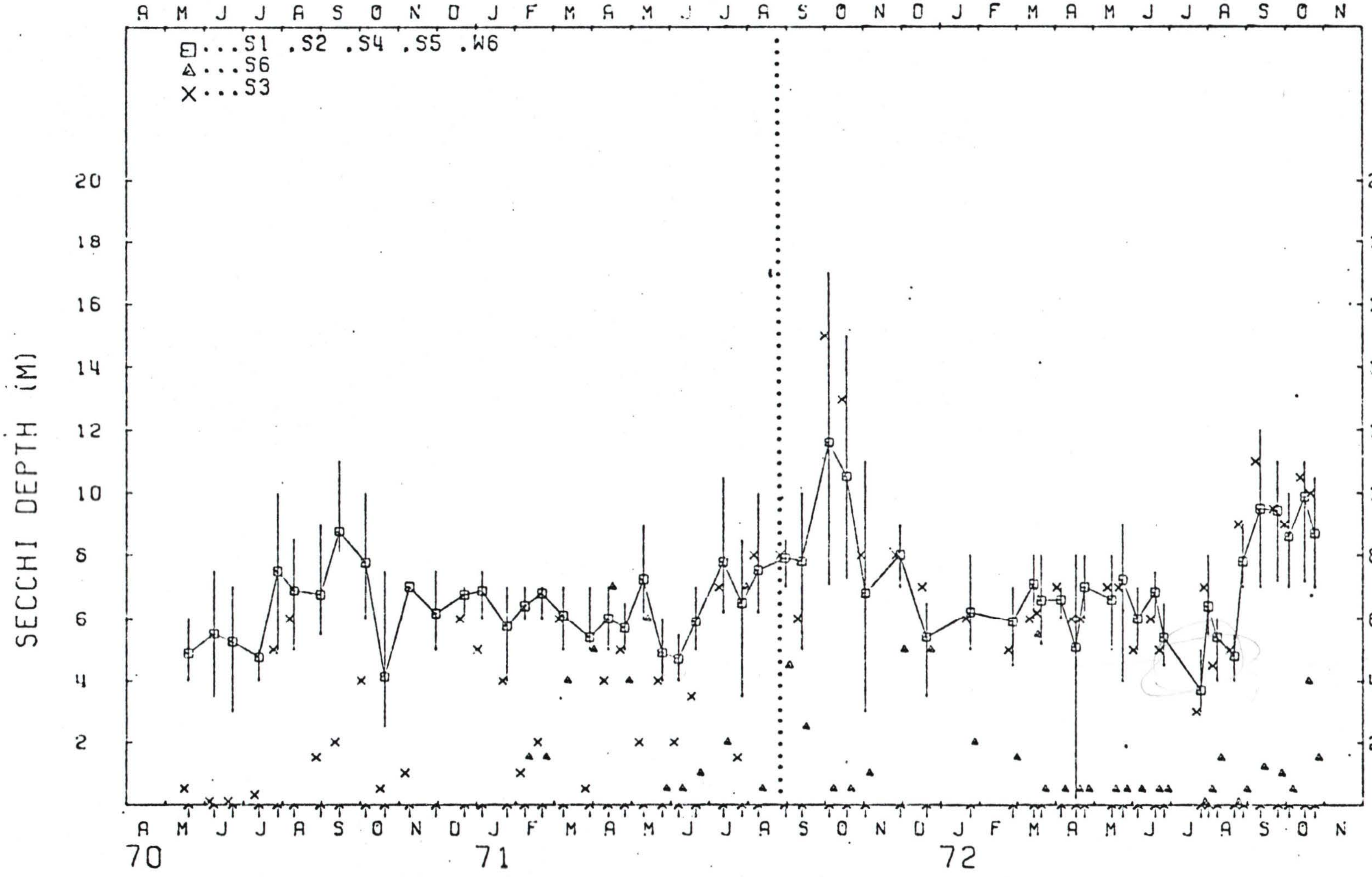

Figure 2.12. Secchi depth values (computer-drawn time series). Measured values at S3 and S6 and the mean and range at the other shoreline stations are plotted. Arrows on X axis denote sampling dates. The dotted line indicates the date of cessation of discharge from the Macaulay Point shoreline outfall (August, 1971).

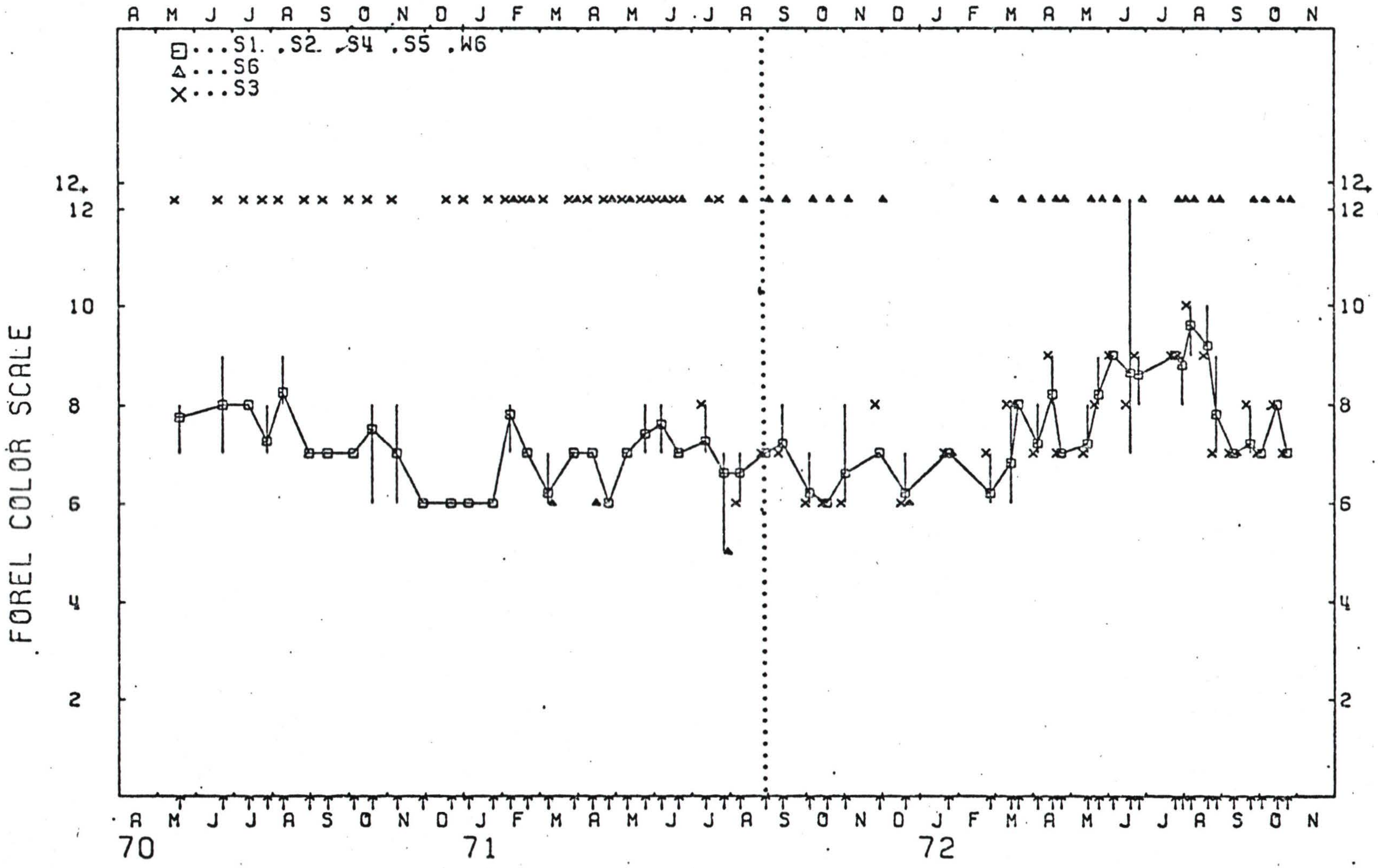

Figure 2.13. Forel colour scale values (computer-drawn time series). Measured values at S3 and S6 and the mean and range at the other shoreline stations are plotted. Arrows on X axis denote sampling dates. The dotted line indicates the date of cessation of discharge from the Macaulay Point shoreline outfall (August, 1971).

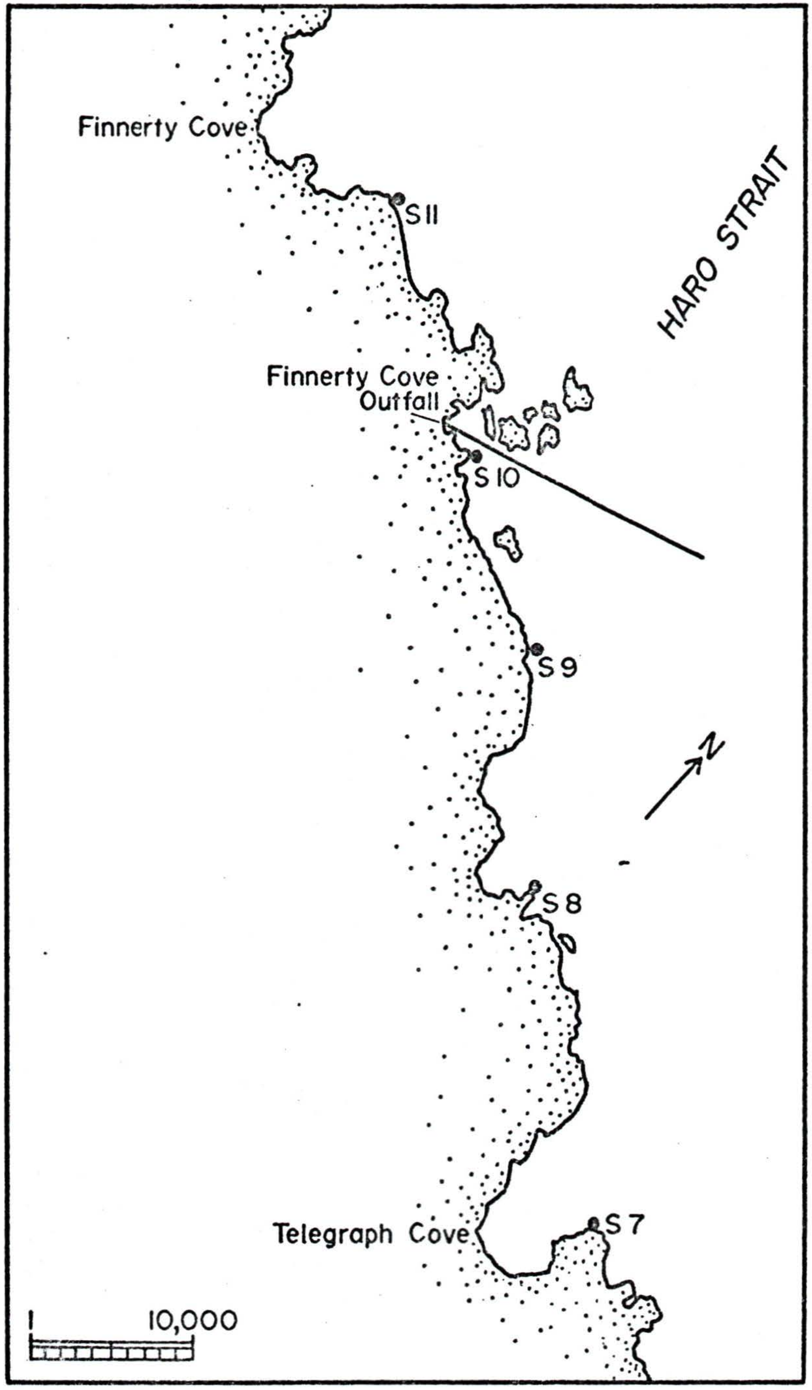

Figure 2.14. Location of shoreline water quality stations sampled during the Finnerty Cove Outfall Monitoring Program.

Table 2.5. Water quality parameters measured at shoreline stations S7 to S11 during the Finnerty Cove Outfall Monitoring Program (Drinnan, Ellis and Littlepage, 1971).

1. June 11, 1971

Station	Time	Temp. (°C)	Surface Sal. (°/oo)	Nitrite (µg/l)	Nitrate (mg/l)	Phosphate (mg/l)	Silicate (mg/l)	Dissolved Oxygen (mg/l)	Chlorophyll (µg/l)
S7		9.65	30.30	3.00	0.244	0.062	1.13	7.06	3.07
S8		9.65	30.30	1.68	0.246	0.063	1.12	7.01	2.61
S9		9.65	30.34	2.79	0.245	0.054	1.09	7.70	2.92
S10		9.65	30.24	1.90	0.233	0.062	1.12	7.09	2.89
S11		9.65	30.27	3.00	0.236	0.078	1.12	7.06	2.93
2. August 17, 1971 (Low tide, + 1.3 feet at 0840 hours)									
S7	0753	11.80	29.34	3.96	0.211	0.052	1.09	-	-
S7	1100	12.30	29.41	3.74	0.212	0.050	1.08	-	-
S8	0722	11.65	29.48	4.14	0.226	0.053	1.14	5.36	-
S8	1128	12.40	29.32	4.26	0.185	N/A	1.09	5.96	-
S9	0718	11.70	29.41	3.75	0.218	0.051	1.13	5.36	-
S9	1133	11.95	29.44	4.14	0.210	0.051	1.11	5.45	-
S10	0815	11.80	29.38	4.45	0.175	0.052	1.09	5.45	-
S10	1213	12.40	29.31	4.00	0.223	0.048	1.05	6.11	-
S11	0837	12.15	29.32	4.22	0.155	0.051	1.09	-	-
S11	1235	12.65	29.29	4.12	0.192	0.048	1.05	-	-

Table 2.6. Total and fecal coliform counts from water (a) and sludge (b) samples taken at shoreline stations during the Finnerty Cove Outfall Monitoring Program (Drinnan, Ellis and Littlepage, 1971).

a. <u>Coliforms in water samples</u>

Station	Date (1971)	Total Coliforms (MPN/100 ml)	Fecal Coliforms (MPN/100 ml)	Date	Total Coliforms (MPN/100 ml)	Fecal Coliforms (MPN/100 ml)
S7	Jun 9	93	4	Jun 23	9	<3
S8		430	21		9	<3
S9		430	43		93	4
S10		<3	<3		9	<3
S11		<3	<3		4	<3
S7	Aug 17	40	<30	Aug 17	40	<30
S8	(Slack water)	40	<30	(Current Series A)	40	<30
S9		<30	<30		<30	<30
S10		<30	<30		<30	<30
S11		<30	<30		<30	<30
S7	Aug 17	40	<30			
S8	(Current Series B)	230	90			
S9		40	<30			
S10		40	40			
S11		<30	<30			

b. <u>Sludge coliforms</u>

S7	Jul 20	900	<30
S8		400	<300
S9		<300	-

quality measurements it was concluded (Drinnan, Ellis and Littlepage, 1971) that the effluent field from the Finnerty Cove Outfall was rapidly dispersed by turbulent tidal currents and remained offshore. It was postulated however that if peak discharge should coincide with slack water and strong onshore winds there is a distinct possibility that the effluent field would be driven onshore. Sludge coliform data available suggests that this is not usually the case as sludge coliform densities decreased in a direction from the mouth of the outfall towards the shoreline.

Water quality data were collected at Albert Head on only four occasions. Albert Head was the control site for several of the studies included in this thesis and was selected as such on the basis of aspect, slope and type of substrate. It was also the closest accessible ground which was sufficiently removed from any major source of sewage effluent to be considered as a control site within the Greater Victoria area. The location of the water sampling sites is given in Figure 2.15; the values of the water quality parameters measured are given in Table 2.7. The data available are very similar to those of the shoreline stations sampled during the Macaulay Point investigation and suggest that the oceanographic conditions influencing the Albert Head intertidal biota are at least not greatly different from those along the south Victoria shoreline.

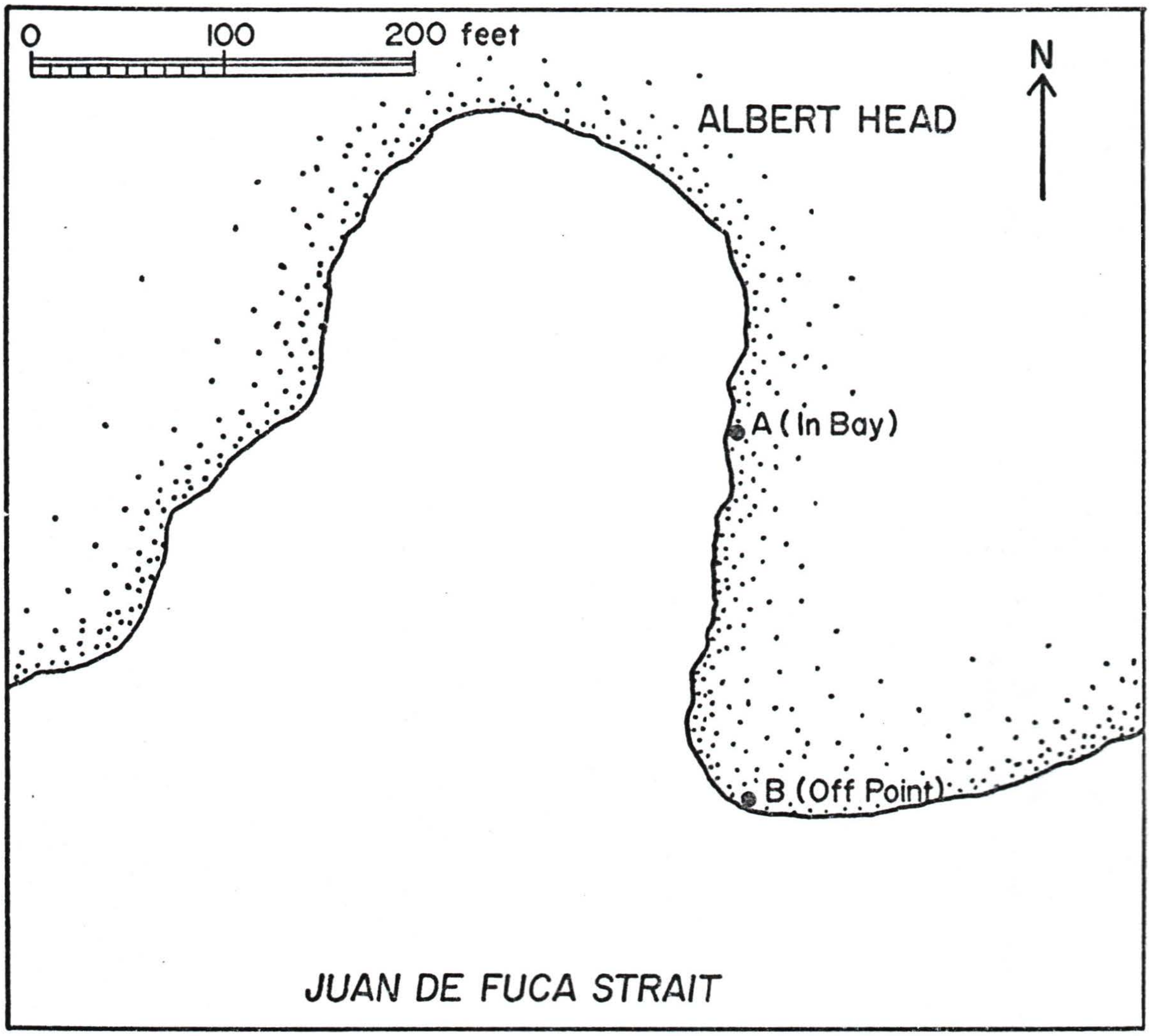

Figure 2.15. Location of shoreline water quality stations at Albert Head.

Table 2.7. Water quality data collected by the author at two sites on Albert Head during 1972.

Station	Date (1972)	Surface Temp. (°C)	Surface Salinity (‰)	Nitrites (µg/l)	Nitrates (mg/l)	Phosphates (mg/l)
A (in Bay)	Jun 27	11.20	29.70	4.65	0.243	0.005
	Jul 19	12.00	-	4.36	0.150	0.043
	Aug 7	-	30.27	5.60	0.149	0.057
	Sep 19	10.09	30.02	-	-	-
B (off Point)	Jun 27	10.90	29.81	4.83	0.176	0.050
	Jul 19	12.00	-	4.03	0.166	0.042
	Aug 7	-	30.27	5.14	0.168	0.057
	Sep 19	10.10	30.02	-	-	-

PART III. INTRODUCTORY SURVEY OF THE EFFECTS OF SEWAGE EFFLUENT ON THE STRUCTURE AND VERTICAL DISTRIBUTION OF INTERTIDAL ALGAL COMMUNITIES

A. INTRODUCTION

Pollution of the marine environment has been linked with a reducttion in species diversity in a number of recent investigations (Storrs, *et al.*, 1969; McNulty, 1961; Bellamy, *et al.*, 1967; and Widdowson 1971a). Storrs *et al.* assume that the reduction in species diversity results from the additional stress load imposed upon organisms, with the consequent loss of sensitive species. Thus, the genetically-controlled morphological and physiological adaptations of intertidal algae to the normal stresses provided by the variability of the intertidal environment may not be sufficiently broad to cope with the additional stress load imposed by a pollutant. The loss of these species from the intertidal algal community will alter the structure of that entity. The presence of high concentrations of sewage effluent in the immediate vicinity of shoreline discharging outfalls will therefore be expected to alter the structure of the intertidal algal community by changing the physico-chemical nature of the medium upon which this community vitally depends. The objective of this introductory study was to determine if there were any major qualitative changes in the structure and vertical distribution of the intertidal algal communities adjacent to shoreline-discharging sewage outfalls.

Diversity indices, in any of their many forms, may be used as an indicator of gross changes in community structure resulting from pollution (Copeland and Cameron, 1969). The simplest measure of species diversity is a count of the number of species. MacArthur (1965) considers these simple species counts as adequate for studying some of the patterns of species diversity. The potential drawback of species counts are that they fail to take into account species abundance and that they depend on sample size. The present study, initiated in the spring of 1971, involved phycological surveys and measurements of the vertical distribution of the biotic subzones in the environs of the Macaulay Point, Clover Point and Finnerty Cove outfalls as well as at selected control sites (see Figure 3.1 for locations). At that time both the Macaulay Point and Clover Point outfalls discharged untreated sewage effluent from shoreline outfalls located at or near the zero tide level. The Finnerty Cove Outfall discharged chlorinated, but otherwise untreated sewage effluent approximately 1300 ft. offshore at a depth of 44 ft. In August, 1971 the old Macaulay Point Outfall ceased operation and the effluent was diverted into a new submarine outfall opening 6000 ft. offshore at a depth of 200 ft. Biomass and numbers data were not collected due to the time restrictions imposed by the short duration of the lower low water periods.

The test sites at Macaulay Point and Clover Point are located on the south-facing coast of Victoria and, since aspect in relation to the prevailing winds is an important factor in determining intertidal

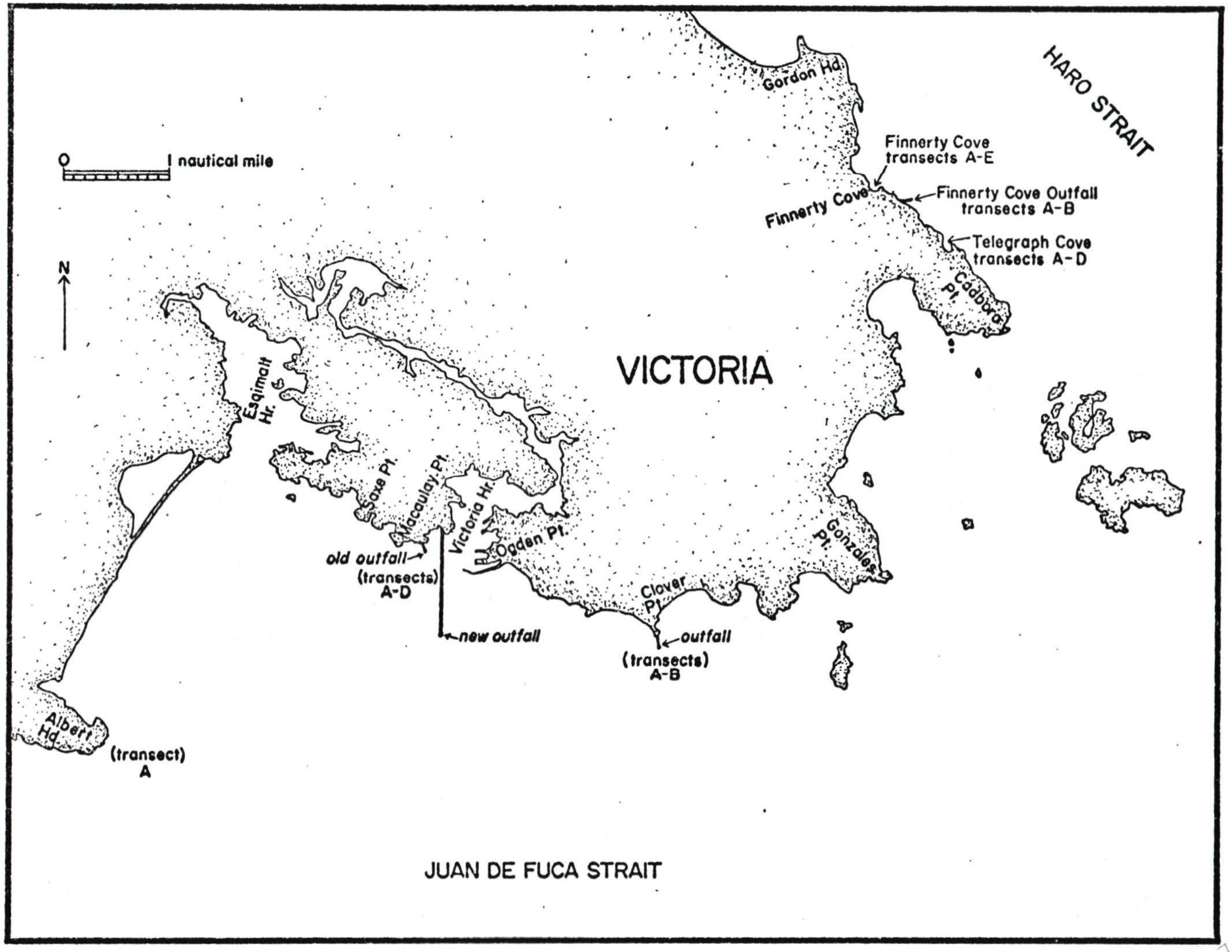

Figure 3.1. Locations of the Macaualy Point, Clover Point and Finnerty Cove outfalls (test sites) and the control sites at Albert Head, Finnerty Cove and Telegraph Cove.

zonation and species distributions (Lewis, 1964), the control site chosen for these areas had to be of similar aspect. Accordingly, Albert Head was chosen as the control site for the Macaulay Point and Clover Point test sites. Albert Head was the closest area which had a similar aspect, was influenced by the same oceanographic conditions (Herlinveaux and Tully, 1961) and yet was far enough away from any major source of sewage effluent to be considered as a control site. On the other hand, the test site adjacent to the landward base of the Finnerty Cove Outfall is located along the east coast of Victoria. Control sites for the Finnerty Cove Outfall were located in Finnerty Cove proper and Telegraph Cove. Similarity in overall aspect was the main factor considered in choosing these two areas as control sites. All three sites on the east Victoria coastline are influenced by the same oceanographic conditions (Herlinveaux and Tully, 1961). At the time this study was initiated no data were available pertinent to the range of the sewage field produced by the Finnerty Cove Outfall.

B. METHODS

A total of 18 transects were qualitatively sampled for species diversity of the intertidal macro-flora as estimated by species number per transect. The length of each transect was determined by the degree of slope of the foreshore. The width of each transect was not quantified precisely since the data were not intended for statistical analysis, but merely to indicate gross changes in community structure which, if present, would be studied in a more quantitative manner at a later date. The vast majority of specimens collected were however taken in a strip 1-2 m wide. On certain occasions, if an obviously common species occurred outside this relatively narrow range, specimens were collected and included as part of the flora of that transect.

Collections were made in each visually prominent zone within each transect. All specimens collected within a given zone were placed in a plastic bag labelled with transect number and zone. The lowermost zones at most transects were sampled during the lowest water period of the sampling day. However, the lowermost zones at Macaulay Point were sampled approximately one hour after low tide.

Some specimens were mounted and dried the day of collection; the rest were preserved in a formalin-seawater mixture and mounted and dried at a later date. Preliminary identifications were made in June and July, 1971. More precise taxonomic work was accomplished in early 1973 with the aid of many taxonomic monographs and an expanded and updated version of Scagel's 1957 key compiled by Dr. T. Widdowson. The collection will be deposited in the University of Victoria Phycological Herbarium. All obvious taxa present at the sampling sites during the collecting period are included in the collection with the exception of the crustose Phaeophyta (*Ralfsia* spp., for example) and the crustose coralline Rhodophyta (*Lithothamnia* spp., for example). The surf grass *Phyllospadix scouleri* Hooker is included with the algae in this study.

Measurements of zonal elevations at each transect were made with a Sokkisha 11 inch dumpy level and a surveying rod graduated in .01 ft.

intervals. All primary levelling was based on Municipal, Canadian Hydrographic Service or Department of National Defence benchmarks (Table 3.1). At Albert Head, Macaulay Point and Telegraph Cove secondary benchmarks were established closer to the transect sites (Table 3.2). All elevations are relative to Chart Datum. Zonal elevations at Albert Head were measured in May, 1972; all other elevating was accomplished in May and June, 1971.

Table 3.3 lists the slope, substrate, aspect, dominant eulittoral organism, date of sampling, and the time and height of low water on the sampling days for each transect. The detailed location of transects within each sampling area is given in Figure 3.2.

C. RESULTS

Table 3.4 documents the presence and absence of intertidal macroalgae at Macaulay Point, Albert Head, Clover Point, Finnerty Cove, the landward base of the Finnerty Cove Outfall and Telegraph Cove. A total of 78 taxa were collected and identified, 75 to the species or variety level and 3 to the generic level (*Ulva*, *Spongomorpha* and *Porphyra*). Some *Ulva* specimens were identified to the species level during the preliminary identification period and these are included separately in the species list. Figure 3.3 documents the vertical distribution of the prominent biotic zones in all transects and indicates the number of taxa collected within each zone.

On a global scale in north temperate regions, there is a replacement of fucoid algae by barnacles on shores progressing from sheltered

Table 3.1. Elevation and location of primary benchmarks.

Area	Elevation of primary benchmark (ft. above chart datum)	Primary benchmark established by	Location of primary benchmark
Macaulay Point	30.26	Capital Regional District	Base of southeast cement corner post of pistol range, approx. 100 ft. west of Macaulay Point Pumping Station.
Clover Point	26.97	City of Victoria	Rim of manhole on south tip of roadway, behind cement pump house.
Albert Head	27.18	Dept. National Defence	DND cement corner marker, southwest corner of Albert Head Reserve; brass plug in upper surface inscribed: Post 1, 180°00", 1952, EL. 21.38 (assumed relative to Geodetic Datum).
Finnerty Cove Outfall and Finnerty Cove	14.20	Canadian Hydrographic Service	Hydrographic BM#25 (1956) is a brass plug set in a sharp rock outcrop on the southeast side of Finnerty Cove about 250 ft. east of the tip of the old outfall.
Telegraph Cove	70.51	Saanich Municipality	Top of Hydrant #327 850 ft. west of Telegraph Bay road on Queenswood Drive.

