GROWTH AND DISTRIBUTION OF THE VEGETATION OF A SOUTHERN FRASER DELTA MARSH

by

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The foreshore marshes of the Fraser River estuary are of great importance to migrating and resident waterfowl and shorebirds, transient juvenile salmonids, and to the many other components of the intricate estuarine food web. Urban residential, agricultural and industrial developments have encroached, and continue to encroach, upon these valuable foreshore marshes. This study was initiated to obtain information on the factors controlling, and characteristics of, the primary productivity, decomposition and spatial and temporal distributions of the emergent vegetation of Brunswick Point marsh.

Sampling locations were selected to cover elevational and salinity gradients in this brackish tidal marsh. Periodic harvesting of the aerial vegetation components was undertaken to estimate net primary productivity. In addition, shoot density, reproductive shoot numbers, and nitrogen content, among other vegetation characteristics were related to such environmental variables as salinity, temperature and elevation. Standing crops for *Scirpus maritimus* and *Carex lyngbyei* showed a positive association with elevation; peak standing crops were 565 g/m² and 909 g/m² respectively. Shoot densities, reproduction shoot numbers and nitrogen content all showed relationships with elevation. The growth rate of *Carex lyngbyei*, the most productive species, was very high, on the order of 20 g/m²/day in May and June.
During litter bag field trials, *Triglochin maritima* and *Salicornia virginica* decomposed much more rapidly than did *S. maritimus* and *C. lyngbyei*. In vitro decomposition studies reflected a similar pattern for these species.

Transplant studies of the species used in the decomposition investigations showed that *S. maritimus* tolerated the varied conditions at the four transplant sites best of all. The role of *S. maritimus* as a pioneer species in marsh succession at Brunswick Point was further supported by field observations and historical information. A simple succession pattern occurs in the Brunswick Point marsh where *S. maritimus* and *S. americanus* colonize the barren mud and sand flats and are succeeded by *C. lyngbyei*.

The emergent marshes of the Fraser River estuary have experienced major modifications during the past century and these may continue. Extensive dyking of high marsh areas has reduced the areal extent of foreshore marshes. The remaining marsh areas are an important source of detrital material which forms the basis of extensive estuarine food webs.
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1. INTRODUCTION