Table 3.2. Elevation and location of secondary benchmarks.

Area	Elevation of secondary benchmark (ft. above chart datum)	Location of secondary benchmark
Macaulay Point	16.99	B.C. Legal Surveys BM#247 (1965) is a brass plug set in a cement square on bedrock on the highest rocky outcropping on the southern most point of land at Macaulay Pt.
Albert Head	22.23	Paint sprayed on top of bedrock outcropping 50 ft. west of transect site.
Telegraph Cove	15.74	Paint sprayed on top of boulder on the northwest corner of beach area.

Table 3.3. Slope, substrate, aspect, dominant organism, date of sampling, time and height of low water on the sampling days for each of the eighteen transects.

Area	Transect	Degree of Slope			Substrate	Aspect	Dominant eulittoral organism	Date of sampling 1971	Time of low water on sampling date*	Height of low water* (in ft.)
		Shallow	Moderate	Steep						
Albert Head	A		X		Bedrock	S	Barnacles	Jun 11	1131	0.1
Macaulay Point	A			X	Bedrock	S	Barnacles	May 26	1115	-0.1
	B			X	Bedrock	S	Barnacles	May 26	1115	-0.1
	C		X		Bedrock	SSE	Barnacles	May 26	1115	-0.1
	D			X	Bedrock	SE	Barnacles	May 26	1115	-0.1
Clover Point	A		X		Bedrock	S	Barnacles	May 27	1208	0.0
	B		X		Bedrock	E	Barnacles	May 27	1208	0.0
Telegraph Cove	A		X		Bedrock	E	*Fucus* sp.	May 27	1245	0.2
	B		X		Bedrock	E	Barnacles	May 27	1245	0.2
	C	X			Bedrock in upper levels, small boulders in lower levels	W	*Fucus* sp.	May 28	1333	0.8
	D			X	Bedrock	W	*Fucus* sp.	May 28	1333	0.8
Finnerty Cove Outfall	A		X		Bedrock	ESE	*Fucus* sp.	Jun 7	1005	1.2
	B		X		Bedrock	N	*Fucus* sp.	Jun 7	1005	1.2
Finnerty Cove	A		X		Bedrock	W	*Fucus* sp.	May 25	1117	0.1
	B		X		Bedrock	ENE	*Fucus* sp.	May 25	1117	0.1
	C			X	Bedrock	ESE	*Fucus* sp.	May 26	1203	0.1
	D			X	Bedrock	WNW	*Fucus* sp.	May 26	1203	0.1
	E	X			Sand in upper levels, small boulders in lower levels	N	*Fucus* sp.	May 26	1203	0.1

* From Water Levels, Vol. 2 - Tidal (1971), actual time and heights. Based on Victoria Harbour and Finnerty Cove Tide Gauges with the appropriate time and height correction for Albert Head.

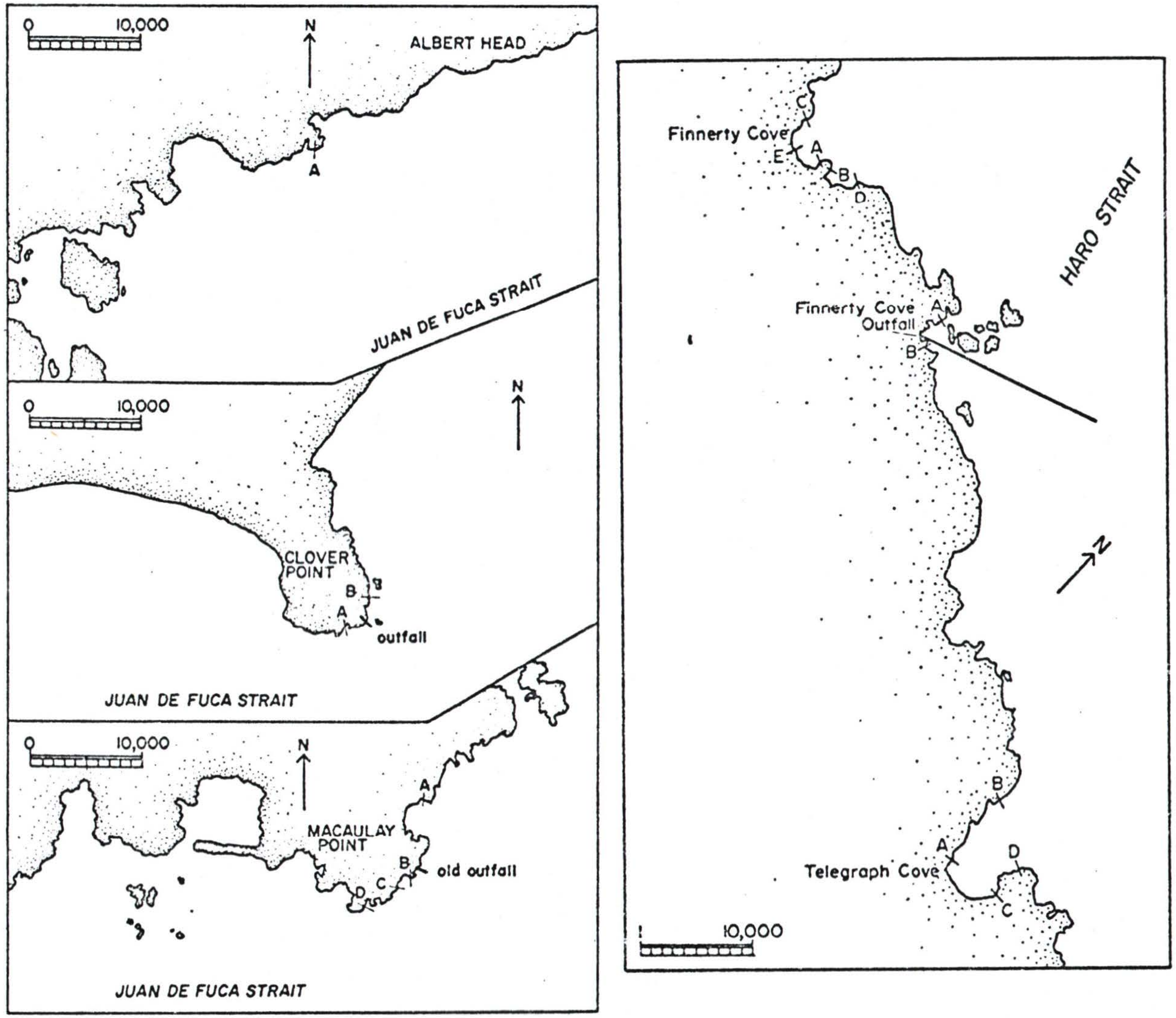

Figure 3.2. Detailed location of transects at Albert Head, Clover Point, Macaulay Point, Finnerty Cove, the landward base of the Finnerty Cove Outfall and Telegraph Cove.

Table 3.4. List of species.

Species	Transects																	
	Macaulay Point				Albert Head	Clover Point		Finnerty Cove					Finnerty Cove Outfall		Telegraph Cove			
	A	B	C	D	A	A	B	A	B	C	D	E	A	B	A	B	C	D
A. Chrysophyta																		
Navicula grevillei (Cleve) C. Agardh	+	-	+	-	+	-	-	-	+	+	+	+	+	+	+	-	+	+
B. Chlorophyta																		
Kornmannia zostericola (Tilden) Bliding	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Enteromorpha intestinalis (L.) Link	-	-	-	-	+	-	-	+	-	-	-	-	+	-	+	-	-	-
Enteromorpha linza (L.) J. Agardh	-	-	-	+	+	-	+	+	+	+	-	+	-	+	-	-	+	+
Enteromorpha tubulosa Kützing	-	-	+	-	+	-	+	-	+	+	-	-	+	+	+	-	-	-
Ulva spp. Thuret[*1]	-	-	-	-	+	+	+	-	+	-	+	+	+	-	-	+	+	+
Ulva expansa (Setchell) Setchell & Gardner	-	-	-	-	-	-	-	+	+	+	-	+	-	+	-	-	+	-
Ulva lactuca L.	+	-	-	-	-	-	+	+	-	+	+	+	+	+	+	-	+	+
Cladophora seriacea (Hudson) Kützing	-	-	-	-	-	+	+	-	-	+	+	-	-	+	+	+	+	+
Cladophora trichotoma (C. Agardh)	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Cladophora microcladioides Collins	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Spongomorpha spp. Kützing[*2]	-	+	-	+	+	+	+	+	-	-	-	+	+	-	-	-	-	+
Rhizoclonium riparium (Roth) Harvey	-	-	-	-	-	+	-	-	-	-	-	-	-	+	+	-	-	-
C. Phaeophyta																		
Leathesia difformis (L.) Areschoug	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Analipus japonicus (Harvey) Wynne	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-
Desmarestia viridis (Müller) Lamouroux	-	-	-	-	-	-	-	+	-	+	+	+	+	-	+	+	-	-
Desmarestia aculeata (L.) Lamouroux	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-	+	-
Desmarestia ligulata var. *liguluta* (Light.) Lamouroux	-	-	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-
Soranthera ulvoidea f. *ulvoidea* Postels & Ruprecht	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-
Colpomenia bullosus (Saunders) Yamada	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-
Laminaria groenlandica Rosenvinge	-	-	-	-	+	+	-	-	-	+	-	-	-	-	-	-	-	-
Laminaria saccharina (L.) Lamouroux	-	-	-	-	+	-	-	-	-	+	-	+	-	+	-	-	-	-
Laminaria farlowii Setchell	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Pleurophycus gardneri Setchell & Gardner	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Cymathere triplicata (Postels & Ruprecht) J. Agardh	-	-	-	-	+	-	+	-	+	-	-	+	-	+	-	+	-	-

Costaria costata (Turner) Saunders	- - - -	+	- +	- - - + +	- -	+ + - -
Hedophyllum sessile (C. Agardh) Setchell	- - + -	-	- +	- - - - -	+ +	- - - -
Nereocystis luetkeana (Mertens) Postels & Ruprecht	- - + -	+	+ -	- + - - -	+ +	+ + + -
Alaria marginata Postels & Ruprecht	- - - -	-	+ +	- - - - -	- -	- - - -
Alaria tenuifolia Setchell <u>in</u> Collins, Holden and Setchell	+ - - -	+	- -	- - - - -	+ +	- + - +
Egregia menziesii (Turner) Areschoug	- - - -	-	+ +	- - - - -	- -	- - - -
Fucus distichus L.	+ + + +	+	+ +	+ + + + +	+ +	+ + + +
Sargassum muticum Yendo	- - - -	-	- -	+ - - + -	- -	- - - -

D. Rhodophyta

Bangia fuscopurpurea (Dillwyn) Lyngbye	- - - -	-	- -	+ - - - -	- -	- - + -
Porphyra spp. C. Agardh*3	+ + + +	+	+ +	- + + + -	+ +	+ - + +
Smithora naiadum Anderson	- - - -	+	- -	- - - - -	- -	- - - -
Bonnemaisonia nootkana (Esper) Silva	- - - -	-	- -	- - - - -	- -	- - + -
Cryptosiphonia woodii J. Agardh	- - - -	-	- +	- + + + -	+ +	+ + - +
Farlowia mollis (Harvey & Bailey) Farlow & Setchell	- - - -	-	- -	- - - - -	- -	+ + - -
Constantinea subulifera Setchell	- - - -	-	- -	+ - + + -	- -	- - - -
Bossiella plumosa (Manza) Silva	- - + -	+	+ -	- + + - -	+ +	- - - -
Corallina vancouveriensis Yendo	- + - +	+	+ +	+ - - - -	- -	+ + - -
Calliarthron regenerans Manza	- - - -	+	- -	- - - - -	- -	- - + -
Endocladia muricata (Harvey) J. Agardh	+ + + -	+	+ +	+ + + + -	+ -	+ + - +
Gloiopeltis furcata (Postels & Ruprecht) J. Agardh	- - - -	-	- -	+ - + - -	- -	- - - -
Halymenia schizymenioides Hollenberg & Abbott	- - - -	-	- -	- - - - -	- +	- - - -
Prionitis lanceolata Harvey	- - - -	-	+ -	- - - - +	+ +	- + - +
Prionitis lyallii Harvey	- - - -	+	- -	+ - - - -	+ -	- + - -
Callophyllis flabellulata (Postels & Ruprecht)	- - - -	-	- -	- - - + -	- -	- - - -
Plocamium coccineum var. *pacificum* (Kylin) Dawson	- - - -	-	- -	+ + + + -	+ -	- - - -
Gracilariopsis sjoestedtii Kylin Fawson	- - - -	-	- -	- - + - -	- -	- - - -
Gymnogongrus leptophyllus J. Agardh	- - - -	-	- -	- - - + -	- -	- - - -
Gigartina corymbifera (Kützing) J. Agardh	- - - -	-	- -	+ + - + -	- -	- - - -
Gigartina exasperata Harvey & Bailey	- - - -	-	- -	+ + + + -	- +	+ - - +
Gigartina mamillosa (Goodenough & Woodward) J. Agardh	- - + +	-	+ +	+ + + + +	+ +	+ - + +
Rhodoglossum affine (Harvey) Kylin	- + - -	+	- -	+ + + + +	+ +	+ - + +
Rhodoglossum roseum (Kylin) Smith	- - - -	-	- -	- - - - +	- -	- - - -
Iridea cordata var. *splendens* (Setchell & Gardner) Abbott	+ - - -	-	+ +	+ - + + +	+ +	+ - - +
Iridea heterocarpa Postels & Ruprecht	+ - - -	+	- -	- + + + +	- +	+ - + +
Fauchea fryeana Setchell	- - - -	-	- +	- - - - -	- -	- - - -
Halosaccion glandiforme (Gmelin) Ruprecht	- - - -	-	- -	- + - - -	+ +	+ - - +
Rhodymenia palmata f. *palmata* (L.) Greville	- - - -	-	- -	+ - + - +	- -	- - - -
Rhodymenia pertusa (Postels & Ruprecht) J. Agardh	- - - -	-	- -	+ - + + -	- -	- - - -
Scagelia occidentale (Kylin) Wollaston	- - - -	-	- -	- - + - -	- -	- - - -
Callithamnion pikeanum Harvey	- - - -	-	- -	- - - - -	- +	- - - -

Ceramium californicum J. Agardh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Microcladia borealis Ruprecht	-	+	-	+	+	+	+	+	+	+	+	-	+	+	+	+	-	+
Microcladia coulteri Harvey	-	-	-	-	-	-	-	-	-	+	-	+	-	-	-	+	-	-
Polyneura latissima (Harvey) Kylin	-	-	-	-	-	-	-	+	+	-	+	+	-	-	-	-	-	-
Hymenena flabelligera (J. Agardh) Kylin	-	-	-	-	+	+	-	-	-	-	+	-	-	-	-	-	-	-
Polysiphonia hendryii var. *deliquescens* (Hollenberg) Hollenberg	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Polysiphonia hendryii var. *gardneri* (Kylin) Hollenberg	-	-	+	+	-	-	-	-	-	+	+	-	+	+	+	-	-	+
Polysiphonia hendryii var. *luxuriens* (Hollenberg) Hollenberg	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Pterosiphonia bipinnata f. *bipinnata* (Postels & Ruprecht) Falkenberg	-	-	+	-	+	+	-	-	-	+	-	-	+	-	+	+	-	+
Pterosiphinia dendroidea (Montagne) Falkenberg	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Rhodomela larix (Turner C. Agardh)	-	-	-	+	+	+	+	+	+	-	-	-	-	-	+	+	-	+
Odonthalia floccosa (Esper) Falkenberg	-	-	+	-	+	+	+	+	+	+	+	+	-	+	+	-	+	-
Odonthalia washingtoniensis Setchell & Gardner	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
E. Spermatophyta																		
Phyllospadix scouleri Hooker	+	-	+	-	+	+	+	+	+	-	-	-	+	-	-	-	-	-
Transect Totals	9	7	13	10	34	23	25	32	26	31	28	22	29	30	27	20	16	22
Area Totals	24				34	32		58					40		42			

Total Number of Taxa = 78

Notes

* Species present in this transect.

- Species absent from this transect.

* Identified only to generic level.

[1] Probably includes *Ulva rigida* C. Agardh, as well as unidentified specimens of *U. lactuca* L.

[2] Probably includes *Spongomorpha coalita* (Ruprecht) Collins and *S. mertensii* (Ruprecht) Setchell & Gardner.

[3] Probably includes several varieties of *Porphyra perforata* J. Agardh, but may include other species as well.

The capital letters A B C D and E refer to the transects in each sampling area.

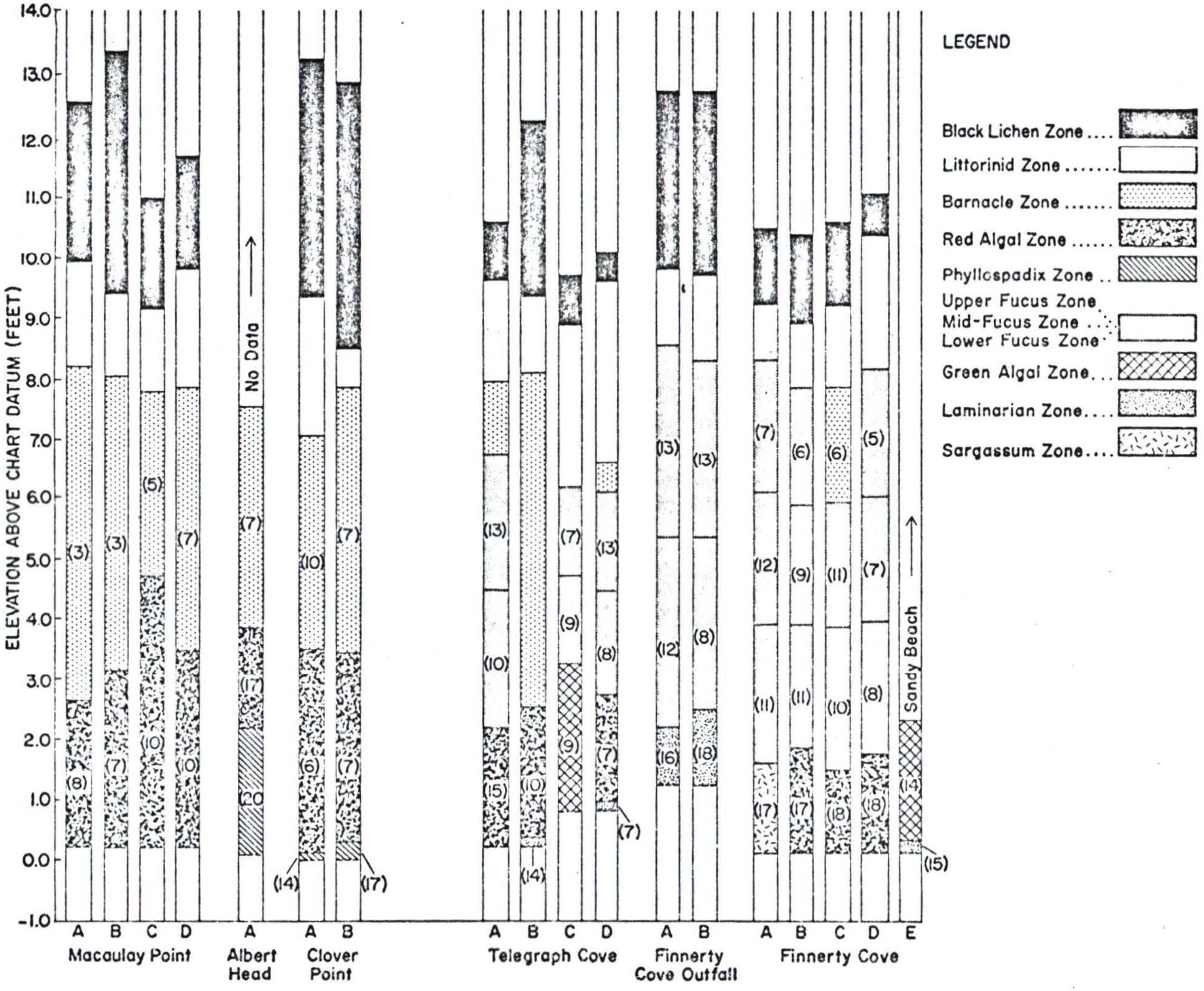

Figure 3.3. Pattern of intertidal zonation, elevation of biotic zones and number of macroalgal species collected in each zone at Macaulay Point, Albert Head, Clover Point, Telegraph Cove, Finnerty Cove Outfall and Finnerty Cove.

to moderately exposed (Lewis, 1964). On the Greater Victoria coastline it is evident that west of Gonzales Point (see Figure 3.1) shorelines have a predominantly southern aspect, whereas north of Cadboro Point, shorelines have a predominantly eastern aspect. Those areas with a southern aspect are more exposed to wave action generated by the strongest prevailing winds (westerlies) than are areas having an eastern aspect (Table 2.4). The data in Table 3.3 indicate that in those areas having a southern aspect (Albert Head, Macaulay Point and Clover Point), barnacles are the dominant eulittoral organism, while in areas having aspects other than southern (Finnerty Cove, Finnerty Cove Outfall and Telegraph Cove), *Fucus distichus* is the dominant eulittoral organism. Because of this important biotic difference between areas, which is unrelated to the discharge of sewage effluent, the presentation of results and interpretations will be divided into two sections based on the degree of exposure of the various areas.

1. Exposed Coast Transects (Macaulay Point, Albert Head and Clover Point)

Collections from four transects at Macaulay Point yielded a total of 24 taxa (9-12 taxa per transect), while two transects at Clover Point yielded 32 taxa (23-26 taxa per transect) and one transect at Albert Head yielded 34 taxa. The extent of species differences between Albert Head and the two test areas apply throughout the Chlorophyta, Phaeophyta and Rhodophyta.

Of a total of 14 species recorded at Albert Head but absent from the Macaulay Point transects, 11 were forms characteristic of the lower intertidal and upper subtidal regions (Table 3.5). All 3 species present at Macaulay Point but absent from the Albert Head transect were characteristically mid- to upper-intertidal forms. It would therefore appear that it was the absence of many lower intertidal and upper subtidal algae, particularly the large Phaeophytes, which was largely responsible for the reduction in diversity at Macaulay Point. The absence of a prominent *Phyllospadix* zone at this site was also notable. While *Phyllospadix scouleri* was present at Macaulay Point, it occurred only in scattered clumps near the zero tide level.

Of 12 species present at Albert Head but absent from the Clover Point transects, 10 were characteristic of the lower intertidal and upper subtidal regions. On a similar scale, of 12 species collected at Clover Point but absent from the Albert Head transect, 8 were characteristically lower intertidal and upper subtidal in their distribution. It would appear therefore that the differences in the diversity of the lower intertidal floras between these two areas was more a random effect than one related to environment disturbance. Many of the macro-Phaeophytes missing intertidally at Macaualy Point were present in the *Phyllospadix* zone at Clover Point. This zone, in contrast to the situation at Macaulay Point, was conspicuous and horizontally continuous at about the +0.2 foot tide level at Clover Point. The majority of the macro-Phaeophytes collected at Albert Head also occurred in the *Phyllospadix* zone, but specimens of *Laminaria saccharina* and *Costaria costata* appeared in the red algal zone as well. The major difference between the intertidal algal communities at

Table 3.5. List of species in the barnacle (B), red algal (R) and *Phyllospadix* (P) zones at Macaulay Point, Albert Head and Clover Point, with comments on vertical distributions.

Species	Macaulay Point		Albert Head			Clover Point			Comments on species vertical distribution[1]
	B	R	B	R	P	B	R	P	
Navicula grevillei	-	+	-	+	+	-	-	-	Lower intertidal, upper subtidal[2]
Enteromorpha intestinalis	-	-	+	-	-	-	-	-	Mid-intertidal
Enteromorpha linza	-	+	+	+	+	-	+	-	Lower intertidal
Enteromorpha tubulosa	-	-	-	+	-	+	-	-	Lower intertidal
Ulva sp.	-	-	-	+	+	+	+	-	Intertidal
Ulva lactuca	-	+	-	-	-	-	-	+	Upper intertidal
Cladophora seriacea	-	-	-	-	-	-	+	+	Lower intertidal
Cladophora microcladioides	-	-	-	-	+	-	-	-	Lower intertidal, upper subtidal
Spongomorpha sp.	-	+	-	+	+	-	+	+	Mid to lower intertidal
Rhizoclonium riparium	-	-	-	-	-	+	-	-	Mid to upper intertidal[3]
Desmarestia aculeata	-	-	-	-	+	-	-	-	Upper subtidal
Desmarestia ligulata var. *ligulata*	-	+	-	-	+	-	-	+	Lower intertidal, upper subtidal, to 10 fathoms
Laminaria groenlandica	-	-	-	-	+	-	-	+	Upper subtidal
Laminaria saccharina	-	-	-	+	-	-	-	-	Lower intertidal, upper subtidal
Pleurophycus gardneri	-	-	-	-	-	-	-	+	Lower intertidal, upper subtidal
Cymathere triplicata	-	-	-	-	+	-	-	+	Upper subtidal
Costaria costata	-	-	-	+	+	-	-	+	Lower intertidal, upper subtidal
Hedophyllum sessile	-	+	-	-	-	-	-	+	Mid to lower intertidal, upper subtidal
Nereocystis luetkeana	-	+	-	-	+	-	-	+	Upper subtidal
Alaria marginata	-	-	-	-	-	-	-	+	Lower intertidal, upper subtidal, exposed area
Alaria tenuifolia	-	+	-	-	+	-	-	-	Lower intertidal, upper subtidal, moderately exposed to sheltered areas
Egregia menziesii	-	-	-	-	-	-	-	+	Lower intertidal, upper subtidal in fairly exposed areas
Fucus sp.	+	+	-	+	-	+	+	-	Upper and mid intertidal
Porphyra sp.	+	+	+	+	-	+	+	-	Upper and mid intertidal
Smithora naiadum	-	-	-	-	+	-	-	-	Epiphytic on *Phyllospadix*; lower intertidal, upper subtidal
Crytosiphonia woodii	-	-	-	-	-	-	+	-	Intertidal
Bossiella plumosa	-	+	-	+	+	-	+	+	Lower intertidal, upper subtidal
Corallina vancouveriensis	+	+	+	-	+	+	+	+	Lower intertidal, upper subtidal and tide pools

Calliarthron regenerans	- -	- + -	- - -	In tide pools and subtidal
Endocladia muricata	+ -	+ - -	+ - -	Upper intertidal
Prionitis lanceolata	- -	- - -	- - +	Lower intertidal, upper subtidal
Prionitis lyallii	- -	+ - -	- - -	In Tide pools
Gigartina mamillosa	+ +	- - -	+ - -	Intertidal
Rhodoglossum affine	- +	- + -	- - -	Lower intertidal
Iridea cordata var. *splendens*	- +	- - -	- - +	Lower intertidal, upper subtidal
Iridea heterocarpa	- +	- + -	- - -	Lower intertidal
Fauchea fryeana	- -	- - -	- - +	Subtidal
Microcladia borealis	+ +	- + +	+ + +	Upper intertidal
Hymenena flabelligera	- -	- + -	- - +	Upper subtidal
Polysiphonia hendryii var. *deliquescens*	- -	- - +	- - -	Intertidal
Polysiphonia hendryii var. *gardneri*	+ +	- - -	- - -	Mid intertidal
Polysiphonia hendryii var. *luxuriens*	- -	- + -	- - -	Mid intertidal
Pterosiphinia bipinnata f. *bipinnata*	- +	- + -	+ + +	Intertidal, upper subtidal
Rhodomela larix	+ +	+ - -	+ - -	Intertidal
Odonthalia floccosa	- +	- - +	- + +	Intertidal
Odonthalia washingtoniensis	- -	- - +	- - -	Intertidal
Phyllospadix scouleri	- +	- - +	- - +	Lower intertidal, upper subtidal

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[1] Scagel, 1957; [2] Druehl, 1967; [3] Scagel, 1967.

Albert Head and Clover Point was the marked depression of the *Phyllospadix* zone and the lower upper limits of the associated macro-Phaeophytes at Clover Point. A more subtle difference, and one more difficult to interpret, was the presence of relatively fewer species in the red algal zone at Clover Point (6-7 taxa) compared to Albert Head (17 taxa) even though this zone was vertically more extensive at Clover Point.

It appears therefore that the location of both shoreline outfalls coincides with intertidal areas exhibiting observable biological alterations from the norm (as determined at Albert Head), the degree of alteration being more noticeable and extensive at Macaulay Point than at Clover Point.

2. Sheltered Coast Transects (Finnerty Cove, Finnerty Cove Outfall and Telegraph Cove)

Collections from five transects at Finnerty Cove yielded a total of 58 taxa (24-32 taxa per transect), while four transects at Telegraph Cove yielded 42 taxa (16-27 per transect) and two transects adjacent to the landward base of the Finnerty Cove Outfall yielded 40 taxa (29-30 taxa per transect). When considered singly, each of the test transects contained as many or more taxa than each of the twelve control transects.

Some variation in the pattern of zonation was evident between transects (Figure 3.3). Telegraph Cove transects A, B and D and Finnerty Cove transect C exhibited definite barnacle zones. At Telegraph Cove transect B there was no fucoid zone, indicating a greater degree of exposure to wave action at this site. Telegraph Cove transect C and Finnerty Cove transect E both exhibited green algal zones in the lower intertidal area; both of these transects have shallow slopes and both had low species diversity. The presence of a Laminarian zone at both Finnerty Cove Outfall transects was due to the abundance of *Hedophyllum sessile* and *Alaria tenuifolia* at these sites. The presence of *A. tenuifolia*, with the absence of a distinct barnacle zone, is indicative of the action of onshore or close inshore tidal currents unaccompanied by wave action (Widdowson, 1971a).

In transects where the fucoid zone was vertically extensive it was subjectively divided into upper, middle and lower zones (Finnerty Cove transects A, B and D); where it was less extensive it was divided into upper and lower zones (Finnerty Cove transect C, Telegraph Cove Transects A, C and D and Finnerty Cove Outfall transects A and B). The purpose of this division was mainly to expedite the sampling procedure, but it also provides a better understanding of the distribution of the mid-intertidal algae.

It is of interest to note the presence of a *Sargassum* zone in the lower intertidal region at Finnerty Cove transect A. *Sargassum muticum* Yendo was transplanted by accident into the Nanaimo area with Japanese oyster spat early this century and has since become well established in the sheltered low intertidal and shallow subtidal waters throughout the Strait of Georgia and eastern Juan de Fuca Strait (Druehl, 1973).

It is felt that the differences in the pattern of zonation noted above are due to slight differences in aspect and slope and are not related to the discharge of sewage effluent from the Finnerty Cove Outfall. The differences in the number of species between the three sheltered coast areas appear to be related more to the sample size than to any obvious biological differences.

D. DISCUSSION

Water quality and environmental data presented in Part II provide the supportive basis for the following discussion which will (1) attempt to relate the observed alterations of the structure and vertical distribution of the intertidal algal communities adjacent to the Macaualy Point and Clover Point shoreline outfalls to changes in the physicochemical nature of the receiving waters at these sites, as well as (2) attempt to illustrate the reasons for the lack of influence of the Finnerty Cove Outfall on the adjacent shore communities.

On the basis of over two years of routine water quality sampling, Balch *et al.* (1972) have determined that the following eight parameters were sufficiently and so consistently influenced by the discharge of sewage effluent from shoreline outfalls to warrant their designation as "gross sewage field indicators"; these are: nitrite, phosphate, total coliforms, fecal coliforms, Secchi depth, Forel colour, salinity and temperature. Of these, only temperature, salinity, Secchi depth and Forel colour might possibly be related to the observed alterations in the intertidal algal communities at Macaulay Point and Clover Point. High nutrient concentrations at these sites would be expected to compliment algal productivity at all levels on the shore. It is considered unlikely that coliform bacteria have any significant influence on marine macroalgae, although several bacterial strains of high densities have been shown to inhibit the growth of unicellular algae (Berland, Bonin and Maestrini, 1972).

Surface temperatures were slightly elevated at Macaulay Point, but not at Clover Point, in the first half of 1971 (Figure 2.6). Surface salinities at both sites were reduced relative to the other shoreline stations, but to a lesser degree, and less consistently, at Clover Point (Figure 2.7). Turbidity at both sites was constantly and markedly increased (Figure 2.12). The Secchi depth provides a rough indication of the quantity of light penetration by estimating the rate of light extinction (Strickland, 1958). Secchi depth readings of less than one meter were common at Macaulay Point and Clover Point, particularly during the spring and summer months at which time light is critical for the seasonal growth maxima of marine algae. The Forel colour scale readings at Macaulay Point and Clover Point were consistently higher (brown) than at the other shoreline stations (Figure 2.13), giving an indication that the quality of light penentrating the surface layer at these two sites was altered by the presence of sewage effluent.

The differences in surface temperatures and salinities between Macaulay Point and Clover Point can be explained on the bases of: (1) the volume of discharge at Macaulay Point being double that at Clover Point (Table 3.6), and (2) the exposure of Clover Point to turbulent tidal currents of higher velocity than those off Macaulay Point (page 29). The more rapid mixing of effluent with the receiving waters

Table 3.6. Average and peak flows (cfs) from the Macaulay Point, Clover Point and Finnerty Cove Outfalls in 1972.

	Macaulay Point[1]	Clover Point[1]	Finnerty Cove[2]
Average cfs	18.7	8.5	2.4
Peak cfs	25.0	13.4	9.6

[1] Technical Discussion on the Victoria and Oak Bay, South Coast Sewage Study, May, 1972.

[2] Finnerty Cove Sewer Outfall Study, 1971.

at Clover Point thereby maintains the temperature and salinity at near background levels. The similarity of the Secchi depth and Forel colour scale readings may simply be related to the insensitivity of the methods.

That salinity and temperature are factors controlling the vertical and horizontal distributions of marine algae is well known and the subject of a number of review publications (Hedgepeth, 1957; Gessner, 1970; and Gessner and Schramm, 1971, for example). Druehl (1967a) and Jorde and Klavestad (1963) have shown that under estuarine surface conditions of reduced salinity and increased temperature, there is a depression of the upper limits of certain marine algae. In a study of the benthic biota in Biscayne Bay, Florida, McNulty (1961) has shown that the addition of sewage effluent to the marine environment resulted in a zonation of macro-organisms, including marine algae and phanerogams, related to the distance from the pollution source. The following three major zones were recognized: a zone of no life or relatively scarce life immediately adjacent to outfalls, a zone of abundant life in which a few species are found in greater than normal abundance outward from the zone of no life, and a zone of normal abundance of many species characterizing clean, unpolluted areas. This zonation follows the pattern classically reported in polluted freshwater systems (Hynes, 1960, for example).

The water quality parameters and literature discussed above suggest that the reduced species diversity and the absence of a prominent *Phyllospadix* zone at Macaulay Point are related to the discharge of sewage effluent from the shoreline outfall at that site. The reduced salinity and increased temperature of the nearshore surface waters, together with the evident changes in the quantity and quality of available light energy, caused by the discharge of sewage effluent, are the likely causative factors related to the observed alterations in the structure and vertical distribution of the intertidal algal community at Macaulay Point. The somewhat less obvious alterations evident at Clover Point are in all likelihood related to the smaller volume of discharge and the more rapid rate of effluent dilution and dissemination at this site.

Sediment coliform bacteria are an indicator of the average range of an effluent field over time (Rittenberg, Mittwer and Ivler, 1958; and Bernard, 1970). Drinnan, Ellis and Littlepage (1971) have shown that the sediment coliform density decreases in a direction from the end of the Finnerty Cove Outfall toward the shoreline. Various water quality parameters monitored on several occasions at five shoreline stations between Finnerty Cove and Telegraph Cove (see Figure 2.13 for locations) failed to indicate the presence of sewage effluent onshore (Tables 2.5 and 2.6). Offshore sampling indicated that the sewage field was rapidly dispersed offshore by strong tidal currents in either a northwesterly or a southeasterly direction. As mentioned previously (page 28) the sewage field produced by the Finnerty Cove Outfall may appear onshore in diluted form on occasions coincident with slack water periods or weakly flooding tides, especially when these are complimented with onshore winds.

The floral similarities evident between Finnerty Cove, the landward base of the Finnerty Cove Outfall and Telegraph Cove, when supplemented by the water quality data discussed above, indicate that effluent from the Finnerty Cove Outfall has little, if any, effect on the structure and vertical distribution of the intertidal algal community along this section of the Greater Victoria coastline. That this is so is probably related to the small volume of discharge (Table 3.6) into an area with strong and turbulent tidal currents.

E. SUMMARY

The intertidal algal communities at a number of sites within the Greater Victoria area responded to the presence of sewage effluent to various degrees which could be related to the volume and means of discharge as well as the rate of sewage field dilution and dissemination. Thus the most obvious biological alterations were observed at Macaulay Point which discharged a large volume of effluent from a shoreline outfall into a receiving area subject to relatively reduced tidal currents. More subtle effects were observed at Clover Point where the discharge volume was less than half that at Macaulay Point and where the discharge from the shoreline outfall enters a receiving area subject to relatively rapid tidal currents. No detectable effects were observed near the Finnerty Cove Outfall which discharged a relatively small volume of effluent from an offshore, submarine outlet into an area subject to relatively rapid tidal currents.

Species characteristic of the lower intertidal and upper subtidal regions were the ones most sensitive to increased temperature and reduced salinity produced as a result of effluent discharge. This concurs with Scagel's (1963) conclusion that these species are the most sensitive floristic indicators of geographical temperature and salinity regimes.

PART IV. THE EFFECT OF SEWAGE EFFLUENT ON THE UPPER LIMIT ELEVATIONS OF THE *PHYLLOSPADIX* AND RED ALGAL ZONES

A. INTRODUCTION

Data reported in Part III (Figure 3.3) indicated a tendency for the upper limits of the lower intertidal subzones, particularly the *Phyllospadix* zone, and, to a lesser degree, the red algal zone, to be depressed on shores adjacent to shoreline-discharging sewage outfalls. This trend was further investigated in the spring of 1972 in order to determine if the zonal depressions noted were significant when weighed against the normal degree of variability due to such environmental factors as aspect and slope, in relation to wave exposure.

B. METHODS

Discrete measurements of the upper limits of the *Phyllospadix* and red algal zones at Clover Point, Macaulay Point and Albert Head were made during the low low tide periods in February, April and May, 1972.

The upper limit elevations of these zones were measured in an east, centre and west cluster of transects within each major area. Figure 4.1 indicates the location of the transects and clusters within each major area. The aspect and slope of the foreshore at each transect site are given in Table 4.1. The centre cluster in each major area was positioned around either a continually functioning

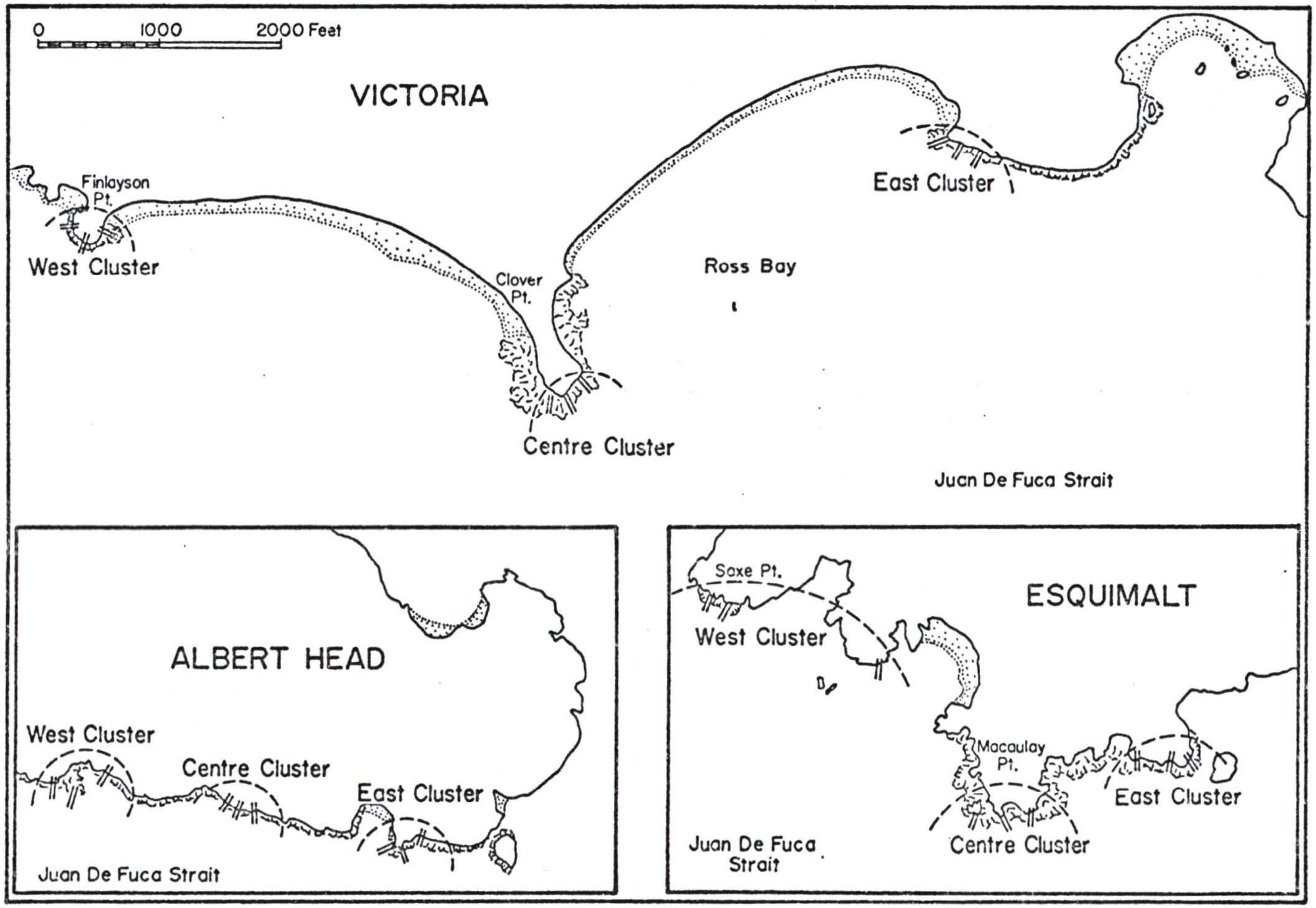

Figure 4.1. Location of transects within west, centre and east clusters at Albert Head, Macaulay Point and Clover Point.

Table 4.1. Slope and aspect at the transects in the west, centre and east cluster at Albert Head, Macaulay Point and Clover Point.

Area	Cluster	Transects	Slope	Aspect
Albert Head	West	1 & 2	Steep	S
		3 & 4	Steep	SSW
		5 & 6	Moderate	SSW
	Centre	1 & 2	Moderate	SSW
		3 & 4	Moderate	SSW
		5 & 6	Moderate	S
	East	1 & 2	Steep	WSW
		3 & 4	Steep	SSE
		5 & 6	Moderate	SSW
Macaulay Point	West	1 & 2	Steep	SSW
		3 & 4	Steep	SSW
		5 & 6	Steep	S
	Centre	1 & 2	Steep	SSW
		3 & 4	Moderate	SSE
		5 & 6	Steep	S
	East	1 & 2	Steep	S
		3 & 4	Steep	SSW
		5 & 6	Steep	SSE
Clover Point	West	1 & 2	Steep	WSW
		3 & 4	Steep	SSW
		5 & 6	Steep	ESE
	Centre	1 & 2	Steep	S
		3 & 4	Steep	SSE
		5 & 6	Moderate	SSE
	East	1 & 2	Steep	WSW
		3 & 4	Moderate	SW
		5 & 6	Moderate	SW

(Clover Point), intermittently functioning (Albert Head)[1] or non-functional (Macaulay Point) shoreline sewage outfall. Zonal upper limits were measured in three duplicated transects within each cluster. Duplicate transects were spaced one pace apart.

All measurements were made with a Sokkisha 11 inch dumpy level and a surveying rod graduated in .01 foot intervals. All primary levelling was based on Municipal or Department of National Defence benchmarks (Table 4.2). For convenience sake, secondary benchmarks were established close to each cluster centre (Table 4.3). All elevations are relative to Chart Datum.

C. RESULTS

The mean upper limit elevations (± two standard errors) of the *Phyllospadix* and red algal zones in the west, centre and east clusters at Albert Head, Macaulay Point and Clover Point are given in Figure 4.2. Each cluster mean is based on six measurements.

1. Statistical Analysis

The data were initially analyzed by Model I, 2 X 2 analyses of variance (ANOVA) with equal cell frequencies (Table 4.4). If significant differences were apparent in these main effects anovas, analyses of simple effects were performed to locate the sources of significance between major areas for each cluster, as well as between

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[1] A small, intertidally-discharging outfall on Albert Head services the barracks on the military reserve at this site. The outfall is used only during the summer training period and is expected to have a small discharge volume.

Table 4.2. Location and elevation of primary benchmarks.

Area	Cluster	Elevation primary benchmark (ft. above chart datum)	Primary benchmark established by	Location of primary benchmark
Macaulay Point	East, centre, part of West	30.26	Capitol Regional District	Base of southeast cement corner post of pistol range, approx. 100 ft. west of Macaulay Pt. Pumping Station.
	Rest of West	58.05	Esquimal Municipality	Rim of manhole in centre of intersection of Fraser and Bewdley.
Clover Point	Centre	26.97	City of Victoria	Rim of manhole on south tip of roadway, behind cement pumphouse.
	East	44.52	City of Victoria	Drill hole in sidewalk at junction of Ross and St. Charles.
		34.46	City of Victoria	Base plate of hydrant # 224, just east of junction of St. Charles and Dallas Rd.
	West	71.73	City of Victoria	Drill hole at northeast end of curb at junction of Dallas Rd. and Camas Circle.
Albert Head	All	27.18	Dept. National Defence	DND cement corner marker southwest corner of Albert Head Reserve; brass plug in upper surface with the inscription: Post 1, $180^{\circ}00''$, 1952, EL. 21.38 (assumed relative to Geodetic datum).

Table 4.3. Location and elevation of secondary benchmarks.

Area	Cluster	Elevation of secondary benchmark (ft. above chart datum)	Location of secondary benchmark
Macaulay Point	West	35.83	Dept. Public Works Benchmark #285 (1952), set in bedrock near top of Saxe Point.
		19.57	Paint sprayed on bedrock at top of Fleming Point.
	Centre	16.99	B.C. Legal Surveys Benchmark #247 (1963), set on bedrock above eastern most transect.
		11.57	Paint sprayed on bedrock above centre transect.
		12.18	Canadian Hydrographic Service Benchmark #25 (1948), set in bedrock above western most transect.
	East	10.24	Paint sprayed on bedrock above western most transect.
Clover Point	West	12.77	Paint sprayed on bedrock above centre transect.
	Centre	20.66	Rim of manhole on cement flooring immediately behind cement pumphouse.
	East	9.80	Paint sprayed on bedrock, on the highest point of the first rocky outcropping on the northeast corner of Ross Bay.
Albert Head	West	24.15	Paint sprayed on bedrock above western most transect.
	Centre	22.23	Paint sprayed on top of bedrock outcropping above centre transect.
	East	22.33	Paint sprayed on bedrock at the top of the point marking the southeast boundary of small embayment.

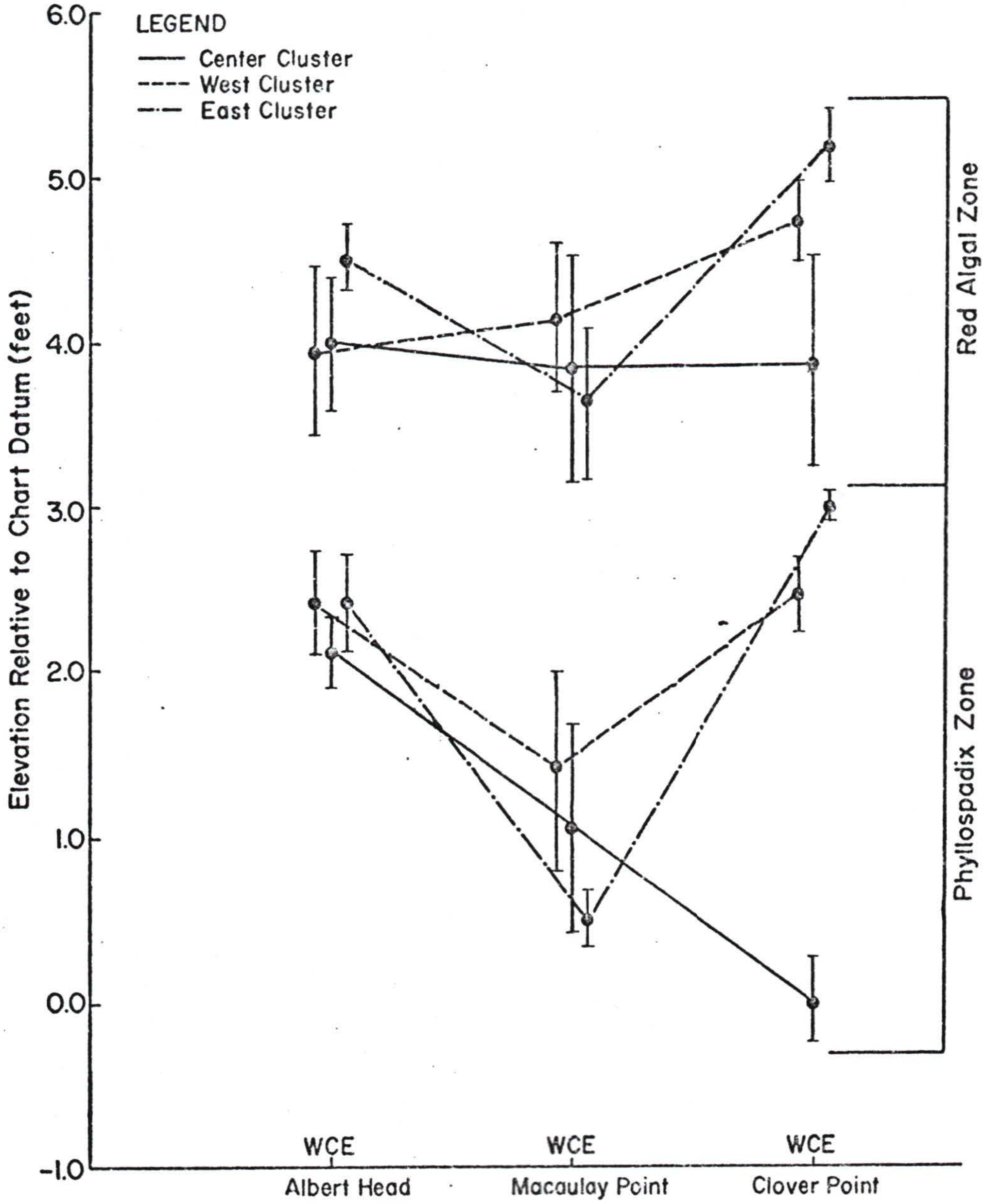


Figure 4.2. Mean upper limit elevation (± two standard errors) of the *Phyllospadix* and red algal zones in the west, centre and east clusters at Albert Head, Macaulay Point and Clover Point. Each mean is based on six measurements.

Table 4.4. ANOVA tables (main effects) for the *Phyllospadix* and Red Algal zone data.

1. *Phyllospadix* Zone

Source of Variation	SS	df	MS	F	P
A (areas)	16.247	2	8.124	41.629	0.001
C (clusters)	11.539	2	5.770	29.567	0.001
AC (interaction)	21.803	4	5.451	27.932	0.001
Error	8.781	45	0.195		

2. Red Algal Zone

Source of Variation	SS	df	MS	F	P
A (areas)	4.988	2	2.494	7.935	0.001
C (clusters)	2.709	2	1.354	4.309	0.019
AC (interaction)	4.635	4	1.159	3.686	0.011
Error	14.144	45	0.314		

clusters within each major area (Table 4.5). The data were then further analyzed using the Student-Newman-Keuls test (SNK), a multiple comparison among means analysis, to determine which cluster means were significantly different ($P < 0.05$) from which other means, or which groups of means are different from other such groups or from single means (Figure 4.3).

2. *Phyllospadix* Zone

Variation in the upper limit of the *Phyllospadix* zone between clusters at Albert Head was not significant. However highly significant variance between clusters was evident at both Macaulay Point ($P < 0.01$) and Clover Point ($P < 0.001$). There was highly significant variance between areas for all three clusters ($P < 0.001$) (Tables 4.4 and 4.5). Three distinct groups of cluster means were separated by the SNK test (Figure 4.3). The first group represented those clusters in which the mean upper limits of the *Phyllospadix* zone were lowest; it included the Clover Point centre (CPC) and Macaulay Point east (MPE) clusters. These means were significantly lower than those of the second group which included the Macaulay Point centre (MPC) and west (MPW) clusters. The third group included the Albert Head west (AHW), centre (AHC) and east (AHE) and the Clover Point west (CPW) and east (CPE) clusters, in which the mean upper limits of the *Phyllospadix* zone were significantly higher than those of the first and second groups. The interaction term in the main effects anova was highly significant ($P < 0.001$).

Table 4.5. ANOVA table (simple effects) for the *Phyllospadix* and Red Algal zone data.

1. *Phyllospadix* Zone

Source of Variation	SS	df	MS	F
B for a_1 (areas for west)	3.952	2	1.976	10.133^{***}
B for a_2 (areas for centre)	13.043	2	6.522	33.446^{***}
B for a_3 (areas for east)	20.649	2	10.325	52.949^{***}
A for b_1 (clusters for AH)	0.368	2	0.184	0.944^{ns}
A for b_2 (clusters for MP)	2.730	2	1.365	7.000^{**}
A for b_3 (cluster for CP)	30.505	2	15.253	78.221^{***}
Error	8.781	45	0.195	

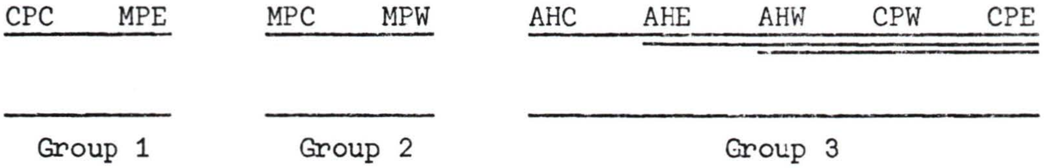
$F_{.05\ (2,45)} = 3.20$ $F_{.01\ (2,45)} = 5.11$ $F_{.001\ (2,45)} = 8.087$

2. Red Algal Zone

Source of Variation	SS	df	MS	F
B for a_1 (areas for west)	5.43	2	2.715	8.646^{***}
B for a_2 (areas for centre)	0.07	2	0.035	0.112^{ns}
B for a_3 (areas for east)	4.11	2	2.055	6.545^{**}
A for b_1 (clusters for AH)	1.19	2	0.595	1.895^{ns}
A for b_2 (clusters for MP)	0.78	2	0.390	1.242^{ns}
A for b_3 (clusters for CP)	5.36	2	2.680	8.535^{***}
Error	14.144	45	0.314	

$F_{.05\ (2,45)} = 3.20$ $F_{.01\ (2,45)} = 5.11$ $F_{.001\ (2,45)} = 8.087$

1. *Phyllospadix* Zone



2. Red Algal Zone

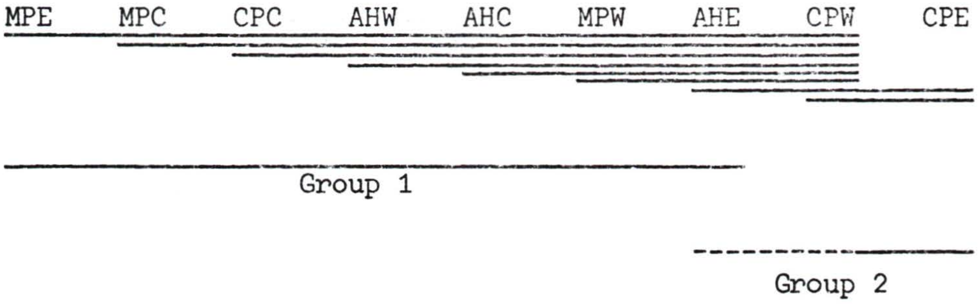


Figure 4.3. Array of cluster means as determined by the SNK Test for the *Phyllospadix* and Red Algal Zones.

3. Red Algal Zone

There was no significant variation in the upper limits of the red algal zone between clusters at either Albert Head or Macaulay Point. Highly significant variance was evident between clusters at Clover Point ($P<0.001$) as well as between areas for the west ($P<0.001$) and east ($P<0.01$) clusters; center clusters were not significantly different (Tables 4.4 and 4.5). The SNK test (Figure 4.3) defined no distinct groups of clusters. A large number of clusters with low and intermediate mean upper limits were not significantly different ($P<0.05$). These include, in order of increasingly higher mean upper limits, the MPE, MPC, CPC, AHW, AHC, MPW and AHE clusters. Of these only the MPE cluster was significantly lower than the CPW cluster. The mean upper limits of the red algal zone in the AHE and CPW clusters were not significantly lower than that at the CPE cluster. The interaction term in the main effects anova was highly significant ($P<0.011$).

D. DISCUSSION

Among the many factors influencing intertidal zonation, the major factor capable of raising the effective wetting level of the tide is wave action (Lewis, 1964). The degree of exposure to wave action in a given locality depends on its aspect relative to the prevailing winds, the uninterrupted distance, or fetch, over which the wind can blow across water and the topography (slope and texture) of the shoreline. One of the major influences on intertidal zonation affected by wave action is the upward displacement of zones, without breaking the stratification (Lewis, 1964 and Gurjanova, 1968).

Albert Head, Macaulay Point and Clover Point all have predominantly southern aspects (Figure 4.1 and Table 4.1), but the geographical location of Clover Point is such that it will receive more wave action than the other two areas (page 32). Albert Head, the southermost tip of Macaulay Point proper and Clover Point should be similarly influenced by waves generated from the southeast. However the Saxe Point area (MPW) may be shielded by the tip of Macaulay Point from waves generated from this direction. The shoreline east of Macaulay Point proper (MPE) may be shielded to some degree from waves generated from the southeast by the Ogden Point Breakwater and Harrison Island. Albert Head is slightly less exposed to wave action generated from the south since it has a shorter southern fetch than either Macaulay Point or Clover Point. The strongest prevailing winds in the Greater Victoria area are from the southwest and west. The wave action generated by these winds will be much heavier at Clover Point than at Macaulay Point and Albert Head which have relatively reduced fetches in these directions.

A gradient of increasing tidal amplitude from west to east in the Greater Victoria area may be expected to slightly raise the upper limits of the algal, subzones at Macaulay Point and Clover Point relative to Albert Head (page 22).

1. *Phyllospadix* Zone

The statistical analysis indicated that the upper limit of the *Phyllospadix* zone at Albert Head was relatively constant and significantly higher that at Macaulay Point and at the tip of Clover Point (CPC).

The highest upper limits observed occurred in the Clover Point east and west clusters but these were not significantly higher than the upper limits observed at the three Albert Head clusters. If the range of upper limits observed at these five locations is considered as representative of the normal degree of variability along the Greater Victoria south coast due to minor differences in aspect and slope, then the relative depression of the *Phyllospadix* zone observed at the three Macaulay Point cluster sites and at the tip of Clover Point may be considered as either: (1) indicative of a more sheltered condition, or (2) possibly representative of the influence of sewage effluent, either in the recent past (Macaulay Point), or on a continuing basis (Clover Point).

The significant variance among the Macaulay Point clusters was due to the depression in the east cluster. As mentioned above, the degree of wave exposure in this area is likely influenced by the Ogden Point Breakwater and its proximity to Harrison Island. The depression evident in the west cluster is also thought to be due to the more sheltered condition of that area. Widdowson (1965) has shown that the upper limit of *Phyllospadix scouleri* is increasingly depressed along a gradient of decreasing wave action. In 1971 there was no conspicuous and horizontally continuous *Phyllospadix* zone at the site of the Macaulay Point centre cluster. Those plants which were present were found in scattered clumps near the zero tide level. The presence of a conspicuous and horizontally continuous zone at the same site in 1972, with a mean upper limit at 1.06 ft. above zero tide, is indicative of the regeneration of the *Phyllospadix* population following the cessation of discharge of sewage effluent from the shoreline outfall.

The highly significant variance between the Clover Point clusters was due to the marked depression of the *Phyllospadix* zone at the centre cluster. The cause of this depression can best be ascribed to the continuing presence of high concentrations of sewage effluent at this site (see Figures 2.6 to 2.13 and the accompanying interpretations). It can not be based on the lack of wave action, as Clover Point proper is probably the single most exposed headland along the south coast of Victoria.

The significant variance between areas was due to the general depression of the *Phyllospadix* zone in the Macaulay Point area and by the marked depression at the Clover Point centre cluster (Figure 4.3). The highly significant interaction term in the main effects anova is attributed to the marked depression at the Clover Point centre cluster (Figure 4.3).

2. Red Algal Zone

There was no significant difference in the elevation of the upper limit of the red algal zones between clusters at Albert Head and Macaulay Point, as well as between the major areas of Albert Head and Macaulay Point. This is in keeping with the aforementioned similarity of the degree of wave action believed to be experienced by these areas.

Although the upper limit of the red algal zone at the Clover Point centre cluster was not significantly different in elevation from those at the Albert Head and Macaulay Point centre clusters, it was significantly lower than those at the Clover Point west and east clusters. Since it is expected that the three cluster sites within the Clover Point area experience very similar degrees of wave action, and, collectively, more than are experienced at Albert Head and Macaulay Point, the depression evident at the tip of Clover Point can be considered as a significant indication of the effect of the continuing discharge of sewage effluent at that site on the red algal populations which compose the red algal zone.

The significant variance observed between areas for the west and east clusters is related to the higher elevation of the red algal zone upper limits at the Clover Point west and east clusters relative to the Albert Head west and the Macaulay Point east cluster, respectively. The reason for the relative depression of the red algal zones at the latter two cluster sites is the reduced degree of wave action believed to be experienced in these areas, relative to the more wave exposed areas adjacent to Clover Point. The significant variance between areas for the west and east clusters is thought to be the cause of the significant interaction term in the main effects anova.

E. SUMMARY

The presence of an intermittently discharging outfall at Albert Head has had no significant affect on the elevation of the upper limit of the *Phyllospadix* zone in the nearby area. The depression of the *Phyllospadix* zone at the tip of Macaulay Point proper is likely related to the recent history of sewage pollution at that site. There is evidence that the *Phyllospadix* population in the area is in the process of recovering from the effects of this pollution. The relative depression of the *Phyllospadix* zone at the Macaulay Point west and east clusters is thought to be due to the reduced exposure to wave action in these areas. The significant depression of the *Phyllospadix* zone in the immediate vicinity of the Clover Point Outfall relative to Albert Head and the Clover Point west and east clusters can best be explained by the continuing discharge of sewage effluent at that site.

Albert Head has had no effect on the elevation of the upper limit of the red algal zone in the adjacent area. The elevation of the upper limit of the red algal zone within the Macaulay Point area was similarily homogeneous. That the upper limit elevations of red algal zones at Albert Head and Macaulay Point were not significantly different, is attributed to the similar degrees of exposure to wave action at these sites. The significant differences between areas for the west and east clusters can be attributed to the increased exposure to wave action at the Clover Point west and east clusters. The highly significant depression of the red algal zone at the tip of Clover Point, relative to the west and east cluster elevations, can best be ascribed to the continuing discharge of sewage effluent from the shoreline outfall at that site.

PART V. SEWAGE EFFLUENT AS A FACTOR DETERMINING THE DISTRIBUTION AND THE UPPER LIMIT ELEVATION OF SELECTED SPECIES OF THE MACRO-PHAEOPHYTA

A. INTRODUCTION

In the preliminary survey of the intertidal algal communities adjacent to the shoreline-discharging Macaulay Point and Clover Point outfalls it was noted that, at Macaulay Point, the diversity of the large brown algae was particularly low and that while the diversity of the macro-Phaeophyta at Clover Point was comparable to that at the Albert Head control site, the upper limits of these algae appeared to be markedly depressed. However, no discrete measurements of the upper limits of these algae were made at that time. An investigation into the effects of sewage effluent on the vertical distribution of selected species of macro-Phaeophyte algae was therefore initiated in the spring of 1972.

The cessation of discharge from the old Macaulay Point Outfall in August, 1971 facilitated this study in two ways. Firstly, an opportunity was made available to study the recovery of an algal community that had exhibited a marked negative response to the presence of sewage effluent in high concentrations. It was hypothesized that many of the macro-Phaeophyte species common to the Victoria area, but not represented in the intertidal algal community at Macaulay Point when the shoreline outfall was operational or, if so, only as scattered individuals, would appear intertidally in more sizeable populations.

Secondly, the upper limit elevations of the populations of selected macro-Phaeophytes at Macaulay Point would be regarded as control elevations with which those of the same species at Clover Point would be compared. The appearance of the selected species intertidally at Macaulay Point and at higher levels than those of the same species at Clover Point would provide correlative evidence linking the presence of sewage effluent to the depression of the upper limits of the macro-Phaeophyta noted in 1971.

B. METHODS

Twelve species of common, local macro-Phaeophyte algae whose normal vertical range is in whole or in part included in the intertidal zone, were selected as the test species for this study (Table 5.1).

Selective sampling to determine the number of test species present in three of the four original Macaulay Point transects (Figure 5.1) was accomplished on May 15, 1972. Collections were made to the same level (+0.2 ft.) sampled in May, 1971. On May 16, 1972 similar collections were made at the two original Clover Point transects (Figure 5.1). Collections at Clover Point were also made to the same level (+0.1 ft.) sampled in May, 1971. Voucher specimens from both localities will be deposited in the University of Victoria Phycological Herbarium.

Measurements to determine the upper limits of the test species present in the transects within each locality were made at the time of collection of voucher specimens, using the same methods and benchmark vertical control described in the methods section of Part IV. The measurements were repeated at both sites in July, 1972.

Table 5.1. List of the twelve selected macro-Phaeophyte species used to test the affect of sewage effluent on vertical distributions.

Laminaria saccharina (L.) Lamouroux

Laminaria groenlandica Rosenvinge

Costaria costata (Turner) Saunders

Cymathere triplicata (Postels and Ruprecht) J. Agardh

Alaria marginata Postels and Ruprecht

Alaria tenuifolia Setchell in Collins, Holden and Setchell

Hedophyllum sessile (C. Agardh) Setchell

Nereocystis luetkeana (Mertens) Postels and Ruprecht

Pleurophycus gardneri Setchell and Saunders, in Saunders

Egregia menziesii (Turner) Areschoug

Desmarestia aculeata (L.) Lamouroux

Desmarestia ligulata var. *ligulata* (Lightfoot) Lamouroux

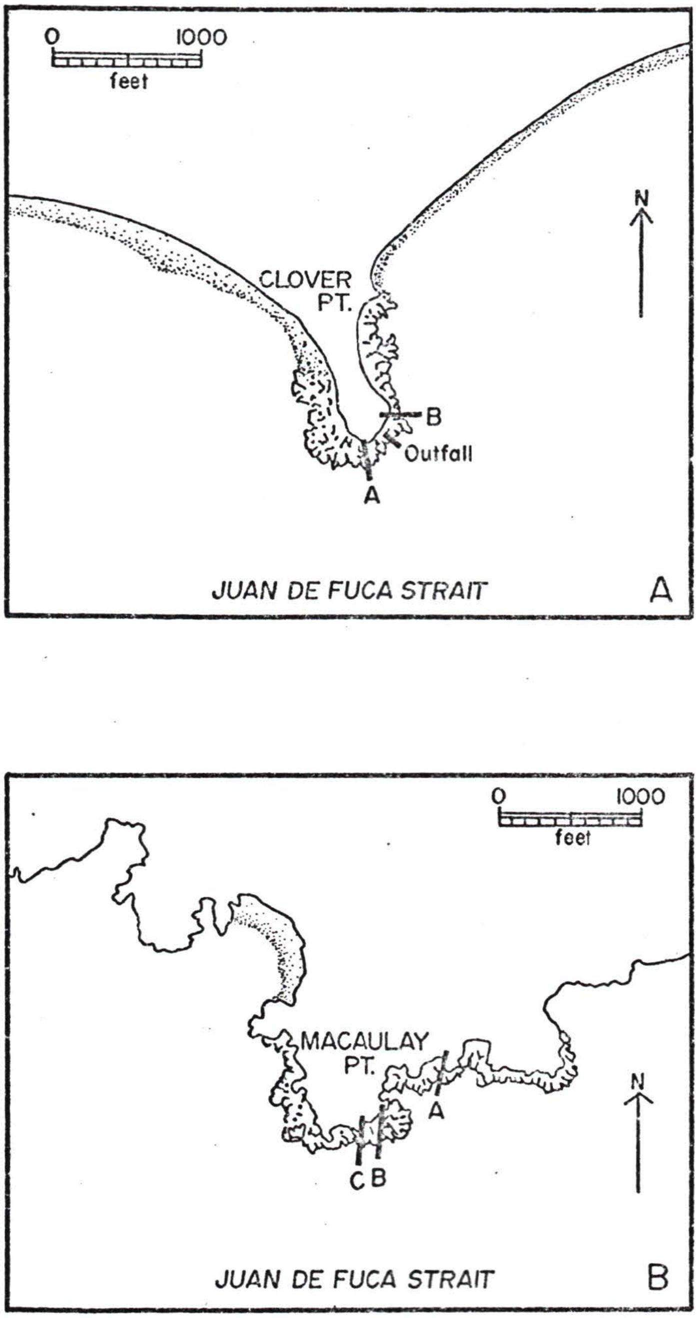


Figure 5.1. Location of transects at Macaulay Point and Clover Point at which collections and measurements of the upper limits of selected species of macro-Phaeophyte algae were made.

C. RESULTS

1. The Increase in Diversity of the Macro-Phaeophyta at Macaulay Point in 1972

The data listed in Table 5.2 document the presence or absence of the twelve test species at Macaulay Point and Clover Point in May, 1971 and gives the mean of two measurements (in most cases) of the upper limits of those species present at each of these sites in May and July, 1972. Qualitative collections made in May, 1971 indicated that only three of the twelve test species were present in the intertidal zone at Macaulay Point while nine of the test species were present at Clover Point. By mid-May, 1972 six more of the test species had established intertidal populations at Macaulay Point; the original three species populations were maintained. Except for the loss of *Costaria costata*, the species present intertidally at Clover Point in May, 1971 were maintained into 1972. *Laminaria saccharina* was not found at either site in 1971 or 1972.

2. Comparison of the Upper Limit Elevations of the Test Species at Macaulay Point and Clover Point

The data given in Figure 5.2 indicate the intertidal vertical distribution of the test species found at Macaulay Point and Clover Point in May, 1972. The top of each bar represents the mean upper limit; the number of measurements upon which each mean is based is given at the base of the bar. The vertical line dissecting the top of each bar indicates the range to two standard errors on either side of the mean. This range gives a close approximation of the 95% confidence limits of each mean.

Table 5.2. Presence or absence of the twelve test species at Macaulay Point and Clover Point in May, 1971 and the mean of two measurements (in most cases) of the upper limits of those species present at each of these sites in May and July, 1972.

	Macaulay Point									Clover Point					
	1971			1972						1971		1972			
				May 15			July 12					May 16		July 8	
Test Species	A	B	C	A	B	C	A	B	C	A	B	A	B	A	B
Laminaria saccharina (L.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laminaria groenlandica Rosenvinge	-	-	-	1.13	1.87	1.15	1.46	1.57	1.53	+	-	0.23	0.47	0.53	1.34
Costaria costata (Turn.) Saunders	-	-	-	1.88	0.69	1.51	1.69	-	1.28	-	+	-	-	-	-
Cymathere triplicata (Post. & Rup.) J. Agd.	-	-	-	1.80	0.98	1.24	0.94	1.56	1.14	-	+	0.04	0.71	0.55	-
Alaria marginata Post. & Rup.	-	-	-	-	-	-	-	-	-	+	+	1.86	2.12	2.01	1.67
Alaria tenuifolia Set. in Collins, Holden & Set.	+	-	-	2.68	2.21	3.33	2.05	2.26	2.38	-	-	-	-	-	-
Hedophyllum sessile (C. Agd.) Setchell	-	-	+	2.11	2.14	1.88	2.40	2.39	1.82	-	+	2.28	2.21	1.97	2.64
Nereocystis luetkeana (Mert.) Post. & Rup.	-	-	+	-	2.40	1.85	-	1.44	1.98	+	-	1.28	1.17	-	1.33
Pleurophycus gardneri Set. & Saund. in Saund.	-	-	-	0.47	-	-	0.36	-	1.27	-	+	-0.42	-0.05	-1.14	-1.14
Egregia menziesii (Turn.) Areschoug	-	-	-	-	-	-	-	-	-	+	+	1.31	1.18	1.51	1.52
Desmarestia aculeata (L.) Lam.	-	-	-	1.03	-	-	-	-	-	-	-	-	-	-	-
Desmarestia ligulata var. *ligulata* (Light.) Lam.	-	-	-	1.15	1.25	1.50	-	0.99	1.56	+	+	0.92	0.58	-	0.71
No. Species per Transect	1	0	2	8	7	7	6	6	8	5	7	8	8	6	7
No. Species per Area	3			9			8			9		8		8	

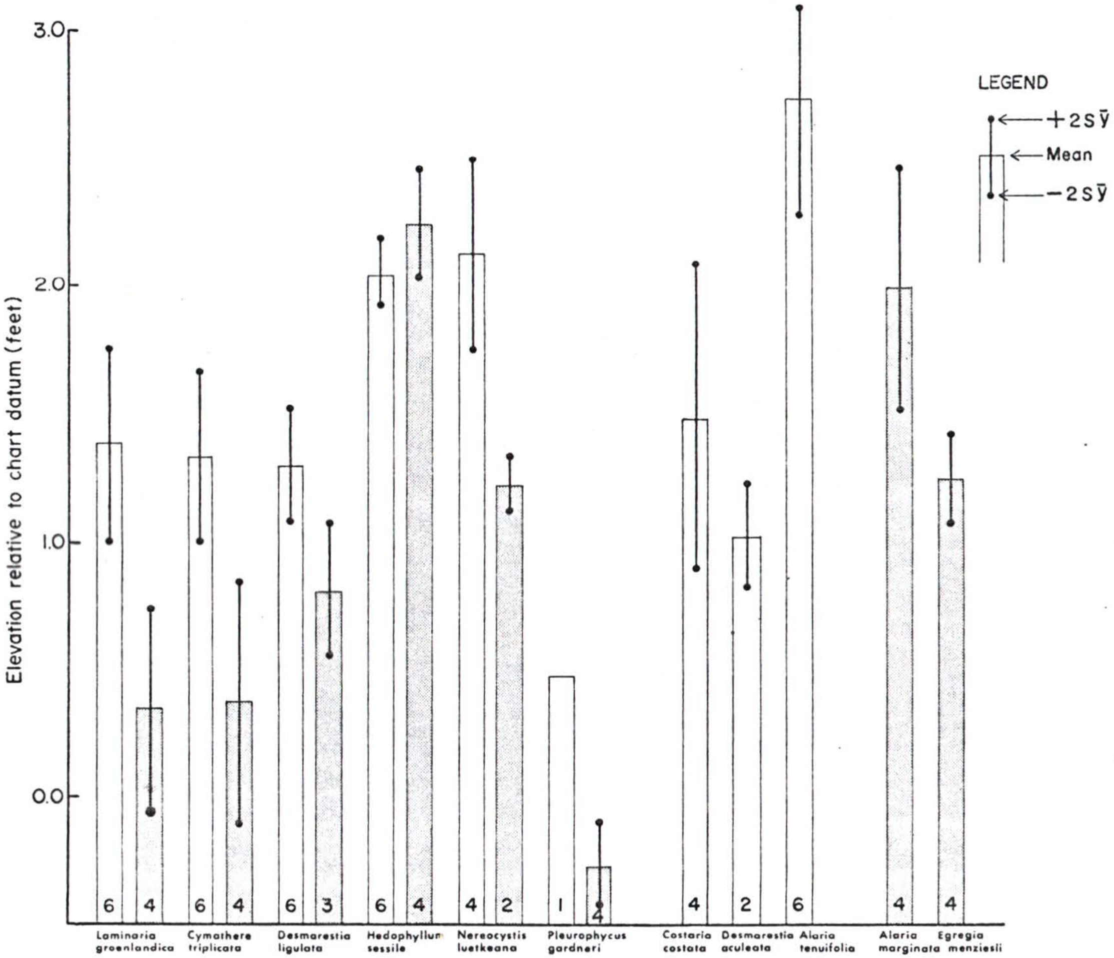


Figure 5.2. The intertidal vertical distribution of selected species of macro-Phaeophyte algae at Macaulay Point (unshaded bars) and Clover Point (shaded bars). The top of each bar represents the mean upper limit elevation; two standard errors are plotted on each side of the mean. The number of measurements upon which each mean is based is given at the base of each bar. (*Hedophyllum sessile* did not appear below the zero tide level).

All of the test species but *Hedophyllum sessile* are also commonly found in the upper intertidal region. At Macaulay Point and Clover Point, *Hedophyllum sessile* appeared to be restricted to the lower intertidal region, an observation supported by upper and lower limit elevations reported by Widdowson (1965) at a number of stations along the north shore of Juan de Fuca Strait.

Six of the twelve test species were common to both Macaulay Point and Clover Point. Of these, five species (*Laminaria groenlandica*, *Cymathere triplicata*, *Desmarestia ligulata* var. *ligulata*, *Nereocystis luetkeana* and *Pleurophycus gardneri*) had significantly higher upper limits at Macaulay Point than at Clover Point, as indicated by the non-overlap of the confidence intervals (Figure 5.2). The upper limit elevations of *Hedophyllum sessile* at Macaulay Point and Clover Point were not significantly different. *Costaria costata* and *Desmarestia aculeata* were found only at Macaulay Point in May, 1972; *Egregia menziesii* was found only at Clover Point. The mean upper limit of *Alaria tenuifolia* at Macaulay Point was higher than the mean upper limit of *Alaria marginata* at Clover Point although the confidence intervals did overlap to some extent.

D. DISCUSSION

The vertical and/or geographical distributions of *Laminaria saccharina* and *Costaria costata* (Druehl, 1967a), *Laminaria groenlandica* (Druehl, 1967b), *Alaria* spp. (Widdowson 1971b) and *Desmarestia aculeata* (Chapman and Burrows, 1971) are known to be determined by species-specific limits of tolerance to waters of reduced salinity and increased temperature. Of these taxa, *Laminaria saccharina* has perhaps the widest limits of tolerance to the above oceanographic factors, but its local intertidal distribution, as with the two local species of *Alaria*, *A. marginata* and *A. tenuifolia*, is controlled by the degree of wave action (Druehl, 1967b; and Widdowson, 1971b).

The absence of *Laminaria saccharina* intertidally at Macaulay Point and Clover Point is indicative of the moderate degree of wave exposure within these areas; *L. saccharina* has been personally observed subtidally at both sites. Floral evidence indicating that Clover Point is more exposed to wave action than Macaulay Point is provided by the presence of *Alaria marginata* and *Egregia menziesii* at Clover Point as well as the presence of *Alaria tenuifolia* at Macaulay Point. *Alaria marginata* characteristically grows near the low tide mark in areas moderately to severely wave exposed, while *A. tenuifolia* is a characteristically sheltered coast form, although often associated with strong tidal currents (Widdowson, 1971b). *Egregia menziesii* characteristically occupies the lower intertidal and upper subtidal zones in fairly exposed areas (Scagel, 1957).

This floristic evidence supports the earlier assumption, based on hydrographic evidence, that Macaulay Point is less wave exposed than Clover Point. Given the same or very similar physico-chemical oceanographic conditions, one would then expect that the upper limits of the macro-Phaeophyta would be located higher up the shore at Clover Point than at Macaulay Point due to the more frequent wetting to higher levels that is the direct result of wave action. The data presented in Figure 5.2 indicate that this is not the case. The upper limit depressions evident at Clover Point must therefore be related to some factor peculiar to that site. The appearance of six new species of macro-Phaeophytes in the intertidal zone at Macaulay Point, (and five of these having significantly higher upper limits than observed at Clover Point) within one year of the cessation of discharge of the shoreline outfall, suggests that the factor limiting the vertical distribution of the macro-Phaeophyta at Clover Point is sewage effluent.

Of the various receiving water parameters which are sufficiently influenced by the discharge of sewage effluent from shoreline outfalls to be termed "gross sewage field indicators" (Balch, *et al.*, 1972), only increased surface temperature, reduced surface salinity and increased turbidity are considered by this author to be capable of producing the effects on community structure and vertical distribution noted in this and the previously discussed studies. The data plotted in Figures 2.6, 2.7 and 2.12 (surface temperature, surface salinity and Secchi depth, respectively) indicate that in the period before the Macaulay Point shoreline outfall ceased operation, the surface waters a short distance offshore had frequently elevated temperatures, constantly reduced salinity and constantly increased turbidity.

These factors have been suggested as the cause of the reduced species diversity evident at Macaulay Point in 1971 (page 77). With the cessation of discharge from the shoreline outfall on Macaulay Point in August, 1971 these water quality parameters returned to background levels. It is felt that the return to normal conditions is directly responsible for the establishment of the intertidal populations of six of the test macro-Phaeophyte species at Macaulay Point by the spring of 1972.

Surface temperatures at Clover Point remained near background levels until the spring of 1972, after which they were consistently elevated. Surface salinities at this site were frequently reduced through 1971 but were more consistently reduced throughout 1972. A similar pattern was found with regard to turbidity. These changes may be related to an increase in the volume of discharge from the Clover Point Outfall, however, no data are available to either confirm or deny this possibility. It is felt that the depressed upper limits of the macro-Phaeophytes at Clover Point were directly related to the continuous discharge of sewage effluent at that site.

If, as suggested by various authors, temperature and salinity are responsible for determining horizontal distributions, then, to quote Druehl (1967a), "it is axiomatic that in regions with stratification of these factors the same organisms will be oriented at depths determined by their tolerance to these factors." Druehl (1967a) and Jorde and Klavestad (1963) have shown that the upper limits of certain marine algae were increasingly depressed along a gradient of decreasing salinity and increasing temperature as found in estuarine environments. The receiving area immediately adjacent to a shoreline-discharging sewage outfall bears certain similarities to a positive estuary in that a brackish surface layer of reduced salinity and increased temperature is maintained.

Thus the depression of the upper limits observed at Clover Point is probably related to the estuarine-like conditions present in the area. It is likely that the degree of depression is related to the adversity of the temperature/salinity regime. The absence of many of the test species intertidally at Macaulay Point in 1971 may then be due to the depression of their upper limits below the tidal zone.

E. SUMMARY

The establishment of intertidal populations of six species of common, intertidally-occurring macro-Phaeophyte algae at Macaulay Point in the spring of 1972 is attributed to the cessation of discharge from the shoreline outfall at that site in August, 1971, followed by an immediate return to background levels of water quality. The significant depression of the upper limits of the macro-Phaeophytes at Clover Point is attributed to the continuous discharge of sewage effluent at that site.

PART VI. *IN SITU* GROWTH RATES OF *LAMINARIA GROENLANDICA*, *NEREOCYSTIS LUETKEANA* AND *EGREGIA MENZIESII* AS AFFECTED BY AMBIENT CONCENTRATIONS OF SEWAGE EFFLUENT AT CLOVER POINT

A. INTRODUCTION

This study was initiated in order to determine if the growth rates of representative macro-Phaeophyte algae were affected by the ambient concentrations of sewage effluent discharged from the Clover Point Outfall. *Laminaria groenlandica* Rosenvinge, short stipe form, *Nereocystis luetkeana* (Mertens) Postels and Ruprecht and *Egregia menziesii* (Turner) Areschoug were chosen as test species since they were abundant components of the Clover Point algal community, and because their growth was relatively easy to measure. Albert Head was chosen as the control site for this study on the basis of its accessibility, its extensive populations of the test species, its distance from any major source of sewage effluent and because it had the most comparable environment to Clover Point of all possible pollution-free and accessible areas within the same oceanographic region (see Part II.B).

Little attention has been given to the possiblity of using algal growth rates to access the sublethal effects of marine pollution. Yet Burrows (1971) states, "size variations in relation to pollution effects would obviously be a better indicator than mere presence of absence as being more sensitive to grades of effect. Attached algae, which draw their nutrients directly from the surrounding medium, should be ideal organisms for this kind of observation."

The growth rates of the test species at test (Clover Point) and control (Albert Head) sites were monitored between late May and early August, 1972, measurements being made during the biweekly periods of low low tides (Table 6.1). Intertidal populations of *Laminaria groenlandica* and *Egregia menziesii*, and subtidal populations of *Nereocystis luetkeana* were utilized in this study. Figures 6.1 and 6.2 indicate the location of the sample populations at the test and control sites respectively.

B. METHODS

1. *Laminaria groenlandica*

Initially, 15 sporophytes were marked at each site. Plants were frequently lost so other plants were marked and used as replacements. Sporophytes were marked for easy identification by attaching a numbered plastic label to the stipe with an elastic band (Figure 6.3). A number of holes were punched in a straight line across the blade at a point 10 cm from the blade base. The width of the blade at that point was recorded. A #2 cork borer was used as the punch. The number of holes punched and the distance between holes was determined by the blade width.

Generally measurements were made at two week intervals coinciding with low low tides, however the last measurements were made in early August after an interval of four weeks. Growth in blade length was monitored by measuring the distance from the base of the blade to each hole. The arithmetic mean of these measurements was then used as the

Table 6.1. Predicted time and height of low water on sampling days for Albert Head and Clover Point (from Canadian Tide and Current Tables, Vol. 5, 1972).

Area	Date	Time	Height (feet)
Albert Head[1]	Jun 2	1212	1.4
	Jun 14	1052	0.2
	Jun 16	1217	1.9
	Jun 27	0922	0.5
	Jul 11	0902	-0.1
	Aug 7	0722	0.5
Clover Point[2]	Jun 2	1225	1.6
	Jun 14	1105	0.2
	Jun 29	1045	1.0
	Jul 10	0835	-0.4
	Aug 5	0600	0.9

[1] Time and height of low water based on Victoria and corrected for William Head.

[2] Based on Victoria.

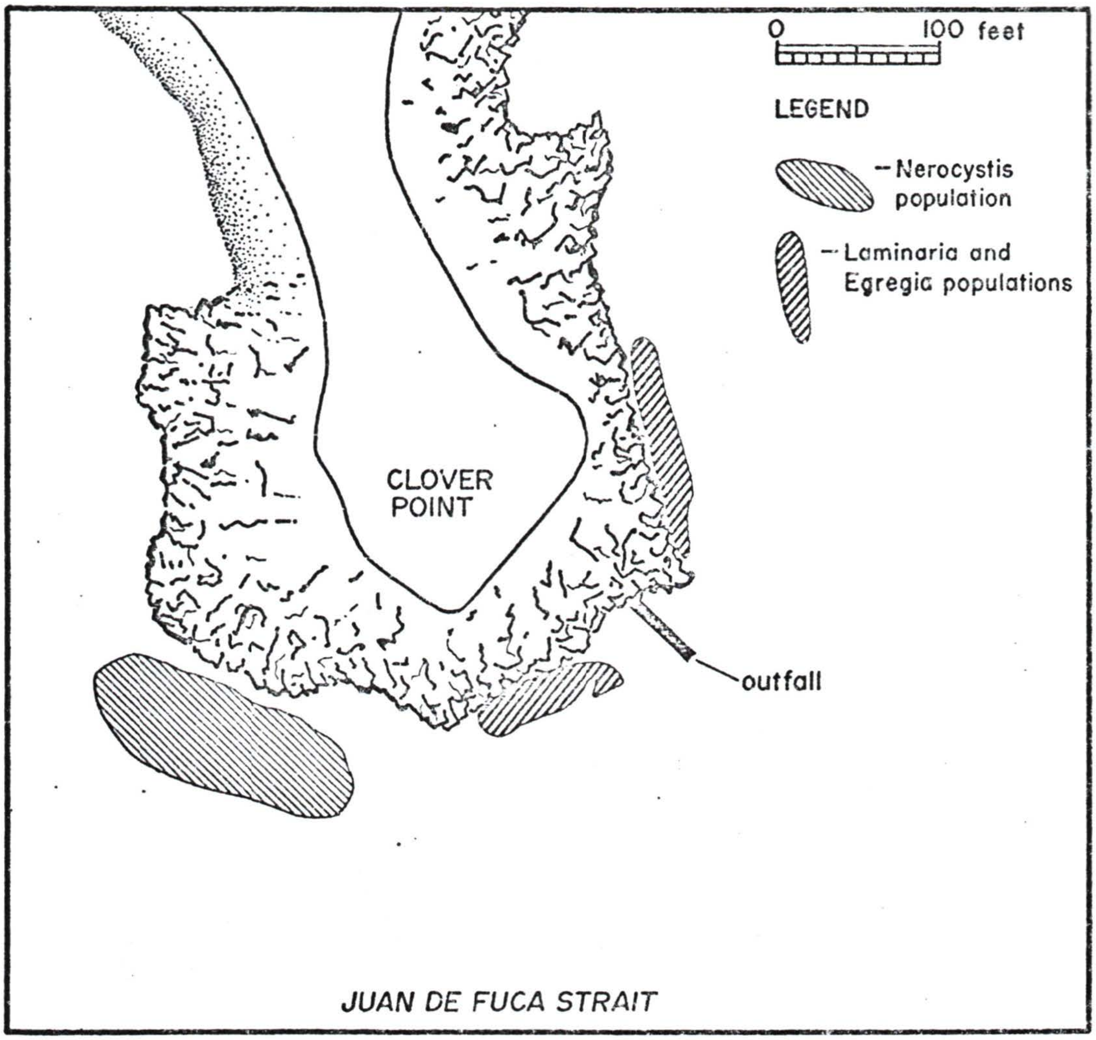


Figure 6.1. Location of test populations of *Laminaria groenlandica*, *Egregia menziesii* and *Nereocystis luetkeana* at Clover Point.

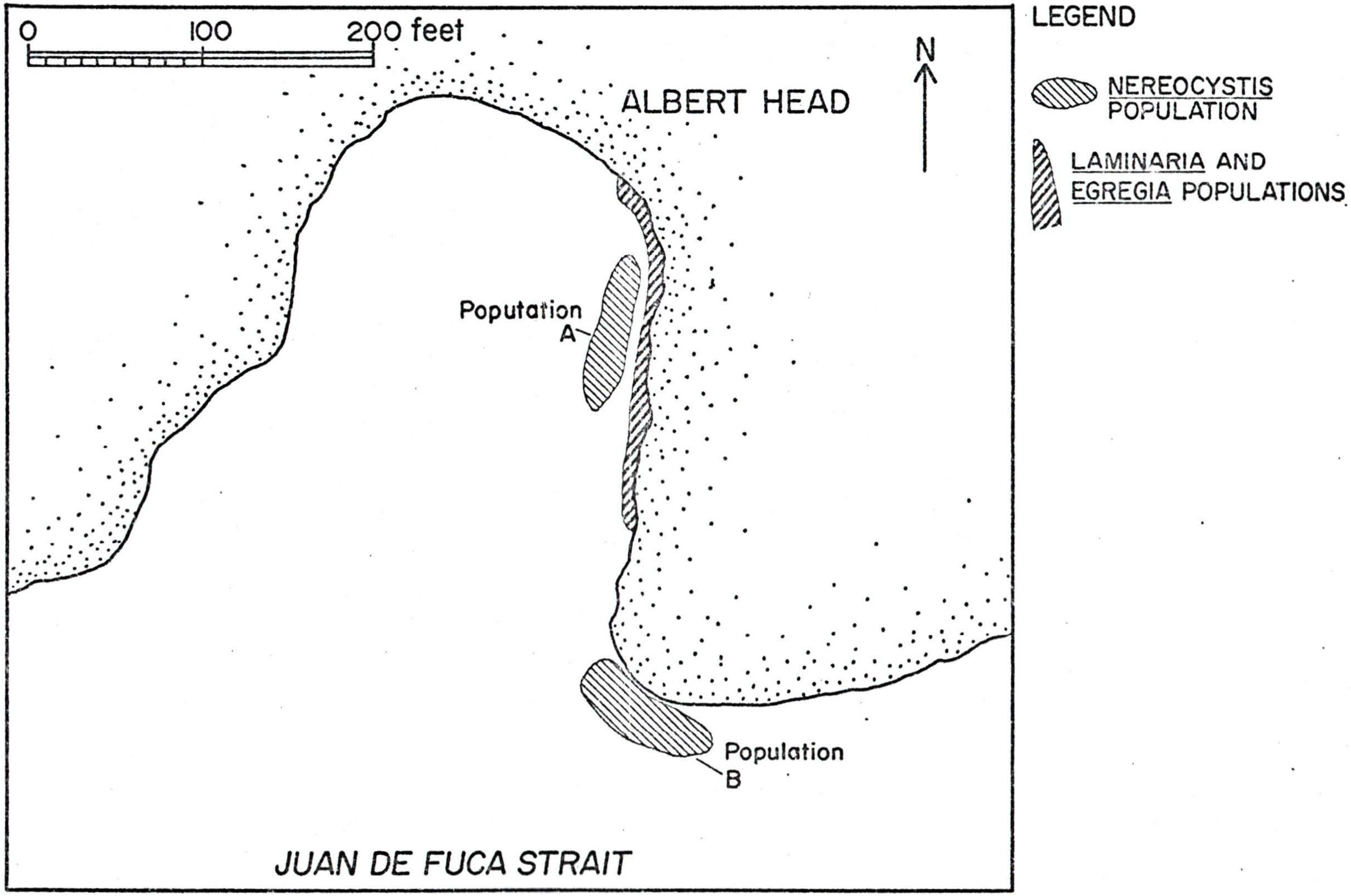


Figure 6.2. Location of control populations of *Laminaria groenlandica*, *Egregia menziesii* and *Nereocystis luetkeana* at Albert Head.

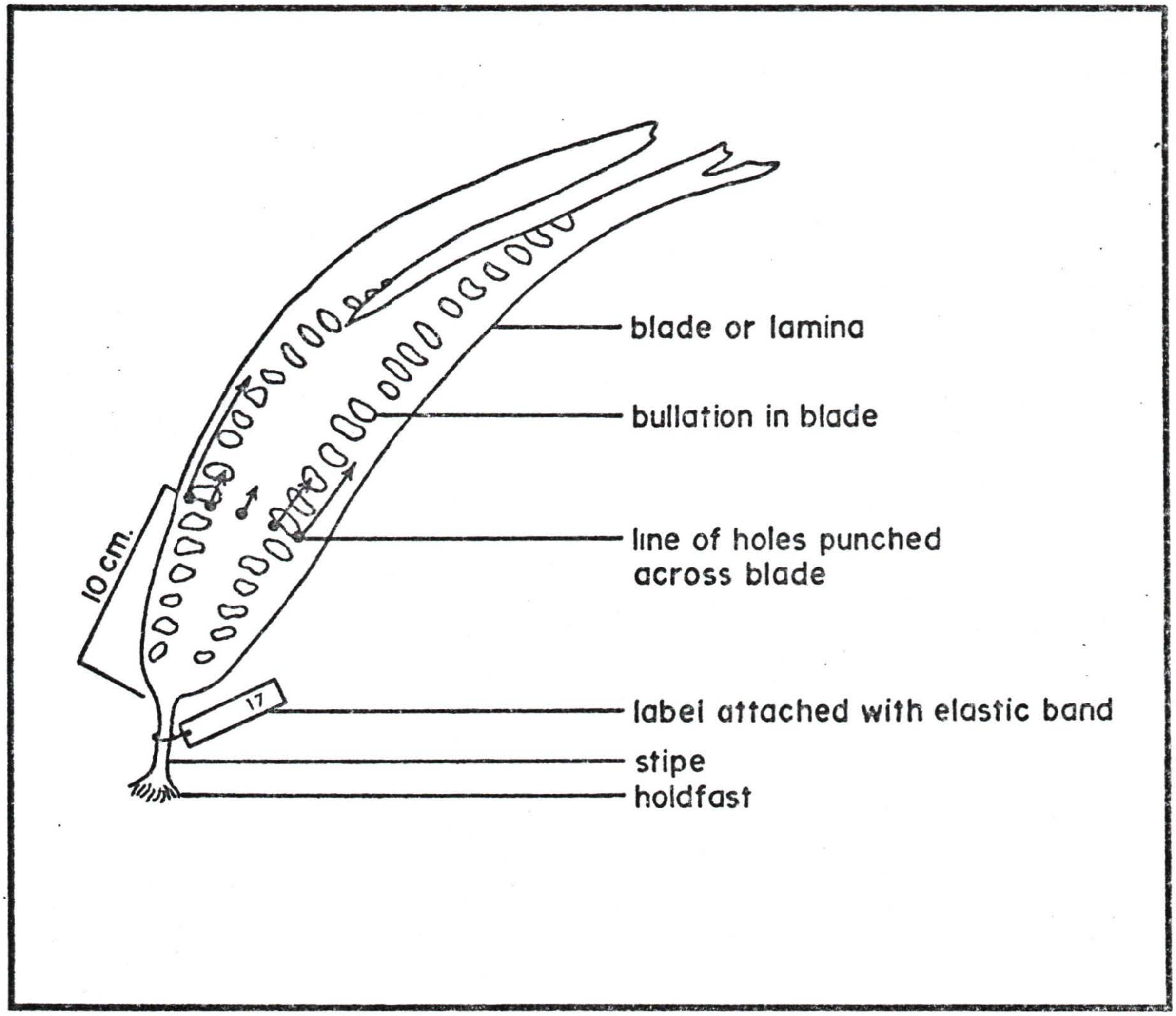


Figure 6.3. Habit sketch of *Laminaria groenlandica* indicating means of labelling. (Arrows indicate general growth pattern).

measure of growth. If the original holes approached the eroding tip of the blade, as occurred with several of the Albert Head specimens, a new set of holes were punched as previously described. Because of the tendency for more rapid growth along the blade margins, growth in width was determined by measurements taken across the blade at the point of the hole most distant from the blade base. A meter rule graduated in centimeters and millimeters was used for the measurements; measurements were recorded to the nearest 0.5 cm.

Albert Head sporophytes were marked on May 31 when the predicted low tide was +1.4 ft. An unsuccessful attempt was made to locate and mark sporophytes at Clover Point on June 2 when the predicted low tide was +1.6 ft. As a result sporophytes at Clover Point were not marked until June 14 when the predicted low tide was +0.2 ft.

2. *Egregia menziesii*

The two largest or apparently most actively growing side branches of each of 8 sporophytes were selected and marked at both test and control sites. The side branches were marked by attaching a numbered plastic label to the base of the branch with an elastic band (Figure 6.4). Replacements were marked whenever side branches or whole plants were lost. The growth rate estimates were based on the elongation of the side branches. Measurements were made from the base of the side branch to the transition zone at the base of the terminal blade. Measurements were made with a meter rule and recorded to the nearest centimeter. Time intervals between measurements were as previously described.

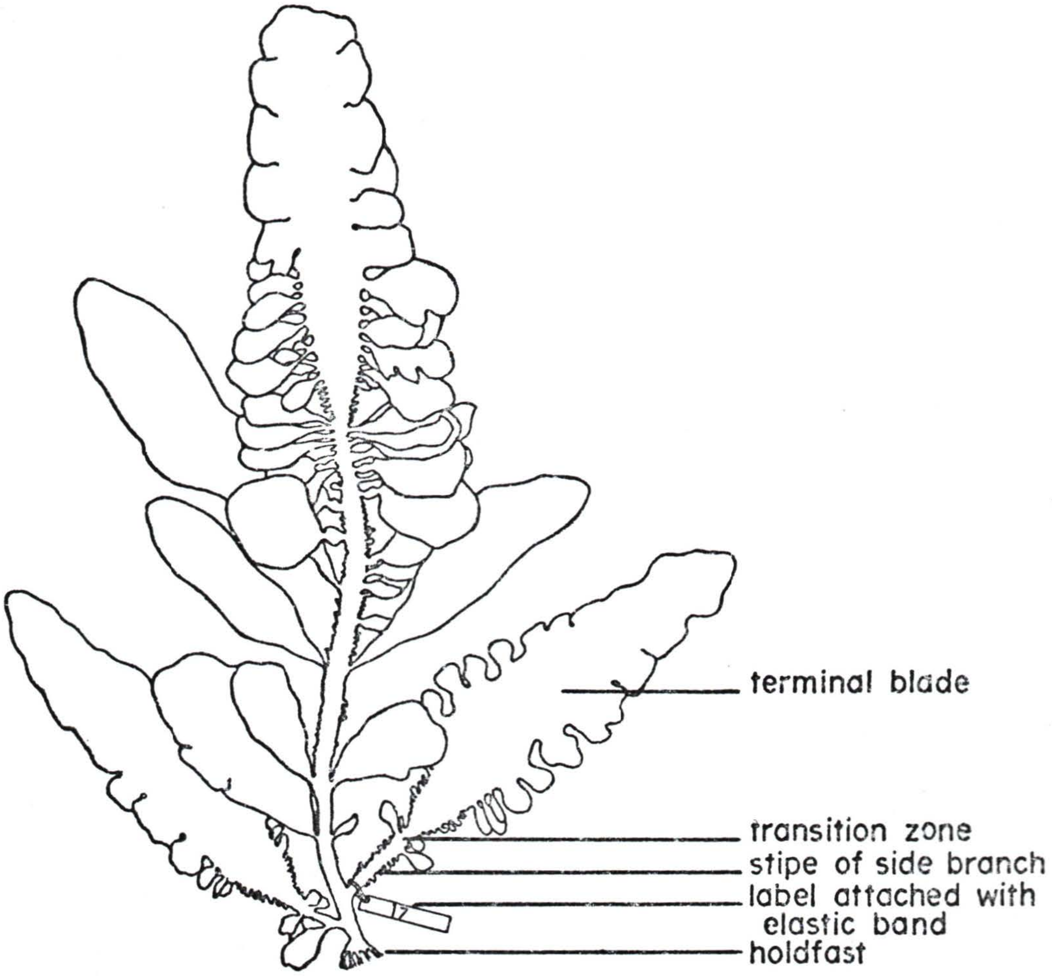


Figure 6.4. Habit sketch of *Egregia menziesii* indicating means of labelling. (After Scagel, 1967; modified).

3. *Nereocystis luetkeana*

The number of sporophytes labelled, replacement procedure, method of labelling and the time interval between measurements were as previously described for *Laminaria groenlandica*. Growth rates of *Nereocystis luetkeana* were based on stipe elongation, measurements being made from the holdfast to the tip of the bulb (pneumatocyst) (Figure 6.5). Measurements were made with a meter rule and recorded to the nearest centimeter.

The rate of stipe elongation was monitored in two populations at Albert Head. Population A, in the small embayment seen in Figure 6.2, was initially labelled and measured on June 2; population B, found just off the point marking the southeastern boundary of the embayment, was initially labelled and measured on June 16. Growth measurements in population B were initiated following the realization that current velocity probably plays a large role in determining the rate of growth (Conover, 1967), and possibly the absolute stipe length in *Nereocystis*. It was therefore desirable to have a control population outside the embayment in an area subject to tidal currents as was the test population at Clover Point. The water depth at all three sites was within the range of 1-2 meters below zero tide level.

C. RESULTS

The mean growth rates per day, plotted against time in weeks, of the populations of *Laminaria groenlandica*, *Egregia menziesii* and *Nereocystis luetkeana* at Clover Point and Albert Head are given in

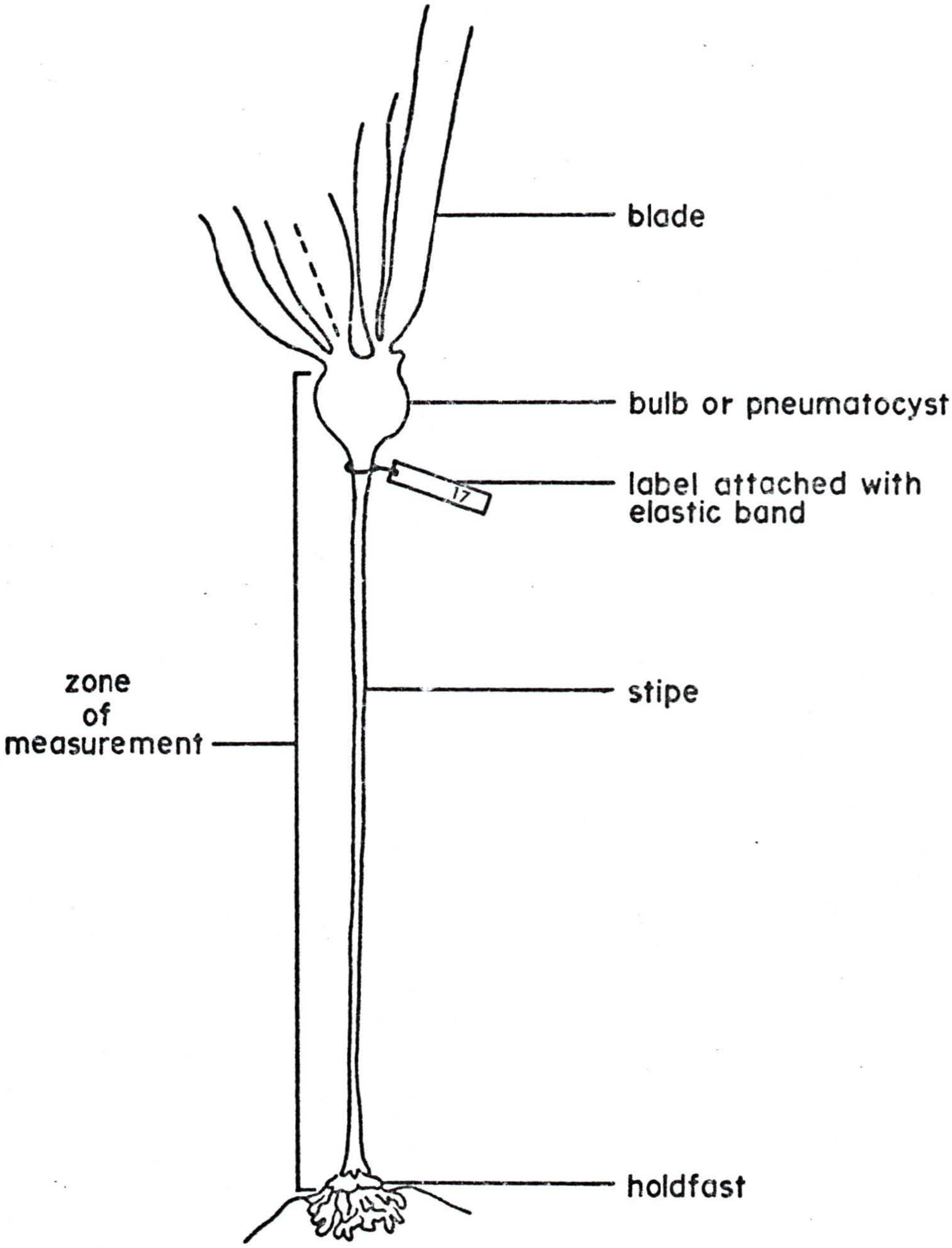


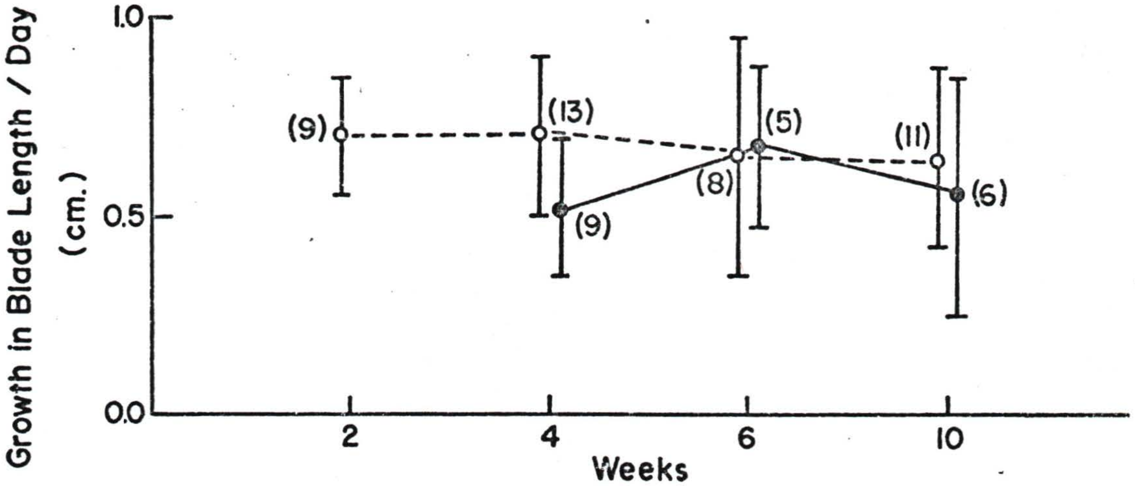
Figure 6.5. Habit sketch of *Nereocystis luetkeana* indicating means of labelling.

Figures 6.6, 6.7 and 6.8 respectively. Each mean is based on the number of observations given in brackets to the side of each plotted point. Two standard errors are plotted on each side of each mean. The range of two standard errors gives a close approximation of the 95% confidence interval.

These results indicate that the growth rates of *Laminaria groenlandica* and *Egregia menziesii* were not significantly affected by the ambient concentrations of sewage effluent discharged from the Clover Point Outfall. There appears to be a significant increase in the rate of stipe elongation in the Clover Point *Nereocystis* population relative to population A at Albert Head. There was no significant difference between the growth rates of the two *Nereocystis* populations inhabiting areas subject to tidal currents. This suggests that the difference between the population inhabiting the embayment at Albert Head and the current exposed population at Clover Point may be related to the absence of marked tidal currents within the confines of the embayment.

D. DISCUSSION AND CONCLUSION

Since the growth rate of *Laminaria* has been shown to be inversely proportional to the level of attachment (Parke, 1948), it is felt that the rates exhibited by the *L. groenlandica* populations at Clover Point and Albert Head are not strictly comparable as there is evidence that the elevation of the sample sporophytes was not the same at both sites (page 115).



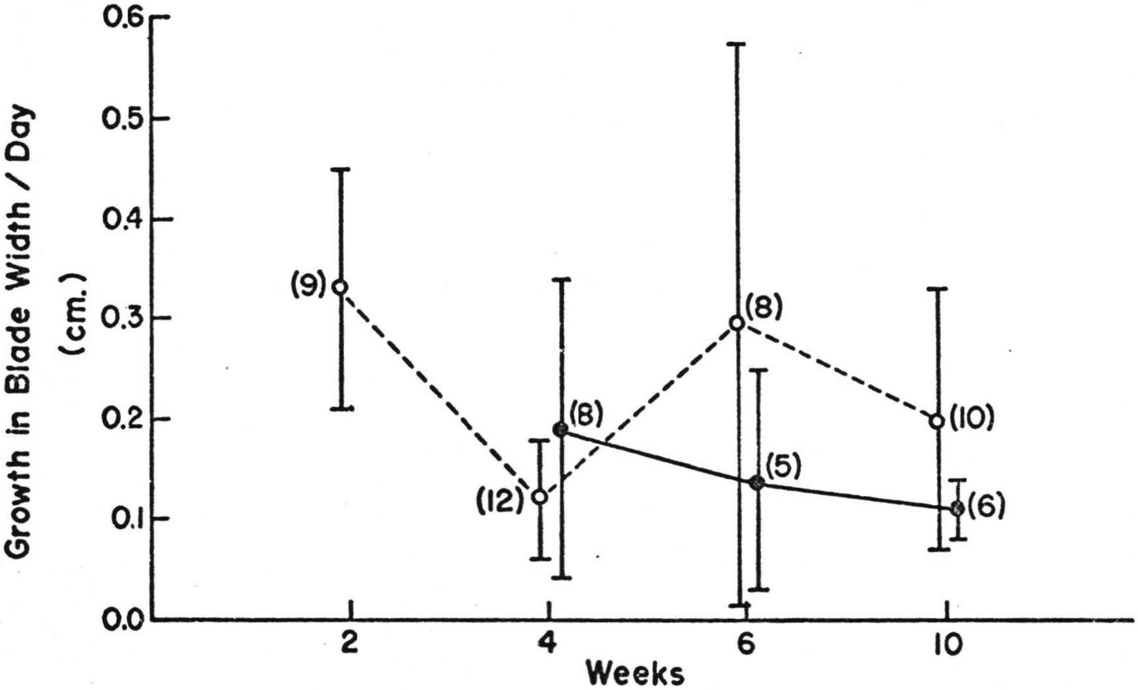


Figure 6.6. Mean growth in blade length (upper) and in blade width (lower) per day of *Laminaria groenlandica* at Clover Point (●) and Albert Head (o). The number of observations upon which each mean is based is given in brackets beside each mean. Two standard errors are plotted on each side of the mean.

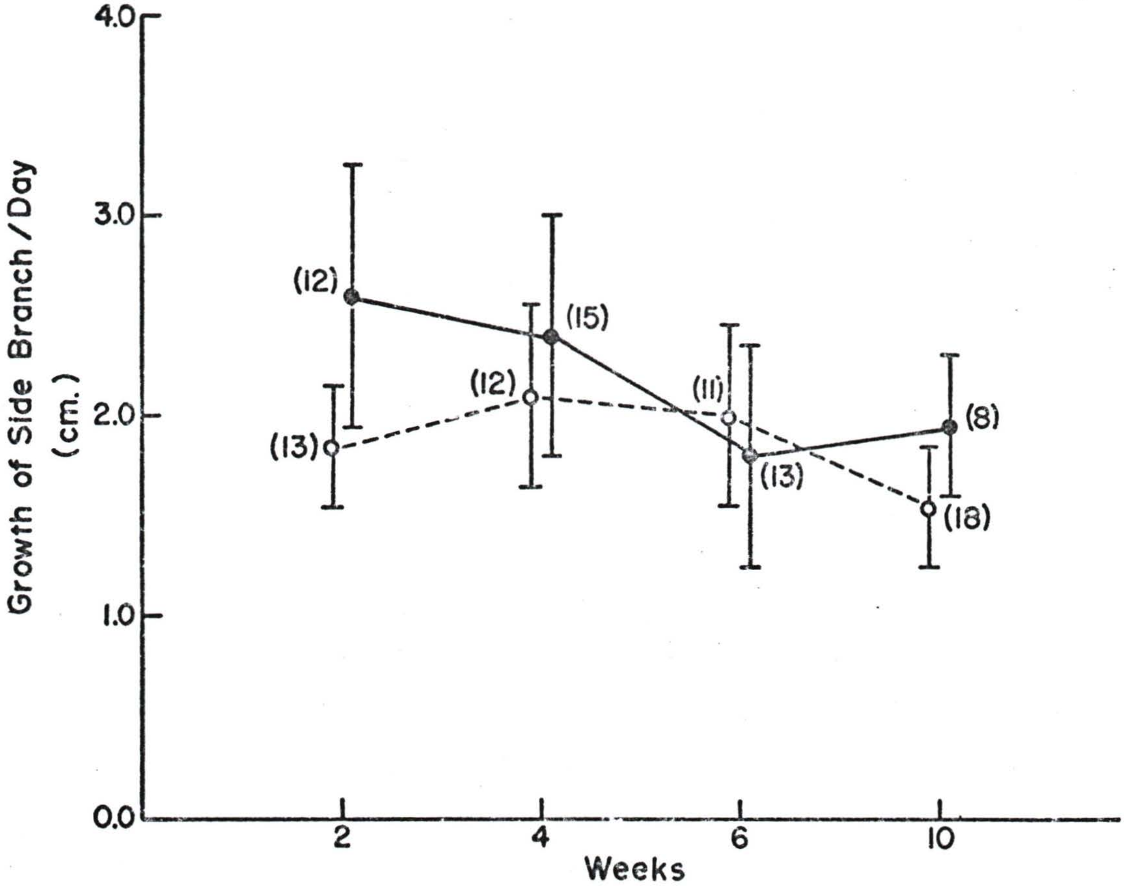


Figure 6.7. Mean rate of side branch elongation per day of *Egregia menziesii* at Clover Point (●) and Albert Head (○). The number of observations upon which each mean is based is given in brackets beside each mean. Two standard errors are plotted on each side of the mean.

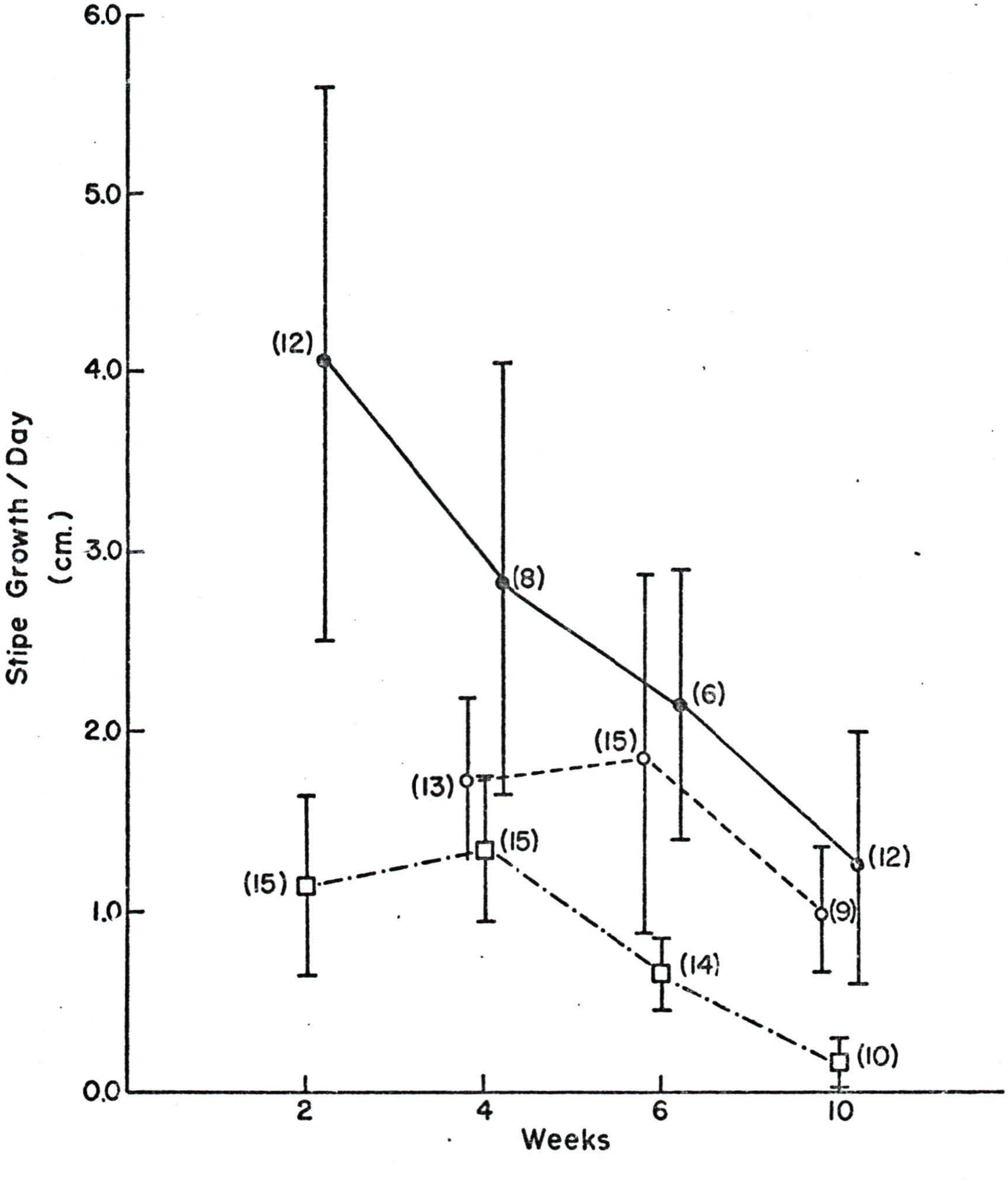


Figure 6.8. Mean rate of stipe elongation per day of *Nereocystis luetkeana* at Clover Point (●) and Albert Head (population A - ☐ , population B - o). The number of observations upon which each mean is based is given in brackets beside each mean. Two standard errors are plotted on each side of the mean.

The comparable growth rates exhibited by the *Egregia menziesii* populations at test and control sites suggests that this species is tolerant to intermittent exposure to relatively high concentrations of sewage effluent. Widdowson (1972) found the Californian species, *Egregia laevigata*, similarly tolerant to sewage pollution.

Nereocystis luetkeana is quite cosmopolitan in distribution, particularly in its tolerance to reduced salinity (Scagel, 1961). The slight increase in stipe growth rate exhibited by the Clover Point population is likely related to the very high nutrient concentrations (Figure 2.7 and 2.8) at that site during the test period. Nutrient concentrations at Albert Head were at background levels during the same period (Table 2.7).

Results presented in Parts III, IV and V indicate that the presence of relatively high concentrations of sewage effluent was related to changes in the structure and vertical distribution of the intertidal macroalgal communities in areas adjacent to shoreline-discharging outfalls. It is felt that these influences were real and were directly related to the physico-chemical alteration of the near-shore waters affected by shoreline discharge of sewage effluent. In the present study, an attempt was made to assess the use of *in situ* growth rates as a parameter to index the sublethal effects of sewage effluent on the intertidal and nearshore environments. In light of the above comments it is felt that the techniques used in this study were, in general, insufficient to define the true effects of sewage effluent on algal growth rates and that another technique, utilizing several refinements listed below, would provide a clearer picture.

A great deal of variation is evident in the results given in Figures 6.6 - 6.8; further work of this type should therefore ensure adequate replication to reduce the within-population variance. Growth rate studies should begin before March and continue through until July or August in order to encompass the whole of the maximum growth period. As much as possible, plants of the same age class should be used since algal growth rates have been shown to be related to age and the time of sporophyte initiation (Parke, 1948). When measuring the growth rate of intertidal populations it is necessary that strict vertical control be maintained since it has been demonstrated that growth rate increases in a gradient towards the sublittoral (Parke, 1948). Similarly, depth control is necessary for measuring the growth of *Nereocystis* since the rate of stipe elongation of this species is controlled by water depth (Foreman, 1970).

PART VII. THE EFFECT OF UNTREATED SEWAGE EFFLUENT ON THE *IN VITRO* NET PHOTOSYNTHETIC AND DARK RESPIRATION RATES OF *LAMINARIA GROENLANDICA*

A. INTRODUCTION

The results presented to this point have indicated that the discharge of sewage effluent from shoreline outfalls may be related to changes in the biological properties of the adjacent intertidal algal communities. It has been suggested (page 77) that these biological alterations resulted from the reduced salinity, increased temperature and increased turbidity produced as a result of effluent discharge into the nearshore receiving waters.

Surface salinity was the one water quality parameter invariably affected by discharge from shoreline sewage outfalls (Figure 2.6). Relative salinity decreases in the order of 1-4°/oo were common at both Macaulay Point and Clover Point and a maximum depression of 10°/oo was recorded at Clover Point (Ellis and Littlepage, 1972). The maximum seasonal range of nearshore surface salinity during 1971 and 1972 was only 3°/oo (Figure 2.7). Constant salinity decreases of 1-4°/oo below background levels therefore presents conditions not normally encountered by the local shoreline macroalgae. It has been suggested therefore (page 106) that reduced surface salinity was the major factor responsible for the observed alterations of the structure and vertical distribution of the intertidal macroalgal communities at

Macaulay Point and Clover Point. Increased surface temperature and reduced light penetration would be expected to compliment the negative effects produced by reduced salinity.

Temperature increases of 0.5-1.5°C were infrequently recorded at Macaulay Point prior to the cessation of discharge from the shoreline outfall at that site; surface temperature at Clover Point did not show influences during the same period (Figure 2.6). However, during 1972 temperature increases in the order of 0.5-2.0°C were frequently recorded at Clover Point. While both respiration and photosynthetic rates of macroalgae are known to be influenced by temperature (Kanwisher, 1966), it is unlikely that temperture increases of only 0.5-2.0°C would, in themselves, be responsible for the changes in the intertidal macroalgal communities noted at Macaulay Point and Clover Point.

The literature suggests that a combination of reduced salinity and increased temperature is often the factor determining the horizontal distribution (Jorde and Klavestad, 1963; Widdowson, 1965; Druehl, 1967b and Chapman and Burrows, 1971) as well as the vertical distribution (Jorde and Klavestad, 1963 and Druehl, 1967a) of many marine algae.

By itself, turbidity would not be expected to produce the observed responses, although the reduction in light penetration caused by turbidity would be expected to contribute to lower rates of production in the areas adjacent to sewage outfalls.

In the final study of this program an attempt was made to experimentally relate the alteration in community structure and vertical distribution observed at the shoreline outfall sites to physiological stress caused by high concentrations of sewage effluent. Sewage effluent is essentially freshwater containing various dissolved and suspended organic and inorganic materials. An *in vitro* experiment was designed to test the effects of increasing concentrations of both the freshwater component and 'whole' sewage effluent on the net photosynthetic and dark respiration rates of *Laminaria groenlandica*. Such an experiment should give an indication of the impact of sewage effluent on algal community metabolism, as compared to the effects produced by reduced salinity.

Laminaria groenlandica was selected as the test species because its *in vitro* sensitivity to reduced salinity had been determined by Druehl (1967b), and because it was sensitive to sewage effluent in the field investigations previously discussed (pages 69 and 104). The responses of both juvenile (basal) and adult (distal) blade tissues of single sporophytes were tested to determine the comparative sensitivities of these tissues to the experimental conditions.

Burrows and Phybus (1971) studied the effects of marine pollution on the growth rate of young sporophytes of *Laminaria saccharina*. Their culture experiments utilized seawater from a number of localities with various degrees of pollution. Hopkin and Kain (1971) performed culture experiments on *Laminaria hyperborea* grown in nutrient media supplimented with different concentrations of various heavy metals, herbicides, pesticides and detergents. Neither of these experiments separated the effects of freshwater from the effects of the other effluent components. Druehl (1967b) has shown that *Laminaria groenlandica* sporophytes respond to reduced salinity with a reduction in the net photosynthetic rate and an irregular increase in the dark respiration rate.

B. METHODS

1. Raw Materials

Table 7.1 lists the locations and dates of collection and pre-treatment of the seawater, untreated sewage effluent and of the algal specimens utilized as test materials. Seawater was filtered the day of collection using Microfil glass-fibre filters (1.2 μ pore diameter). Immediately following filtration, the seawater was decanted into a glass aquarium and stirred to ensure homogeneity. Then a sample was drawn for salinity determination. All salinities were measured with a Hytech Laboratory Salinometer standardized with University of Victoria secondary standard seawater. The salinity of all seawater used in this study was adjusted to $31 \pm 0.05\,^{o}/oo$ by the following procedure: (a) if the intial salinity was less than $31\,^{o}/oo$, Instant Ocean Synthetic Sea Salts were added according to the formulae 0.12 gm synthetic salts/$0.1\,^{o}/oo$ salinity increment required/liter seawater or, (b) if the initial salinity was more than $31\,^{o}/oo$, by dilution with distilled water. After each addition of synthetic salts or distilled water, the solution was stirred and a sample drawn for salinity determination.

Table 7.1. Location and dates of collection and pretreatment of raw materials (1972).

		Seawater Medium		Sewage Effluent		Algal Specimens		
Experiment No.	Experimental concentration of effluent or tapwater (ppt)	Place Collected	Date Collected and Filtered	Place Collected	Date Collected and Filtered	Place Collected	Date Collected and Discs cut	Date of Experiment
1	0	Ten Mile Pt.	Nov 6	Macaulay Pt.*	Nov 7	Macaulay Pt.	Nov 6	Nov 8
2	1	Ten Mile Pt.	Nov 8	Macaulay Pt.*	Nov 9	Macaulay Pt.	Nov 8	Nov 10
3	10	Ten Mile Pt.	Nov 20	Macaulay Pt.*	Nov 21	Macaulay Pt.	Nov 20	Nov 22
4	25	Ten Mile Pt.	Nov 22	Macaulay Pt.*	Nov 23	Macaulay Pt.	Nov 22	Nov 24
5	50	Ten Mile Pt.	Nov 27	Macaulay Pt.*	Nov 28	Macaulay Pt.	Nov 27	Nov 29
6	100	Ten Mile Pt.	Nov 29	Macaulay Pt.*	Nov 30	Macaulay Pt.	Nov 29	Dec 1
7	200	Ten Mile Pt.	Dec 4	Macaulay Pt.*	Dec 5	Macaulay Pt.	Dec 4	Dec 6
8	300	Ten Mile Pt.	Dec 6	Macaulay Pt.*	Dec 7	Macaulay Pt.	Dec 6	Dec 8
9	400	Ten Mile Pt.	Dec 11	Macaulay Pt.*	Dec 12	Macaulay Pt.	Dec 11	Dec 13
10	500	Ten Mile Pt.	Dec 13	Macaulay Pt.*	Dec 14	Macaulay Pt.	Dec 13	Dec 15

* Effluent was collected from the Macaulay Pt. Pumping station.

This procedure was repeated if necessary until the salinity of the filtered seawater was adjusted to the required level. Equal measured volumes of this adjusted seawater were then decanted into two scrubbed and labelled plastic carbuoys, one used solely for a seawater/tapwater mixture and the other used solely for a seawater/sewage effluent mixture. The carbuoys were then stored in a darkened cold room (8°C) until required.

Untreated sewage effluent was drawn from the storage well in the Macaulay Point Pumping Station and, following transport to the laboratory, was immediately filtered (Whatman #1 Qualitative Filters) to remove suspended solids. Equal, measured volumes of this filtered effluent and tapwater were placed in separate, labelled glass flasks and stored overnight in a darkened cold room (8°C).

Table 7.2 indicates the volumes of adjusted seawater and filtered effluent or tapwater required to produce each experimental concentration tested, and indicates the salinities as determined from the seawater/tapwater mixture.

Non-reproductive specimens of the short stipe form of *Laminaria groenlandica* Rosenvinge were hand collected, using self-contained underwater breathing apparatus (SCUBA), from the lower intertidal and upper subtidal population (0 to -4 ft. below Chart Datum) at Macaulay Point (Figure 7.1). Specimens were transported to the laboratory in either large plastic bags or plastic pails filled with ambient seawater. The presence of mucilage ducts in the stipe was used as the criterion for positive identification of each specimen (Druehl, 1968). Voucher

Table 7.2. Volumes of salinity-adjusted filtered seawater and filtered sewage effluent or tapwater required to produce the desired experimental concentrations, and the salinity ($^{o}/oo$) at each concentration as determined from the seawater/tapwater mixture.

Experimental conc. (ppt)	Volume Filtered seawater (ml)	Volume Filtered sewage effluent or tapwater (ml)	Salinity of mixture ($^{o}/oo$)
0	8000	-	31.00
1	7992	8	30.90
10	7920	80	30.76
25	7800	200	30.31
50	7600	400	29.50
100	7200	800	28.01
200	6400	1600	24.97
300	5600	2400	21.78
400	4800	3200	18.80
500	4000	4000	15.64

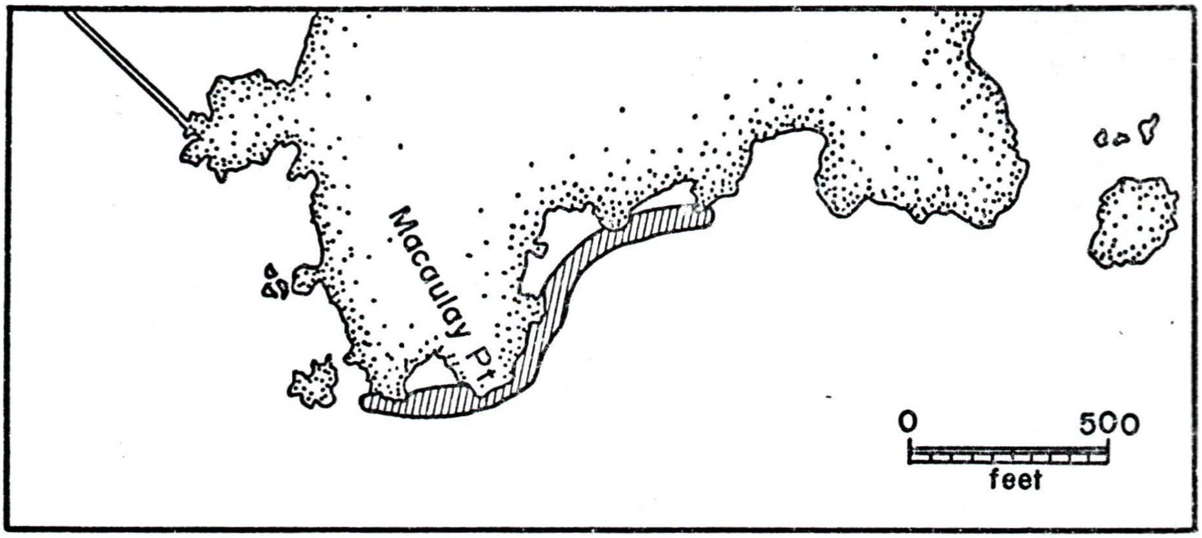


Figure 7.1. Area in which sporophytes of *Laminaria groenlandica* were collected (Macaulay Point).

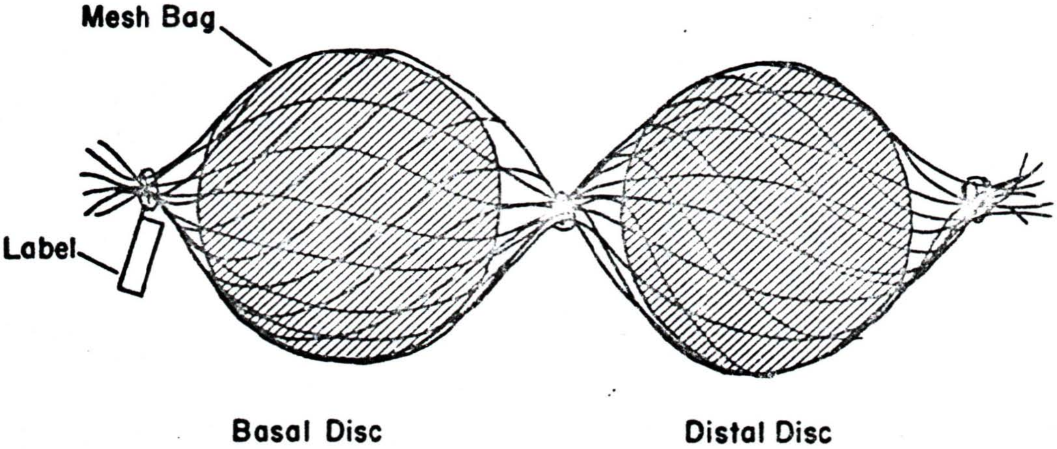


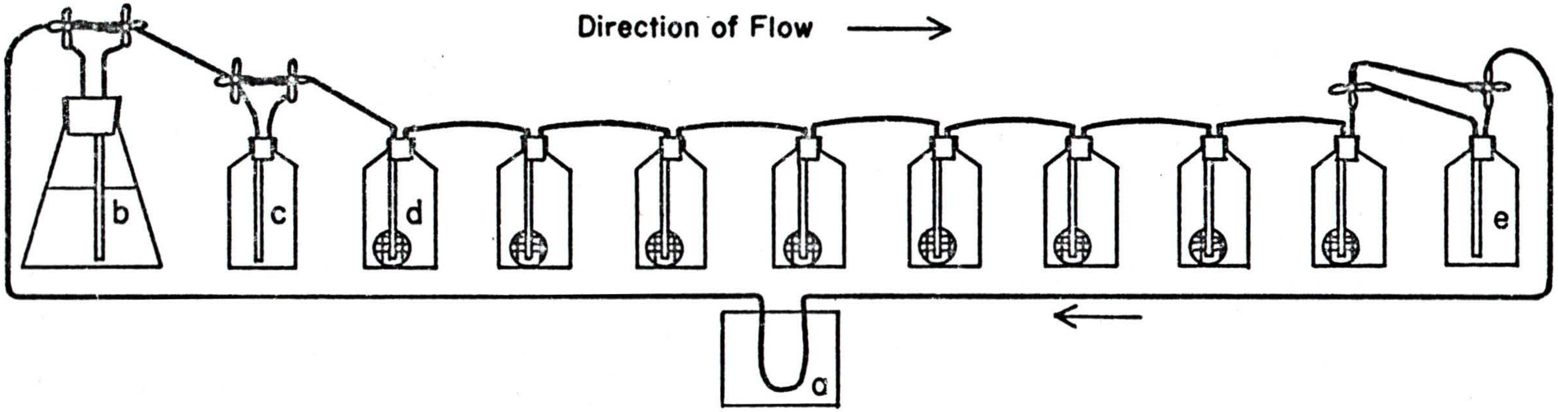
Figure 7.2. Sketch of plastic mesh bag used to ensure identification of basal and distal discs of *Laminaria groenlandica* after cutting.

specimens will be deposited in the University of Victoria Phycological Herbarium. Eight sporophytes were required for each experiment. After wiping with paper towelling to remove epiphytes, two discs were cut from the blade of each sporophyte. One disc was cut from the meristematic tissue in the transition zone at the base of the blade (basal disc), the other disc being cut from the adult tissues at a distance of 15 cm from the blade base (distal disc). In order that the discs could be identified after cutting, the two discs from each sporophyte were placed in a compartmentalized plastic mesh bag, the basal disc in the labelled compartment (Figure 7.2). The discs were than stored until required in an Instant Ocean Aquarium maintained at 8°C and 31.0°/oo. The first three experiments utilized discs with an area of 33 cm^2; the last seven used discs with an area of 24.25 cm^2. This change in disc size was necessitated by the difficulty in locating non-reproductive sporophytes large enough to accomodate the larger discs cutter as the season progressed.

2. The Experimental Apparatus and Procedure

A modified version of the apparatus employed by Hoos (1970) to measure the oxygen tolerance of zooplankton was designed and utilized in this bioassay procedure (Figure 7.3). Preliminary trials used a simpler apparatus (Ellis *et al.*, 1973), the development of which was discontinued. Two apparatuses were prepared, one for use with test media (effluent-diluted seawater), the other for use with control media (tapwater-diluted seawater). This allowed for simultaneous testing with both media.

Figure 7.3. Diagram of the apparatus used in measuring rates of net photosynthesis and dark respiration.



a. Water pump
b. Reservoir flask
c. 300 ml BOD bottle used in the dark period to measure bacterial respiration.
d. BOD bottle containing algal disc.
e. BOD bottle used to measure the initial dissolved oxygen concentration.

The desired concentrations of test and control media were produced just prior to the beginning of each experiment by mixing the appropriate premeasured components in the labelled carbuoys (Table 7.2). The carbuoys were then vigourously shaken and the contents immediately decanted into reservoir flasks and biological oxygen demand (BOD) bottles (Figure 7.3). A sample was drawn from the control medium for salinity determination.

The algal discs, following transport from the aquarium in beakers of aquarium seawater, were inserted into the BOD bottles. The two apparatuses were then assembled equidistant from the light source. The basal and distal discs from a single sporophyte were placed in adjacent BOD bottles within a given apparatus. The rest of the apparatus was assembled as shown in Figure 7.3.

Once assembly was complete, the pumps were turned on. The first several minutes of continuous flow through each apparatus were used to evacuate air bubbles, the air being replaced with media from the reservoir flasks. Once all air was purged, the pumps were shut off and the valves were adjusted to direct the flow past the reservoir flasks. The pumps were then turned on again. In each apparatus, the flow then passed through the pump (a, in Figure 7.3), past the reservoir flask (b) and the first BOD bottle (c), which was used only during the dark period, and then flowed into the bottom and out of the top of the seven remaining, disc-containing BOD bottles, into the last BOD bottle (e), which did not contain a disc since it was used to measure the initial dissolved oxygen concentration, and finally, back to the pump. Hoos (1970) determined, using carmine dye, that all the water in each of the bottles was continually being replaced during continuous flow periods.

This state of continuous flow was maintained, in the dark, for one hour in order that an equilibrium of oxygen concentration be reached within each apparatus. Hoos (1970) found that at a flow rate of 40-50 ml/minute it took approximately 25-30 minutes for an oxygen equilibrium to be reached in a system containing 7 liters of seawater. Each apparatus used in this investigation contained approximately 8 liters of medium; the flow rate was maintained between 170 and 230 ml/minute. It was therefore assumed that an oxygen equilibrium would be reached within each apparatus within one hour.

At the end of the continuous flow period the pumps were shut off and the last BOD bottles of each apparatus removed. The valves were adjusted so that air would not enter the system. To each of these bottles were added: (a) Winkler reagents to fix the dissolved oxygen, and (b) three clean glass spheres to displace air. The concentration of dissolved oxygen in these bottles was assumed to represent that present throughout each apparatus.

The lights were then turned on for a period of two hours, during which time the bottles were not agitated. After the light period was over, the discs were carefully removed and placed in a new set of BOD bottles freshly filled with the appropriate medium. The first set of bottles were treated with Winkler reagents, air being displaced with glass spheres as above.

Each apparatus was then reassembled for the dark period. Fresh media was also added to the reservoir flasks. The flow during the equilibrium phase was directed into the first BOD bottle of the series as this bottle was used to detect changes in oxygen concentration due to bacterial activity. The rest of the procedure was as previously described except that the dark period was of four hours duration. All oxygen determinations were made with a modified Winkler method (Drinnan and Littlepage, 1971).

The light source consisted of a bank of six Sylvania Lifeline F72T12-CW bulbs. The distribution of spectral energy supplied by these bulbs is shown in Figure 7.4. The light energy available for photosynthesis was 0.019 langelys/minute as measured with a KahlSico Model 28AM100 Pyranometer.

The temperature of the media were recorded at the beginning and end of the light period, and again at the end of the dark period (Table 7.3). A mean temperature increase of 1.1°C was apparent during the light period, while a mean decrease of 0.5°C from the initial temperature was apparent during the dark run. It is believed that the temperature increases were due to heating from the bank of lights.

The metabolic responses of basal and distal discs of *Laminaria groenlandica* were tested at the following concentrations of sewage effluent and tapwater: 0, 1, 10, 25, 50, 100, 200, 300, 400 and 500 parts per thousand (ppt). The results are given as: µliter O_2 produced or taken up/cm^2 blade tissue/hour. Data sheets, which include the formulae used to calculate net photosynthetic and dark respiration rates for each experiment, are given in Appendix I.

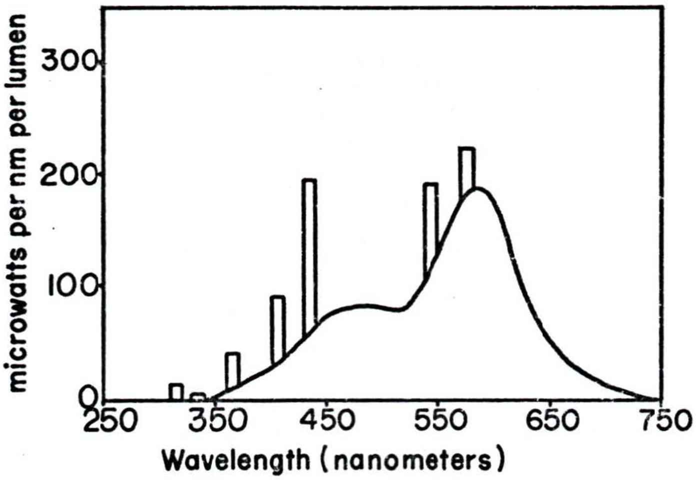


Figure 7.4. The distribution of light energy supplied by Sylvania Lifeline F72T12-CW bulbs.

Table 7.3. Temperature changes during the light and dark runs of each experiment, and the mean temperature changes.

Exp. No.	Media conc. (ppt)	Initial Temp. (°C)	Temp. End light run (°C)	Δt During light run (°C)	Temp. End dark run (°C)	Δt End Dark Run compared to initial temp. (°C)
1	0	8.0	8.5	+1.5	7.8	-0.2
2	1	7.7	8.4	+0.7	7.6	-0.1
3	10	8.5	9.5	+1.0	7.7	-0.8
4	25	10.0	10.5	+0.5	7.8	-2.2
5	50	8.0	9.5	+0.5	7.8	-0.2
6	100	8.4	9.5	+1.1	7.8	-0.6
7	200	8.5	9.0	+0.5	8.0	-0.5
8	300	8.0	9.1	+1.1	7.7	-0.3
9	400	8.2	10.0	+1.8	8.0	-0.2
10	500	8.1	10.3	+2.2	8.0	-0.1
	Means	8.3	9.4	+1.1	7.8	-0.5

C. RESULTS

Figures 7.5 and 7.6 indicate the effect of increasing concentrations of sewage effluent and tapwater on the net photosynthetic and dark respiration rates of basal and distal discs of *Laminaria groenlandica*, respectively. Each point represents the mean of four replicate measurements.

1. Statistical Analysis

The data were initially analyzed by Model I, 2 X 2 analyses of variance (ANOVA) with equal cell frequencies (Table 7.4). If significance was indicated in these main effects anovas, analyses of simple effects (Table 7.5) were performed to locate the sources of significance between the various concentrations for both test and control media, and between the test and control media for each of the ten concentrations tested. If significance was indicated within the series of concentrations for either the test or the control media, an SNK test, a multiple comparison among means analysis, was performed to determine which means in a series were significantly different from the others (Figure 7.7).

2. Net Photosynthetic Rate

The main effects analyses of variance indicated that there were significant differences between the effects of test and control media on the net photosynthetic rates of basal and distal discs (Table 7.4). Subsequent analyses of simple effects showed that rates of net photosynthesis in test media were significantly depressed at concentrations

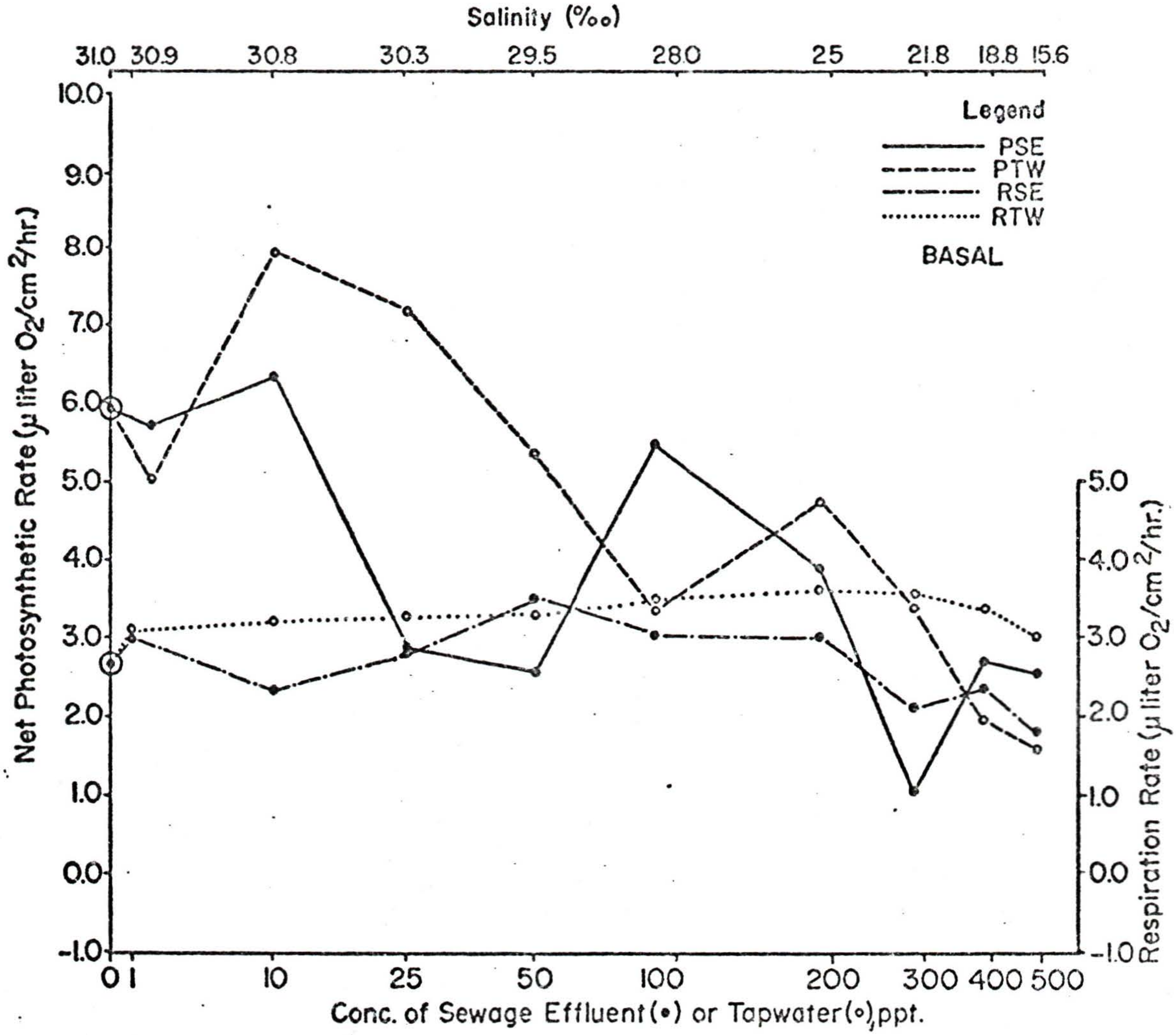


Figure 7.5. Mean rates of net photosynthesis and dark respiration of basal discs of *Laminaria groenlandica* with increasing concentrations of sewage effluent and tapwater. Means based on four measurements. (PSE = photosynthesis in sewage effluent-diluted seawater, RTW = respiration in tapwater-diluted seawater, etc.)

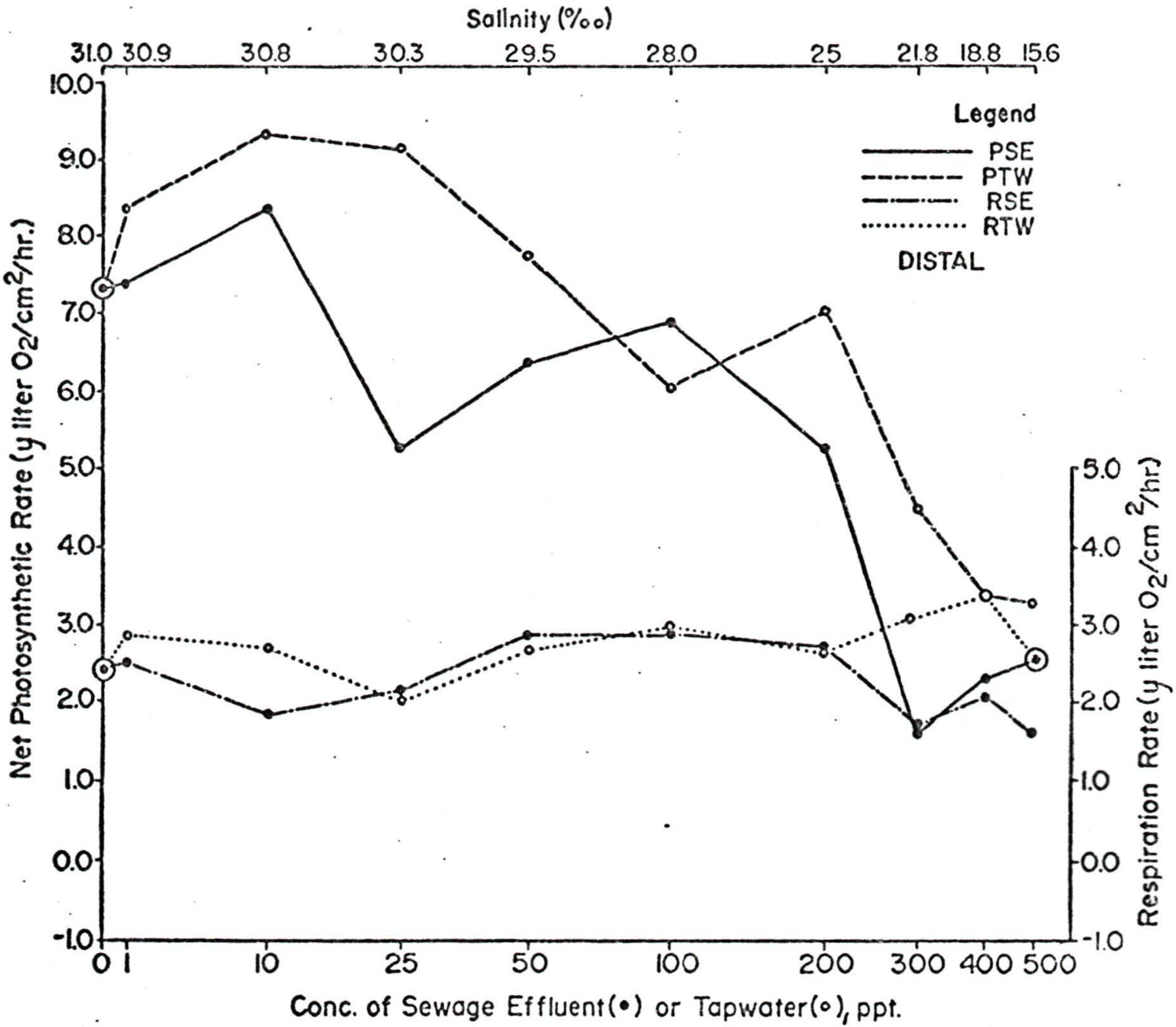


Figure 7.6. Mean rates of net photosynthesis and dark respiration of distal discs of *Laminaria groenlandica* with increasing concentrations of sewage effluent and tapwater. Means based on four measurements.

(PSE = photosynthesis in sewage effluent-diluted seawater, RTW = respiration in tapwater-diluted seawater, etc.)

Table 7.4. Main effect ANOVA tables for the net photosynthetic and dark respiration rates of basal and distal discs of *Laminaria groenlandica*.

1. Net Photosynthetic Rates

a) Basal Discs

Source of Variation	SS	df	MS	F	P<
Between test and control	11.078	1	11.078	4.217	0.044
Between concs.	206.279	9	22.920	8.725	0.001
Interaction	72.573	9	8.064	3.070	0.004
Error	157.615	60	2.627		

b) Distal Discs

Source of Variation	SS	df	MS	F	P<
Between test and control	32.181	1	32.181	14.144	0.001
Between concs.	354.611	9	39.401	17.317	0.001
Interaction	31.747	9	3.527	1.550	0.151
Error	136.515	60	2.275		

2. Dark Respiration Rates

a) Basal Discs

Source of Variation	SS	df	MS	F	P<
Between test and control	7.218	1	7.218	53.251	0.001
Between concs.	6.720	9	0.747	5.509	0.001
Interaction	5.470	9	0.608	4.484	0.001
Error	8.133	60	0.136		

b) Distal Discs

Source of Variation	SS	df	MS	F	P<
Between test and control	4.168	1	4.168	16.522	0.001
Between concs.	6.372	9	0.708	2.807	0.008
Interaction	6.554	9	0.728	2.887	0.007
Error	15.135	60	0.252		

Table 7.5. Simple effects ANOVA tables for the net photosynthetic and dark respiration rates of basal and distal discs of *Laminaria groenlandica*.

1. Net Photosynthetic Rates

a) Basal Discs

Source of Variation	SS	df	MS	F
Between concs. for test	120.29	9	13.37	5.09^{***}
Between concs. for control	158.58	9	17.62	6.71^{***}
Between test and control for 0 ppt	0.00	1	0.00	0.00^{ns}
Between test and control for 1 ppt	0.93	1	0.93	0.35^{ns}
Between test and control for 10 ppt	5.30	1	5.30	2.02^{ns}
Between test and control for 25 ppt	37.54	1	37.54	14.29^{***}
Between test and control for 50 ppt	15.74	1	15.74	5.99^{*}
Between test and control for 100 ppt	8.87	1	8.87	3.38^{ns}
Between test and control for 200 ppt	1.43	1	1.43	0.54^{ns}
Between test and control for 300 ppt	10.88	1	10.88	4.14^{*}
Between test and control for 400 ppt	1.15	1	1.15	0.44^{ns}
Between test and control for 500 ppt	1.57	1	1.57	0.60^{ns}
Error	157.62	60	2.63	

b) Distal Discs

Source of Variation	SS	df	MS	F
Between concs. for test	202.91	9	22.55	9.91^{***}
Between concs. for control	150.36	9	16.71	7.35^{***}
Between test and control for 0 ppt	0.00	1	0.00	0.00^{ns}
Between test and control for 1 ppt	2.02	1	2.02	0.89^{ns}
Between test and control for 10 ppt	1.88	1	1.88	0.83^{ns}
Between test and control for 25 ppt	29.38	1	29.38	12.91^{***}
Between test and control for 50 ppt	3.88	1	3.88	1.71^{ns}
Between test and control for 100 ppt	1.69	1	1.69	0.74^{ns}
Between test and control for 200 ppt	6.09	1	6.09	2.68^{ns}
Between test and control for 300 ppt	16.04	1	16.04	7.05^{*}
Between test and control for 400 ppt	2.13	1	2.13	0.94^{ns}
Between test and control for 500 ppt	0.98	1	0.98	0.43^{ns}
Error	136.52	60	2.28	

$F_{.05\ (9,60)} = 2.04$ $F_{.01\ (9,60)} = 2.72$ $F_{.001\ (9,60)} = 3.69$

$F_{.05\ (1,60)} = 4.00$ $F_{.01\ (1,60)} = 7.08$ $F_{.001\ (1,60)} = 12.00$

.../cont'd.

2. Dark Respiration Rates

a) Basal Discs

Source of Variation	SS	df	MS	F
Between concs. for test	9.43	9	1.05	7.72***
Between concs. for control	2.78	9	0.31	2.28*
Between test and control for 0 ppt	0.00	1	0.00	0.00^{ns}
Between test and control for 1 ppt	0.02	1	0.02	0.15^{ns}
Between test and control for 10 ppt	1.55	1	1.55	11.40**
Between test and control for 25 ppt	0.44	1	0.44	3.24^{ns}
Between test and control for 50 ppt	0.08	1	0.08	0.59^{ns}
Between test and control for 100 ppt	0.40	1	0.40	2.94^{ns}
Between test and control for 200 ppt	0.67	1	0.67	4.93*
Between test and control for 300 ppt	4.30	1	4.30	31.62***
Between test and control for 400 ppt	2.17	1	2.17	15.96***
Between test and control for 500 ppt	3.07	1	3.07	22.57***
Error	8.13	60	0.14	

b) Distal Discs

Source of Variation	SS	df	MS	F
Between concs. for test	8.26	9	0.92	3.65**
Between concs. for control	4.63	9	0.51	2.02^{ns}
Between test and control for 0 ppt	0.00	1	0.00	0.00^{ns}
Between test and control for 1 ppt	0.26	1	0.26	1.03^{ns}
Between test and control for 10 ppt	1.48	1	1.48	5.87*
Between test and control for 25 ppt	0.02	1	0.02	0.08^{ns}
Between test and control for 50 ppt	0.07	1	0.07	0.28^{ns}
Between test and control for 100 ppt	0.00	1	0.00	0.00^{ns}
Between test and control for 200 ppt	0.01	1	0.01	0.04^{ns}
Between test and control for 300 ppt	3.75	1	3.75	14.88***
Between test and control for 400 ppt	3.22	1	3.22	12.78***
Between test and control for 500 ppt	1.99	1	1.99	7.90**
Error	15.14	60	0.25	

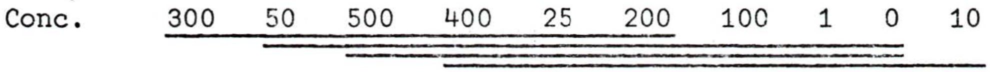
$F_{.05\ (9,60)} = 2.04$ $F_{.01\ (9,60)} = 2.72$ $F_{.001\ (9,60)} = 3.69$

$F_{.05\ (1,60)} = 4.00$ $F_{.01\ (1,60)} = 7.08$ $F_{.001\ (1,60)} = 12.00$

1. Net Photosynthetic Rates

a) Basal Discs

i. Test Means

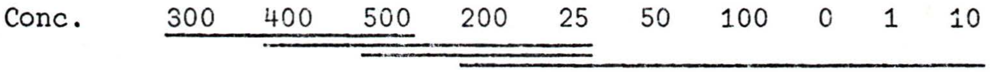

Conc. 300 50 500 400 25 200 100 1 0 10

ii. Control Means

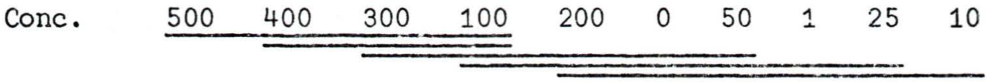

Conc. 500 400 100 300 200 1 50 0 25 10

b) Distal Discs

i. Test Means


Conc. 300 400 500 200 25 50 100 0 1 10

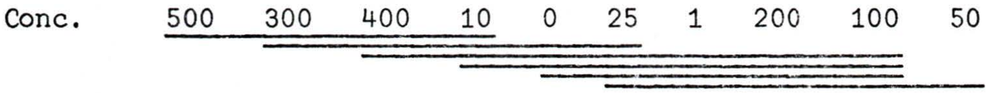
ii. Control Means


Conc. 500 400 300 100 200 0 50 1 25 10

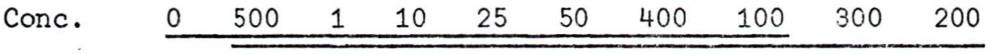
2. Dark Respiration Rates

a) Basal Discs

i. Test Means

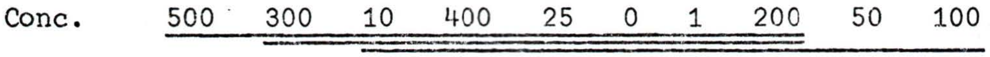

Conc. 500 300 400 10 0 25 1 200 100 50

ii. Control Means


Conc. 0 500 1 10 25 50 400 100 300 200

b) Distal Discs

i. Test Means


Conc. 500 300 10 400 25 0 1 200 50 100

Means are arranged in order of ascending magnitude.
Means underlined are not significantly different
($P<0.05$).

Figure 7.7. Array of means as determined by the SNK test for the net photosynthetic and dark respiration rates of basal and distal discs of *Laminaria groenlandica*.

of 25, 50 and 300 ppt (basal discs) and 25 and 300 ppt (distal discs) (Figure 7.7 and Table 7.5).

The net photosynthetic rate was also affected by concentrations of sewage effluent (test) and tapwater (control) (Figures 7.5, 7.6 and 7.7 and Table 7.4 and 7.5). Net photosynthesis in basal and distal discs of *Laminaria groenlandica* was stimulated by low concentrations of sewage effluent and tapwater, with maximum rates recorded in all cases at 10 ppt. The subsequent decrease in net photosynthetic rates below the maximum was more rapid for basal and distal discs in test media, with rates in test media being significantly depressed at 25 ppt (basal and distal) and at 50 ppt (basal only). In all cases an initial minimum rate was reached but this minimum always occurred at lower concentrations in the test media (25 or 50 ppt) than in the control media (100 ppt). The initial minimum was followed by an increase in apparent photosynthesis to a secondary maximum at some higher concentration. Net photosynthetic rates at this secondary maximum were in all cases not significantly different than the rates recorded at 0 and 10 ppt, but the secondary maximum was always attained at a lower concentration in the test media (100 ppt) than in the control media (200 ppt). Following the secondary maximum there was a depression of net photosynthetic rates that, in the control media, continued to the highest concentration tested (500 ppt). However, in the test media a secondary minimum was attained at 300 ppt, followed by an increase at 400 and 500 ppt which, in the basal discs, resulted in mean rates of net photosynthesis that were greater than those recorded in control media. Net photosynthetic rates of basal and distal discs in test media at 300 ppt were however significantly lower than those measured in control media.

The significant interaction term in the main effects anova for basal discs can be attributed to a number of factors: (1) the significant depression of the net photosynthetic rates in test media at 25 and 50 ppt, (2) the relative increase in net photosynthesis in test media at 400 and 500 ppt, and (3) the differences in the period of the maximum and minimum rates of net photosynthesis in test and control media. The insignificance of the interaction term for the distal discs probably is due to the less erratic response of the adult blade tissues and the overall similarity of response to test and control media.

3. Dark Respiration Rates

The main effects anovas indicated that there were significant differences in the rate of dark respiration between both basal and distal discs in test and control media (Table 7.4). Analysis of simple effects showed that dark respiration rates of basal discs in test media were significantly depressed at concentrations of 10, 200, 300, 400 and 500 ppt, and of distal discs at concentrations of 10, 300, 400 and 500 ppt (Table 7.5).

In control media, dark respiration rates of basal discs tended to increase with concentration to 300 ppt then decrease to 500 ppt (Figure 7.5). Rates recorded in the concentration range from 1-500 ppt were not significantly different but rates at 200 and 300 ppt were significantly higher than at 0 ppt (Figure 7.7). Dark respiration rates of distal discs in control media were not significantly affected by salinities as low as 15.64^{0}/oo (500 ppt) (Table 7.5). The response of the distal discs to decreasing salinity was more variable than that of basal discs with depressions occurring at concentrations of 25 and 200 ppt, which were not evident in basal discs (Table 7.5).

Except for the significant depression at 10 ppt, curves of dark respiration rate for basal and distal discs in test media were similar in shape and period to that of the distal discs in control media for concentrations up to 200 ppt. At concentrations greater than 200 ppt, the dark respiration rate of basal and distal discs in test media exhibited a significant depression (Figures 7.5 and 7.6 and Table 7.5). Dark respiration rates of the basal discs in test media were significantly depressed at a lower concentration than that of the distal discs suggesting that the basal discs were more sensitive to high concentrations of sewage effluent (Figures 7.5, 7.6 and 7.7 and Table 7.5). The significant interaction was due to the depressions exhibited by discs in test media.

D. DISCUSSION

1. Net Photosynthetic Rate

The results indicate that the freshwater component of sewage effluent is largely responsible for the significant depression of net photosynthesis of *Laminaria groenlandica* observed at high concentrations of tapwater and sewage effluent. This is probably related to the fact that freshwater comprises 99.9% of sewage effluent by weight (Associated Engineering Services, Ltd., 1966). Generally, the rates of net photosynthesis were significantly depressed at concentrations of tapwater and sewage effluent greater than or equal to 300 ppt (salinities less than $22^{0}/oo$).

It is obvious however, that some other component of sewage effluent is active in further depressing the rate of net photosynthesis. The presence of such a component is indicated by: (1) the generally lower mean rates of net photosynthesis in test media throughout the range of concentrations tested, (2) the shift of the net photosynthetic curve of discs in test media, and (3) the significantly lower rates observed in test media at concentrations of 25, 50 and 300 ppt. These indications suggest that the "active" component is continually present in sewage effluent and that either the concentration or the character, or both, of the component may vary with time.

Hopkin and Kain (1971) tested various pollutants, including a variety of detergents, for their effects on the time taken for sporophyte production from gametophytes, the growth rate of young sporophytes, and the respiration rate of adult blade tissues of *Laminaria hyperborea*. The detergents proved toxic to gametophytes and young sporophytes at concentrations of 1-10 ppm, but produced little effect on the respiration rates of adult tissue. Similarly, Burrows (1971) tested the effects of the detergent 'Blusyl' on the growth rate of *Laminaria saccharina* and showed that, in the range of 0-10 ppm, growth rates of sporophytes were inversely proportional to detergent concentration.

Detergents are likely to be a regular component of sewage effluent in the Victoria sewerage system.

Other common household products such as phenolic solvents and bleaches may also be expected to enter the sewerage system. Phenols have been shown to have antialgal properties (McLachlan and Craigie, 1966). Hopkin and Kain (1971) found that phenol was toxic at 50 and 100 ppm to gametophytes and adult tissues, respectively, of *Laminaria hyperborea*.

It therefore appears that a number of household products may be toxic to algae at concentrations that may be expected to occur in sewage effluent. However, the possibility that a natural, or non-manufactured, component of sewage effluent (i.e., bacterial toxins) is responsible for the observed effect can not be eliminated. Whatever the cause, "whole" sewage effluent generally depressed the rate of net photosynthesis of *Laminaria groenlandica* to lower levels than the freshwater component.

Net photosynthetic rates of distal discs was generally greater at all concentrations in test and control media than rates of basal discs. Differences in the rates between basal and distal discs decreased with increasing concentration in the test medium. The lower rate of net photosynthesis in basal discs may be due to the immaturity of the chloroplast ultrastructure in the cells of the meristematic and juvenile tissues (Wildman, 1969). The decreasing differences in rates between basal and distal discs in test media suggests that the basal tissues are more resistent to sewage effluent. Evidence supporting this possibility has been published by Burrows (1971). She showed that juvenile tissues of *Laminaria saccharina* were more resistant to the detergent 'Blusyl', than were mature tissues.

The rates of net photosynthesis of distal discs in test and control media, were quite variable particularly at intermediate concentrations. The degree of variability exhibited by the basal discs was even more notable as it persisted throughout the whole range of concentrations. Dark respiration rates were less variable than rates of net photosynthesis, indicating that only the photosynthetic potentials of the sporophytes collected for this experiment were different.

Differences in age class, reproductive condition, individual salinity tolerance as well as the lack of precontioning are factors that may possibly be related to the variability observed in the net photosynthetic rate. Parke (1948) has shown that the growth rate (and therefore the rate of net photosynthetic production) of *Laminaria saccharina* varies considerably with the age and the time of sporophyte initiation, although in all age classes the minimum growth rates occur between September and December (the period of this investigation). Some of the sporophytes may have been in the early stages of reproductive development. Such plants would not be recognizable in the field since the distinctive soral patches would not have appeared. It is possible that as the cells in the meristoderm layer begin to develop into reproductive sori, there is a decrease in the photosynthetic potential. Also, the lack of preconditioning at the salinity levels to be tested may be partially responsible for the variability. Druehl (1967b) preconditioned discs of *Laminaria groenlandica* at a particular temperature/salinity regime for five days prior to measuring the rates of net photosynthesis and dark respiration. Perhaps within this period the osmoregulatory and metabolic processes of the blade tissues were able to attain steady state conditions. Druehl however did not publish any statistic describing the variability of net photosynthetic rates obtained with his technique.

Seawater influences biological processes both as far as the total osmoconcentration of the medium is concerned and through the specific effects of its many ions. Ultimately, the biological responses to variations in salinity are based on ionic or molecular exchanges between the organism and the ambient medium (Gessner and Schramm, 1971).

The actual physiological mechanisms by which reduced salinity affects photosynthesis is poorly understood. It is known that in hypotonic solutions marine benthic algae lose ions; the rapidity and reversibility of this process in certain algae show that ion movement out of and into an "apparent free space" is involved (Gessner and Hammer, 1968). Thus through its "free space" an alga establishes ionic equilibrium with its external medium. In a pre- 1960 literature review, Munda (1964) has concluded that the protein/lipoprotein gel layers of cell membranes provide a major barrier to ionic diffusion. The permeability and the resistance of protoplasts to ionic diffusion is determined by the density and the structure of gel layers, while the number of osmotically active groups in the cell membrane is controlled by enzyme action. The "free space" must therefore be confined to the cell wall.

Experiments with *Fucus virsoides*, *F. serratus* and *Laminaria saccharina* showed that the "free space" of these species was able to tolerate the rapid loss of ions during short periods of immersion in distilled water, and was able to rapidly accumulate ions when returned to seawater (Gessner and Hammer, 1968; and Hammer, 1969). On the other hand, Gessner's (1969) experiments on the sublittoral brown alga *Dictyopteris membranacea* showed that salinities lower than 20^{0}/oo resulted in irreversible damage to the photosynthetic mechanism due to rapid ion loss. Later experiments (Gessner, 1971) showed that rapid water uptake in hypotonic solutions may also be related to the irreversible destruction of the photosynthetic ability in *D. membranacea.* In the same study Gessner demonstrated that rapid water uptake in hypotonic solutions was solely responsible for the irreversible destruction of the photosynthetic mechanism of the red alga *Halymenia floresia.* Montfort, as reported by Gessner and Schramm (1971), emphasized that the relationship between salinity and photosynthesis varies as a function of exposure time.

Ogata and Schramm (1971) reported that both cell walls and protoplasts of *Porphyra umbilicus* were swollen when cultured in hyposaline media. Gessner and Schramm (1971) conclude that swelling of algal cells in hyposomotic media is not restricted to the cell wall, or "free space", but also occurs in the protoplast. High turgor pressures resulting from either slow or rapid water uptake may affect photosynthesis either by altering the three dimensional structure of the protoplast, thereby affecting enzyme kinetics related to photosynthesis, or by causing disruption of the cell membrane, thereby allowing ion loss directly from the protoplast, or both.

Another possible mechanism by which reduced salinity would effect photosynthesis is by changing the nature and the amount of the carbon supply. Changes in salinity, osmotic pressure, pH and carbon supply in seawater are inseparably associated; as the salinity decreases so does the pH and total carbon supply (Ogata and Matsui, 1965). Hammer (1968) found that marine plants, phanerogams as well as algae, show a proportional decrease in photosynthetic rate when the salinity is lowered by dilution with distilled water. In addition, she found that if tapwater was used it was absolutely necessary to consider the carbon content. If freshwater with low alkalinity was used, photosynthetic rates decreased, but if freshwater with high bicarbonate content was used, photosynthetic rates were higher than in seawater.

Truly marine algae have lesser capacities for osmoregulation and turgor regulation. Most stenohaline marine algae tend to remain hyperosmotic and to establish fairly constant osmotic gradients over the salinity range tolerated (Gessner and Schramm, 1971). The short stipe form of *Laminaria groenlandica* has been demonstrated to be stenohaline and relatively stenothermal. Its distribution is restricted to localities having moderate wave action and little to moderate seasonal variation in salinity (25-32^{0}/oo) and temperature (2-17^{o}C)

(Druehl, 1967b). The response of the net photosynthetic rate of *Laminaria groenlandica* to reduced salinity in this experiment concurs with the effect of this factor on its geographical distribution. Thus at salinities less than 25°/oo there was a steady decrease in the rate of net photosynthesis, the depression being statistically significant at salinities less than 22°/oo.

A general stimulation of net photosynthesis occurred at very low concentrations of both sewage effluent and tapwater and was followed by a depression to an initial minimum at slightly higher concentrations (= slightly lower salinities). The initial minimum was followed by an increase in photosynthesis to a secondary maximum which, with the discs in tapwater-diluted seawater, occurred at a concentration of 200 ppt. The salinity at this concentration was close to 25°/oo the lowest salinity which *Laminaria groenlandica* will tolerate under field conditions (Druehl, 1967b). The osmoregulatory mechanisms of *Laminaria groenlandica* must therefore be able to maintain a constant osmotic gradient over the salinity range tolerated. At concentrations greater than 200 ppt, net photosynthetic rates steadily decreased.

The consistent presence of the two peaks may be indicative of the sequential activity of two mechanisms. The initial peak is related to a stimulation of photosynthesis by a minor reduction of salinity. The actual reason for this stimulation is not known. Nellen, as reported by Gessner and Schramm (1971), has shown that short-term stimulations of photosynthesis occur in *Delesseria sanguinea* and *Fucus serratus* upon any change in salinity. Through its "free space", *Laminaria groenlandica* can apparently cope with the degree of ion loss and water uptake at slightly reduced salinities. The ability of the "free space" to cope is rapidly diminished as the salinity is further reduced and, at a salinity of 28°/oo, is at a minimum. At this salinity, blade tissues of *Laminaria groenlandica* exhibit the initial minimum rate of net photosynthesis. Once this level is reached the tissues will experience osmotic stress and lose ions from the protoplast, by the process of exosmosis, unless an osmoregulatory mechanism involving active transport begins functioning. The attainment of the secondary maximum rate of net photosynthesis at salinities lower than those responsible for the initial minimum may therefore be directly related to the functioning of an active transport mechanism. The subsequent depression of net photosynthesis at even lower salinities is likely due to the inability of the active transport mechanism to maintain the cytoplasmic osmoconcentration.

2. Dark Respiration Rate

The dark respiration rate of basal and distal discs of *Laminaria groenlandica* responded irregularly to increasing concentrations of effluent and decreasing salinity. A similar irregular response to decreasing salinity was noted by Druehl (1967b). The rate of oxygen uptake was significantly depressed at several concentrations in test media.

The dark respiration rate of basal discs was greater than the rate of distal discs at most concentrations in test and control media. The relative increase in respiration in the meristematic tissues at the base of the blade is probably associated with the rapid rate of cell division in this tissue. Nath (1967) found that respiratory rates of *Laminaria saccharina* were highest in the basal meristematic tissues and decreased towards the tip of the blade.

The relation between respiratory rates and salinity have been dealt with in very few papers. Gessner and Schramm (1971), in review of the little information available, concluded that only at very low or very high salinities will the osmotic processes interfere with and directly influence the intensity of algal respiration.

There appeared to be a relationship between the initial dissolved oxygen concentration and the rate of dark respiration, particularly at high concentrations of effluent. A linear regression analysis was performed to determine if the relationship was significant. Table 7.6 lists the complete anova tables with regression. A significant linear regression ($P< 0.05$) was indicated between the dark respiration rate of basal discs in test media and initial oxygen concentration. Distal discs in test media and basal and distal discs in control media had non-significant linear regressions. Scatter plots of the dark respiration rates of basal and distal discs in test and control media are given in Figure 7.8. The regression line and regression equation for basal discs in test media are indicated.

The regression analysis indicates that when the oxygen supply in test media falls below a certain critical level, the rate of dark respiration of basal tissue is proportional to the concentration of dissolved oxygen. The relationship between respiration rates and

Table 7.6. Complete ANOVA tables with regression statistics. Linear regression analysis: dark respiration rates versus initial oxygen concentration.

1. Test Media (Sewage Effluent)

a) Basal Discs

Source of Variation	df	SS	MS	F
Among	9	9.4227	1.0469	6.3680^{***}
Linear regression	1	4.8257	4.8257	8.3983^{*}
Deviations from regression	8	4.5970	0.5746	3.4950^{**}
Within	30	4.9330	0.1644	
Total	39	14.0602		

b) Distal Discs

Source of Variation	df	SS	MS	F
Among	9	8.2567	0.9174	4.7931^{***}
Linear regression	1	2.6797	2.6797	3.8440^{ns}
Deviations from regression	8	5.5770	0.6971	3.6420^{**}
Within	30	5.7441	0.1914	
Total	39	14.0008		

2. Control Media (Tapwater)

a) Basal Discs

Source of Variation	df	SS	MS	F
Among	9	2.7676	0.3075	2.8846^{**}
Linear regression	1	0.0047	0.0047	0.0136^{ns}
Deviations from regression	8	2.7629	0.3454	3.2400^{**}
Within	30	3.2000	0.1066	
Total	39	5.9676		

b) Distal Discs

Source of Variation	df	SS	MS	F
Among	9	4.6688	0.5187	1.6571^{ns}
Linear regression	1	1.3828	1.3828	3.366^{ns}
Deviations from regression	8	3.2860	0.4108	1.3125^{ns}
Within	30	9.3914	0.3130	
Total	39	14.0602		

$F_{.001\ (9,30)} = 4.39$ $F_{.005\ (8,30)} = 3.58$ $F_{.05\ (1,8)} = 5.32$

$F_{.05\ (9,30)} = 2.21$ $F_{.01\ (8,30)} = 3.17$ $F_{.025\ (1,8)} = 7.57$

$F_{.01\ (9,30)} = 3.07$ $F_{.05\ (8,30)} = 2.27$

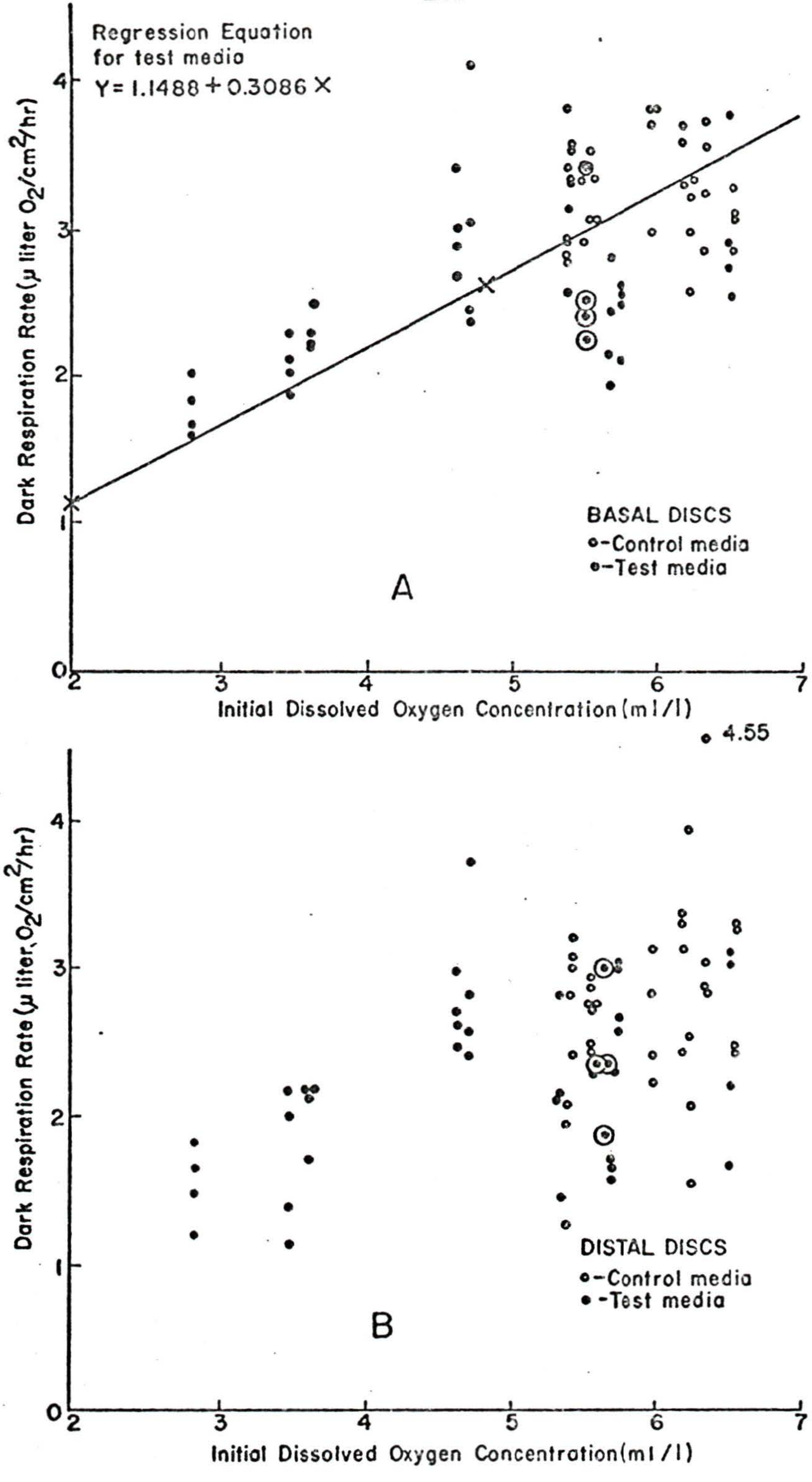


Figure 7.8. Scatter plots of dark respiration rates of basal (A) and distal (B) discs of *Laminaria groenlandica* in test and control media versus initial dissolved oxygen concentration. The line and equation for the significant linear regression of basal discs in test media are indicated.

oxygen concentration has been demonstrated in the past. Gessner and Pannier (1958) found that the respiratory rate of phytoplankton was depressed with a reduction in the ambient oxygen supply. Nath (1967) tested the rates of respiration of various brown and green algae at different oxygen saturations and found that respiratory activity was always proportional to the degree of oxygen saturation.

Depressed respiratory activity produced as a consequence of the low oxygen supply in sewage effluent is of basic ecological importance. Since active transport requires energy derived from respiration (Gessner and Schramm, 1971), low levels of oxygen in the surface waters adjacent to outfalls could affect the capacity of this mechanism to cope with the osmotic stress provided by the reduced salinity of these waters. Oxygen concentration could then indirectly influence the tolerance of marine algae to reduced salinity.

The significant depression of dark respiration recorded in both basal and distal discs in test media at 10 ppt can not be attributed to reduced oxygen supply. It is possible that some component of sewage effluent, possibly a phenolic substance, was active in depressing the rate of dark respiration of *Laminaria groenlandica* as has been demonstrated with *Laminaria hyperborea* (Hopkin and Kain, 1971).

At salinities of $19^0/oo$ or lower, the rate of dark respiration of distal discs was equal to or greater than the rate of photosynthesis (Figure 7.6). The basal discs (Figure 7.5) had generally lower net photosynthetic and higher dark respiration rates than the distal discs throughout the whole range of salinities tested, and, in addition to exhibiting higher rates of dark respiration than net photosynthesis at salinities of 22°/oo or lower, also had higher respiration than photosynthetic rates during the initial photosynthetic minimum. Salinities as low as 20°/oo have been recorded on only one occasion near a shoreline-discharging sewage outfall (Ellis and Littlepage, 1972).

Druehl (1967b) demonstrated that after five days exposure to seawater medium at 28°/oo, or lower, and at 13°C, discs of adult blade tissues of *Laminaria groenlandica* exhibited no net oxygen production after a two hour light period. The mean dark respiration rate under the same temperature conditions increased from 1.6 µl $O_2/cm^2/hr.$ at 28°/oo to 2.2 µl $O_2/cm^2/hr.$ at 20°/oo. Surface temperatures at 13°C and salinities of 28°/oo were frequently concurrent at both Macaulay Point and Clover Point during the summer months. On the basis of Druehl's results, it is assumed that the *in situ* rate of net photosynthesis of *Laminaria groenlandica* would be greatly depressed under these conditions; the degree of depression would probably be related to the persistance of the stressing conditions.

If the rates of net photosynthesis and dark respiration exhibited at low salinities are extrapolated to cover equal 12 hour light and dark periods, the net daily production of organic matter will be very low, nil or even negative at very reduced salinities. If the temperature is incremented, the salinity at which there will be zero net daily production will be higher in proportion to the degree of increase. In view of the relatively low net production of the basal tissues exhibited in this experiment, it is possible that the photosynthetic production of organic matter by these tissues is not sufficient to maintain active growth at low salinities. While translocation of photosynthates from distal to basal blade tissues is known to occur in several species of *Laminaria* (Luning, Schmitz and Willenberg, 1972), the amount will decrease with decreasing salinity. Thus it is possible that at low salinities the growth of the whole sporophyte will be inhibited. If the salinity is depressed over an extended period of time, particularly if complimented by increased temperature, a form of starvation will occur as the food stores are depleted. This is the probable mechanism by which temperature and salinity control the distribution of marine algae.

Druehl (1967a) showed that in an inlet with vertical stratification of temperature and salinity, species of marine algae were oriented at levels determined by their tolerance to these factors. The upper limits of species which inhabited the lower intertidal and upper subtidal regions at the mouth of the inlet, were depressed into the subtidal region at the head of the inlet where the surface temperature was highest and the salinity lowest. As a result of Druehl's findings, it is felt that the ability of an intertidal alga to maintain itself at a particular level on the shore is directly related to the conditions of temperature and salinity and their control of the amount of net production over time. The significant depression of the upper limits of whole zonal associations (*Phyllospadix* and red algal zones), as well as of individual species of macro-Phaeophyte algae at

Clover Point, can therefore be attributed to a metabolic response to the marine flora to the conditions of increased temperature and reduced salinity produced in that area by the discharge of sewage effluent. The more notable alterations evident at Macaulay Point, during the spring of 1971, could then be attributed either to the depression of the upper limits of certain species into the subtidal region, or the complete loss of sensitive species from the area, or both. These responses would be directly related to the large volume of discharge and the relatively slower rate of dilution and dissemination of the effluent from the shoreline outfall at that site.

E. SUMMARY

The freshwater component of sewage effluent was largely responsible for the significant depression of net photosynthesis of *Laminaria groenlandica* at high concentrations of tapwater and sewage effluent. Depression of net photosynthetic rates are believed due to the inability of the osmoregulatory mechanisms to cope with osmotic stress produced at salinities less than $25^{0}/oo$. This concurs with the limiting effect of salinities below this level on the geographical distribution of *Laminaria groenlandica*. Some component of sewage effluent other than freshwater was active in further depressing the rate of net photosynthesis. The nature of this component is not known, but various detergents and phenolic substances have been implicated in the literature.

The dark respiration rate of *Laminaria groenlandica* varied irregularly with increasing concentration of effluent and tapwater. Regression analysis indicated that at concentrations of dissolved oxygen less than some critical level, the rate of dark respiration is proportional to oxygen concentration. However, significant regression was apparent only in the rates of basal discs in test media.

An attempt was been made to explain the depressions of the upper limits of whole zonal associations, as well as individual species of intertidal macroalgae in terms of temperature/salinity controlled levels of net production.

PART VIII. SUMMARY

1. An initial survey, using species counts as a measure of diversity and algal community structure, and measurements of zonal elevations to determine the vertical distribution of intertidal dominants, indicated that the response of the intertidal macroalgal community to the presence of sewage effluent could be related to the volume and means of discharge as well as the rate of sewage field dilution and dissemination. The most obvious effects were observed at Macaulay Point where a shoreline outfall discharged a large volume of effluent into a receiving area subject to relatively reduced tidal currents. More subtle effects were observed at Clover Point where a smaller volume of effluent was discharged into waters subject to rapid tidal currents. No detectable effects were noted near the Finnerty Cove Outfall which discharged a small volume of effluent offshore, in an area subject to rapid tidal currents. Species characteristic of the lower intertidal and upper subtidal regions were most sensitive to the presence of sewage effluent.
2. The continuous discharge of sewage effluent at Clover Point has resulted in a significant depression of the upper limits of the *Phyllospadix* and red algal zones at that site. The *Phyllospadix* population at Macaulay Point showed signs of recovery in 1972 following the cessation of discharge from the shoreline outfall in 1971.

3. Only three species of macro-Phaeophyte algae were present intertidally at Macaulay Point in 1971. By the spring of 1972 six additional species of macro-Phaeophyte algae had established intertidal populations at this site; of these, five had significantly higher upper limits than corresponding populations at Clover Point.
4. Populations of *Laminaria groenlandica*, *Egregia menziesii* and *Nereocystis luetkeana* at Clover Point were monitored to determine the effects of sewage effluent on their *in situ* rates of growth. With the techniques employed, no significant differences in growth rate were apparent between the test populations at Clover Point and the control populations at Albert Head.
5. The freshwater component of sewage effluent was largely responsible for the significant depression of net photosynthesis of *Laminaria groenlandica* at high concentrations of effluent and tapwater. The depression is believed due to the inability of the osmoregulatory mechanisms to cope with osmotic stress produced at low salinities. This is concurrent with the limiting effect of low salinity on the geographical distribution of this species. Some component of sewage effluent other than freshwater, possibly detergent or a phenolic substance, was active in further depressing the rate of net photosynthesis. The dark respiration rate of *Laminaria groenlandica* was generally unaffected by reduced salinity at the experimental temperature. However, the dark respiration rate of basal discs in test media was significantly affected by the reduced oxygen supply at high concentrations of effluent.

6. An attempt was made to explain the depressions of the upper limits of whole zonal associations, as well as individual species of intertidal macroalgae, in terms of temperature/salinity controlled levels of net production.

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APPENDIX I

UNIVERSITY OF VICTORIA

Photosynthetic and respiratory rates of macroalgae measured by the Gaarder and Gran light and dark bottle oxygen method.

Experiment # 1 Date Nov. 8, 1972 Algal Species *L. groenlandica*

Disc area (A) 33 Cm^2 Conc. sewage effluent 0 ppt. Salinity 31.00 °/oo

Illumination .019 ly/min. Volume B.O.D. Bottle (v) .294 1

Water temp. start 8.0 °C Water temp. end 7.8 °C

	LB + SE + ALGA (TEST)							
	1		2		3		4	
	A	B	A	B	A	B	A	B
D.O. End (ml/l) = O_E	7.04	7.09	6.50	7.27	7.13	6.82	6.84	7.34
Net Photosynthesis[1]	6.64	6.86	4.23	7.66	7.04	5.66	5.75	7.97

D.O. Start (ml/l) = O_S 5.55

Time start 0945 Time end 1145 Duration (hr)=N 2

	LB + TW + ALGA (CONTROL)							
	5		6		7		8	
	A	B	A	B	A	B	A	B
D.O. End (ml/l)=O_E								
Net Photosynthesis[1]								

D.O. Start (ml/l)=O_S

Time start Time end Duration (hr)=N

	DB + SE + ALGA (TEST)								DB + SE
	9		10		11		12		13
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	4.29	4.23	4.22	4.23	3.77	4.45	4.17	3.95	5.30
Algal Respiration[3]	2.25	2.38	2.41	2.38	3.41	1.89	2.52	3.01	
D.O. Start (ml/l)=O_S 5.63								Bacterial Respiration[2]	24.26

Time start 1310 Time end 1710 Duration (hr)=N 4

	DB + TW + ALGA (CONTROL)								DB + TW
	14		15		16		17		18
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E									
Algal Respiration[3]									
D.O. Start (ml/l) = O_S								Bacterial Respiration[2]	

Time start Time end Duration (hr)=N

[1] Net Photosynthesis, µ liter $O_2/cm^2/hr = P_n = (((O_E-O_S)1000V)/A)/N$

[2] Bacterial Respiration, µ liter $O_2/hr = R_B = ((O_S-O_E)1000V)/N$

[3] Algal Respiration, µ liter $O_2/cm^2/hr = R_A = ((((O_S-O_E)1000V)/N)-R_B)/A$

UNIVERSITY OF VICTORIA

Photosynthetic and respiratory rates of macroalgae measured by the Gaarder and Gran light and dark bottle oxygen method.

Experiment # 2 Date Nov. 10, 1972 Algal Species *L. groenlandica*

Disc area (A) 33 Cm^2 Conc. sewage effluent 1 ppt. Salinity 30.9 $^0/_{oo}$

Illumination .019 ly/min. Volume B.O.D. Bottle (v) .294 l

Water temp. start 7.7 ^oC Water temp. end 7.6 ^oC

	LB + SE + ALGA (TEST)							
	1		2		3		4	
	A	B	A	B	A	B	A	B
D.O. End (ml/l) = O_E	7.08	8.05	8.08	8.52	8.04	8.22	7.75	7.68
Net Photosynthesis[1]	2.76	7.08	7.22	9.18	7.04	7.84	5.75	5.43

D.O. Start (ml/l) = O_s 6.46
Time start 1030 Time end 1230 Duration (hr)=N 2

	LB + TW + ALGA (CONTROL)							
	5		6		7		8	
	A	B	A	B	A	B	A	B
D.O. End (ml/l)=O_E	7.69	8.41	7.62	7.97	7.11	8.31	7.92	8.68
Net Photosynthesis[1]	5.48	8.69	5.17	6.73	2.90	8.24	6.50	9.89

D.O. Start (ml/l)=O_s 6.46
Time start 1030 Time end 1230 Duration (hr)=N 2

	DB + SE + ALGA (TEST)								DB + SE
	9		10		11		12		13
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	5.25	5.39	5.07	5.62	5.14	5.02	4.68	4.99	6.38
Algal Respiration[3]	2.52	2.21	2.92	1.69	2.76	3.03	3.79	3.10	

D.O. Start (ml/l)=O_s 6.52 Bacterial Respiration[2] 10.29
Time start 1330 Time end 1730 Duration (hr)=N 4

	DB + TW + ALGA (CONTROL)								DB + TW
	14		15		16		17		18
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	4.80	4.72	4.82	4.73	4.72	5.09	4.92	5.11	6.20
Algal Respiration[3]	3.12	3.30	3.07	3.27	3.30	2.47	2.85	2.43	

D.O. Start (ml/l) = O_s 6.56 Bacterial Respiration[2] 26.46
Time start 1330 Time end 1730 Duration (hr)=N 4

[1] Net Photosynthesis, μ liter $O_2/cm^2/hr = P_n = (((O_E - O_s)1000V)/A)/N$

[2] Bacterial Respiration, μ liter $O_2/hr = R_B = ((O_s - O_E)1000V)/N$

[3] Algal Respiration, μ liter $O_2/cm^2/hr = R_A = ((((O_s - O_E)1000V)/N) - R_B)/A$

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Photosynthetic and respiratory rates of macroalgae measured by the Gaarder and Gran light and dark bottle oxygen method.

Experiment # 3 Date Nov. 22, 1972 Algal Species *L. groenlandica*

Disc area (A) 33 Cm^2 Conc. sewage effluent 10 ppt. Salinity 30.76 ^{o}/oo

Illumination .019 ly/min. Volume B.O.D. Bottle (v) .294 l

Water temp. start 8.5 ^{o}C Water temp. end 7.7 ^{o}C

	LB + SE + ALGA (TEST)							
	1		2		3		4	
	A	B	A	B	A	B	A	B
D.O. End (ml/l) = O_E	6.98	7.82	7.65	8.21	7.65	8.10	7.57	7.57
Net Photosynthesis[1]	4.14	7.88	7.13	9.62	7.13	9.13	6.77	6.77

D.O. Start (ml/l) = O_S 6.05

Time start 1000 Time end 1200 Duration (hr)=N 2

	LB + TW + ALGA (CONTROL)							
	5		6		7		8	
	A	B	A	B	A	B	A	B
D.O. End (ml/l)=O_E	7.91	8.00	7.70	8.01	7.30	7.70	7.52	8.00
Net Photosynthesis[1]	9.27	9.67	8.33	9.71	6.55	8.33	7.53	9.67

D.O. Start (ml/l)=O_S 5.83

Time start 1000 Time end 1200 Duration (hr)=N 2

	DB + SE + ALGA (TEST)								DB + SE
	9		10		11		12		13
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	4.29	4.63	4.51	4.61	4.40	4.69	4.17	4.34	5.38
Algal Respiration[3]	2.43	1.67	1.94	1.72	2.18	1.57	2.70	2.32	

D.O. Start (ml/l)=O_S 5.69 Bacterial Respiration[2] 22.79

Time start 1330 Time end 1730 Duration (hr)=N 4

	DB + TW + ALGA (CONTROL)								DB + TW
	14		15		16		17		18
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	4.07	4.06	3.91	4.09	3.88	4.29	3.92	4.26	5.38
Algal Respiration[3]	2.92	2.94	3.27	2.87	3.34	2.43	3.25	2.49	

D.O. Start (ml/l) = O_S 5.51 Bacterial Respiration[2] 9.56

Time start 1330 Time end 1730 Duration (hr)=N 4

[1] Net Photosynthesis, μ liter $O_2/cm^2/hr = P_n = (((O_E - O_S)1000V)/A)/N$

[2] Bacterial Respiration, μ liter $O_2/hr = R_B = ((O_s - O_E)1000V)/N$

[3] Algal Respiration, μ liter $O_2/cm^2/hr = R_A = ((((O_s - O_E)1000V)/N) - R_B)/A$

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Photosynthetic and respiratory rates of macroalgae measured by the Gaarder and Gran light and dark bottle oxygen method.

Experiment # 4 Date Nov. 24, 1972 Algal Species *L. groenlandica*
Disc area (A) 24.25 Cm^2 Conc. sewage effluent 25 ppt. Salinity 30.31 °/oo
Illumination .019 ly/min. Volume B.O.D. Bottle (v) .2941
Water temp. start 10.0 °C Water temp. end 7.8 °C

	LB + SE + ALGA (TEST)							
	1		2		3		4	
	A	B	A	B	A	B	A	B
D.O. End (ml/l) = O_E	6.04	5.93	5.36	6.45	5.51	5.64	6.20	6.69
Net Photosynthesis[1]	4.43	3.76	0.30	6.91	1.21	2.00	5.40	8.37

D.O. Start (ml/l) = O_S 5.31
Time start 1030 Time end 1230 Duration (hr)=N 2

	LB + TW + ALGA (CONTROL)							
	5		6		7		8	
	A	B	A	B	A	B	A	B
D.O. End (ml/l)=O_E	6.99	7.03	6.36	6.81	6.80	7.12	6.70	7.16
Net Photosynthesis[1]	8.85	9.09	5.03	7.76	7.70	9.64	7.09	9.88

D.O. Start (ml/l)=O_S 5.53
Time start 1030 Time end 1230 Duration (hr)=N 2

	DB + SE + ALGA (TEST)								DB + SE
	9		10		11		12		13
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	4.39	4.52	4.38	4.74	4.26	4.29	4.18	4.51	5.22
Algal Respiration[3]	2.52	2.12	2.55	1.46	2.91	2.82	3.15	2.15	

D.O. Start (ml/l)=O_S 5.39 Bacterial Respiration[2] 12.50
Time start 1500 Time end 1900 Duration (hr)=N 4

	DB + TW + ALGA (CONTROL)								DB + TW
	14		15		16		17		18
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	3.96	4.53	4.09	4.80	4.29	4.29	4.25	4.58	5.22
Algal Respiration[3]	3.82	2.09	3.42	1.27	2.82	2.82	2.94	1.94	

D.O. Start (ml/l) = O_S 5.38 Bacterial Respiration[2] 11.76
Time start 1500 Time end 1900 Duration (hr)=N 4

[1] Net Photosynthesis, μ liter $O_2/cm^2/hr = P_n = (((O_E - O_S)1000V)/A)/N$

[2] Bacterial Respiration, μ liter $O_2/hr = R_B = ((O_S - O_E)1000V)/N$

[3] Algal Respiration, μ liter $O_2/cm^2/hr = R_A = ((((O_S - O_E)1000V)/N) - R_B)/A$

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Photosynthetic and respiratory rates of macroalgae measured by the Gaarder and Gran light and dark bottle oxygen method.

Experiment # 5 Date Nov. 29, 1972 Algal Species *L. groenlandica*
Disc area (A) 24.25 Cm^2 Conc. sewage effluent 50 ppt. Salinity 29.50°/oo
Illumination .019 ly/min. Volume B.O.D. Bottle (v) .294 l
Water temp. start 8.0 °C Water temp. end 7.8 °C

	LB + SE + ALGA (TEST)							
	1		2		3		4	
	A	B	A	B	A	B	A	B
D.O. End (ml/l) = O_E	5.82	7.04	6.46	6.92	5.75	6.57	6.19	6.21
Net Photosynthesis[1]	1.09	8.49	4.97	7.76	0.67	5.64	3.33	3.46

D.O. Start (ml/l) = O_s 5.64
Time start 0930 Time end 1130 Duration (hr)=N 2

	LB + TW + ALGA (CONTROL)							
	5		6		7		8	
	A	B	A	B	A	B	A	B
D.O. End (ml/l)=O_E	6.75	7.16	7.00	7.34	6.42	7.14	6.54	6.61
Net Photosynthesis[1]	5.76	8.24	7.27	9.34	3.76	8.43	4.49	4.91

D.O. Start (ml/l)=O_s 5.80
Time start 0930 Time end 1130 Duration (hr)=N 2

	DB + SE + ALGA (TEST)								DB + SE
	9		10		11		12		13
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	4.52	4.82	4.67	4.71	4.51	4.85	4.53	4.70	5.70
Algal Respiration[3]	3.58	2.67	3.12	3.00	3.61	2.58	3.55	3.03	
Bacterial Respiration[2]									2.94

D.O. Start (ml/l)=O_s 5.74 Bacterial Respiration[2] 2.94
Time start 1300 Time end 1700 Duration (hr)=N 4

	DB + TW + ALGA (CONTROL)								DB + TW
	14		15		16		17		18
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	4.26	4.51	4.40	4.51	4.31	4.65	4.40	4.52	5.42
Algal Respiration[3]	3.52	2.76	3.09	2.76	3.36	2.33	3.09	2.73	
Bacterial Respiration[2]									9.56

D.O. Start (ml/l) = O_s 5.55 Bacterial Respiration[2] 9.56
Time start 1300 Time end 1700 Duration (hr)=N 4

[1] Net Photosynthesis, μ liter $O_2/cm^2/hr = P_n = (((O_E-O_s)1000V)/A)/N$

[2] Bacterial Respiration, μ liter $O_2/hr = R_B = ((O_s-O_E)1000V)/N$

[3] Algal Respiration, μ liter $O_2/cm^2/hr = R_A = ((((O_s-O_E)1000V)/N)-R_B)/A$

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Photosynthetic and respiratory rates of macroalgae measured by the Gaarder and Gran light and dark bottle oxygen method.

Experiment # 6 **Date** Dec. 1, 1972 **Algal Species** *L. groenlandica*

Disc area (A) 24.25 **Cm²** **Conc. sewage effluent** 100 **ppt. Salinity** 28.01 **°/oo**

Illumination .019 **ly/min. Volume B.O.D. Bottle (v)** .294 1

Water temp. start 8.4 **°C Water temp. end** 7.8 **°C**

	LB + SE + ALGA (TEST)							
	1		2		3		4	
	A	B	A	B	A	B	A	B
D.O. End (ml/1) = O_E	5.84	5.98	5.84	6.06	6.04	6.28	5.19	5.53
Net Photosynthesis[1]	6.12	6.97	6.12	7.46	7.34	8.79	2.18	4.24

D.O. Start (ml/1) = O_s 4.83
Time start 0930 **Time end** 1130 **Duration (hr)=N** 2

	LB + TW + ALGA (CONTROL)							
	5		6		7		8	
	A	B	A	B	A	B	A	B
D.O. End (ml/1)=O_E	6.55	7.25	6.30	6.63	6.21	6.58	6.34	6.71
Net Photosynthesis[1]	4.55	8.79	3.03	5.03	2.49	4.73	3.27	5.52

D.O. Start (ml/1)=O_s 5.80
Time start 0930 **Time end** 1130 **Duration (hr)=N** 2

	DB + SE + ALGA (TEST)								DB + SE
	9		10		11		12		13
	A	B	A	B	A	B	A	B	
D.O. End (ml/1)=O_E	3.89	3.47	3.69	3.91	3.91	3.66	3.34	3.77	4.70
Algal Respiration[3]	2.46	3.73	3.06	2.39	2.39	2.55	4.12	2.82	

D.O. Start (ml/1)=O_s 4.72 **Bacterial Respiration[2]** 1.47
Time start 1300 **Time end** 1700 **Duration (hr)=N** 4

	DB + TW + ALGA (CONTROL)								DB + TW
	14		15		16		17		18
	A	B	A	B	A	B	A	B	
D.O. End (ml/1)=O_E	4.23	4.60	4.29	4.34	4.30	4.38	4.22	4.41	5.40
Algal Respiration[3]	3.55	2.43	3.36	3.21	3.33	3.09	3.58	3.00	

D.O. Start (ml/1) = O_s 5.42 **Bacterial Respiration[2]** 1.47
Time start 1300 **Time end** 1700 **Duration (hr)=N** 4

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[1] Net Photosynthesis, μ liter $O_2/cm^2/hr = P_n = (((O_E - O_s)1000V)/A)/N$

[2] Bacterial Respiration, μ liter $O_2/hr = R_B = ((O_s - O_E)1000V)/N$

[3] Algal Respiration, μ liter $O_2/cm^2/hr = R_A = ((((O_s - O_E)1000V)/N) - R_B)/A$

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Photosynthetic and respiratory rates of macroalgae measured by the Gaarder and Gran light and dark bottle oxygen method.

Experiment # 7 Date Dec. 6, 1972 Algal Species *L. groenlandica*

Disc area (A) 24.25 Cm^2 Conc. sewage effluent 200 ppt. Salinity 24.97 °/oo

Illumination .019 ly/min. Volume B.O.D. Bottle (v) .294 l

Water temp. start 8.5 °C Water temp. end 8.0 °C

	LB + SE + ALGA (TEST)							
	1		2		3		4	
	A	B	A	B	A	B	A	B
D.O. End (ml/l) = O_E	5.15	5.36	4.93	5.04	4.91	5.29	4.96	5.17
Net Photosynthesis[1]	4.85	6.12	3.52	4.18	3.40	5.70	3.70	4.97

D.O. Start (ml/l) = O_s 4.35

Time start 1030 Time end 1230 Duration (hr)=N 2

	LB + TW + ALGA (CONTROL)							
	5		6		7		8	
	A	B	A	B	A	B	A	B
D.O. End (ml/l)=O_E	6.98	7.41	7.27	7.70	6.43	6.84	6.87	7.10
Net Photosynthesis[1]	5.27	7.88	7.03	9.64	1.94	4.43	4.61	6.00

D.O. Start (ml/l)=O_S 6.11

Time start 1030 Time end 1230 Duration (hr)=N 2

	DB + SE + ALGA (TEST)								DB + SE
	9		10		11		12		13
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	3.50	3.59	3.54	3.51	3.60	3.68	3.36	3.63	4.49
Algal Respiration[3]	3.00	2.73	2.88	2.97	2.70	2.46	3.42	2.61	

D.O. Start (ml/l)=O_S 4.64 Bacterial Respiration[2] 11.03

Time start 1400 Time end 1800 Duration (hr)=N 4

	DB + TW + ALGA (CONTROL)								DB + TW
	14		15		16		17		18
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	4.72	5.18	4.72	5.25	4.76	4.95	5.00	5.05	5.98
Algal Respiration[3]	3.82	2.42	3.82	2.21	3.70	3.12	2.97	2.82	

D.O. Start (ml/l) = O_S 5.98 Bacterial Respiration[2] 0

Time start 1400 Time end 1800 Duration (hr)=N 4

[1] Net Photosynthesis, μ liter $O_2/cm^2/hr = P_n = (((O_E-O_s)1000V)/A)/N$

[2] Bacterial Respiration, μ liter $O_2/hr = R_B = ((O_s-O_E)1000V)/N$

[3] Algal Respiration, μ liter $O_2/cm^2/hr = R_A = ((((O_s-O_E)1000V)/N)-R_B)/A$

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Photosynthetic and respiratory rates of macroalgae measured by the Gaarder and Gran light and dark bottle oxygen method.

Experiment # 8 **Date** Dec. 8, 1972 **Algal Species** *L. groenlandica*

Disc area (A) 24.25 **Cm^2 Conc. sewage effluent** 300 **ppt. Salinity** 21.78 **‰**

Illumination .019 **ly/min. Volume B.O.D. Bottle (v)** .294 1

Water temp. start 8.0 **°C Water temp. end** 7.7 **°C**

	LB + SE + ALGA (TEST)							
	1		2		3		4	
	A	B	A	B	A	B	A	B
D.O. End (ml/l) = O_E	4.11	4.17	3.76	3.71	3.56	3.82	3.77	3.88
Net Photosynthesis[1]	2.91	3.27	0.79	0.49	-0.42	1.15	0.85	1.52

D.O. Start (ml/l) = O_S 3.63
Time start 0930 **Time end** 1130 **Duration (hr)=N** 2

	LB + TW + ALGA (CONTROL)							
	5		6		7		8	
	A	B	A	B	A	B	A	B
D.O. End (ml/l)=O_E	6.83	6.80	6.12	6.94	6.87	7.01	7.08	6.86
Net Photosynthesis[1]	4.00	3.82	-0.30	4.67	4.24	5.09	5.52	4.18

D.O. Start (ml/l)=O_S 6.17
Time start 0930 **Time end** 1130 **Duration (hr)=N** 2

	DB + SE + ALGA (TEST)								DB + SE
	9		10		11		12		13
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	2.11	2.12	2.16	2.06	2.02	2.40	2.08	2.32	2.78
Algal Respiration[3]	2.03	2.00	1.88	2.18	2.30	1.15	2.12	1.39	

D.O. Start (ml/l)=O_S 3.49 **Bacterial Respiration[2]** 52.19
Time start 1300 **Time end** 1700 **Duration (hr)=N** 4

	DB + TW + ALGA (CONTROL)								DB + TW
	14		15		16		17		18
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	5.09	5.09	4.96	5.38	5.00	5.15	4.99	5.07	6.74
Algal Respiration[3]	3.30	3.30	3.70	2.42	3.58	3.12	3.61	3.36	

D.O. Start (ml/l) = O_S 6.18 **Bacterial Respiration[2]** 0
Time start 1300 **Time end** 1700 **Duration (hr)=N** 4

[1] Net Photosynthesis, μ liter $O_2/cm^2/hr = P_n = (((O_E - O_S)1000V)/A)/N$

[2] Bacterial Respiration, μ liter $O_2/hr = R_B = ((O_S - O_E)1000V)/N$

[3] Algal Respiration, μ liter $O_2/cm^2/hr = R_A = ((((O_S - O_E)1000V)/N) - R_B)/A$

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Photosynthetic and respiratory rates of macroalgae measured by the Gaarder and Gran light and dark bottle oxygen method.

Experiment # 9 Date Dec. 13, 1972 Algal Species *L. groenlandica*

Disc area (A) 24.25 Cm^2 Conc. sewage effluent 400 ppt. Salinity 18.80 °/oo

Illumination .019 ly/min. Volume B.O.D. Bottle (v) .294 l

Water temp. start 8.2 °C Water temp. end 8.0 °C

	LB + SE + ALGA (TEST)							
	1		2		3		4	
	A	B	A	B	A	B	A	B
D.O. End (ml/l) = O_E	4.34	4.00	3.83	3.91	4.11	4.04	3.80	3.87
Net Photosynthesis[1]	4.61	2.55	1.52	2.00	3.21	2.79	1.33	1.76

D.O. Start (ml/l) = O_S 3.58

Time start 0930 Time end 1130 Duration (hr)=N 2

	LB + TW + ALGA (CONTROL)							
	5		6		7		8	
	A	B	A	B	A	B	A	B
D.O. End (ml/l)=O_E	6.61	7.02	6.85	6.96	6.69	6.83	6.72	7.01
Net Photosynthesis[1]	1.21	3.70	2.85	3.33	1.70	2.55	1.88	3.64

D.O. Start (ml/l)=O_S 6.41

Time start 0930 Time end 1130 Duration (hr)=N 2

	DB + SE + ALGA (TEST)								DB + SE
	9		10		11		12		13
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	2.25	2.45	2.27	2.29	2.19	2.29	2.28	2.29	3.01
Algal Respiration[3]	2.30	1.70	2.24	2.18	2.49	2.18	2.21	2.18	

D.O. Start (ml/l)=O_S 3.63 Bacterial Respiration[2] 45.57

Time start 1300 Time end 1700 Duration (hr)=N 4

	DB + TW + ALGA (CONTROL)								DB + TW
	14		15		16		17		18
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	5.41	5.41	5.12	5.35	5.18	4.85	5.27	5.40	6.35
Algal Respiration[3]	2.85	2.85	3.73	3.03	3.55	4.55	3.27	2.88	

D.O. Start (ml/l) = O_S 6.35 Bacterial Respiration[2] 0

Time start 1300 Time end 1700 Duration (hr)=N 4

[1] Net Photosynthesis, μ liter $O_2/cm^2/hr = P_n = (((O_E-O_S)1000V)/A)/N$

[2] Bacterial Respiration, μ liter $O_2/hr = R_B = ((O_S-O_E)1000V)/N$

[3] Algal Respiration, μ liter $O_2/cm^2/hr = R_A = ((((O_S-O_E)1000V)/N)-R_B)/A$

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Photosynthetic and respiratory rates of macroalgae measured by the Gaarder and Gran light and dark bottle oxygen method.

Experiment # 10 **Date** Dec. 15, 1972 **Algal Species** *L. groenlandica*

Disc area (A) 24.25 Cm^2 **Conc. sewage effluent** 500 **ppt. Salinity** 15.64 °/oo

Illumination .019 **ly/min. Volume B.O.D. Bottle (v)** .294 l

Water temp. start 8.1 °C **Water temp. end** ____ °C

	LB + SE + ALGA (TEST)							
	1		2		3		4	
	A	B	A	B	A	B	A	B
D.O. End (ml/l) = O_E	3.65	3.84	3.46	3.41	3.61	3.84	3.82	3.45
Net Photosynthesis[1]	2.61	3.76	1.45	1.15	2.36	3.76	3.64	1.39

D.O. Start (ml/l) = O_S 3.22
Time start 0930 **Time end** 1130 **Duration (hr)=N** 2

	LB + TW + ALGA (CONTROL)							
	5		6		7		8	
	A	B	A	B	A	B	A	B
D.O. End (ml/l)=O_E	7.02	7.36	6.81	6.90	7.12	7.30	6.64	7.12
Net Photosynthesis[1]	2.30	4.37	1.03	1.58	2.91	4.00	0	2.91

D.O. Start (ml/l)=O_S 6.64
Time start 0930 **Time end** 1130 **Duration (hr)=N** 2

	DB + SE + ALGA (TEST)								DB + SE
	9		10		11		12		13
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	1.46	1.39	1.39	1.50	1.32	1.59	1.44	1.45	1.99
Algal Respiration[3]	1.61	1.82	1.82	1.49	2.03	1.21	1.67	1.64	
D.O. Start (ml/l)=O_S 2.83 **Bacterial Respiration[2]**									61.74

Time start 1330 **Time end** 1730 **Duration (hr)=N** 4

	DB + TW + ALGA (CONTROL)								DB + TW
	14		15		16		17		18
	A	B	A	B	A	B	A	B	
D.O. End (ml/l)=O_E	5.40	5.74	5.27	5.57	5.15	5.41	5.19	4.96	6.83
Algal Respiration[3]	2.58	1.55	2.97	2.06	3.33	2.55	3.21	3.91	
D.O. Start (ml/l) = O_S 6.25 **Bacterial Respiration[2]**									0

Time start 1330 **Time end** 1730 **Duration (hr)=N** 4

[1] Net Photosynthesis, μ liter $O_2/cm^2/hr = P_n = (((O_E - O_S)1000V)/A)/N$

[2] Bacterial Respiration, μ liter $O_2/hr = R_B = ((O_S - O_E)1000V)/N$

[3] Algal Respiration, μ liter $O_2/cm^2/hr = R_A = ((((O_S - O_E)1000V)/N) - R_B)/A$

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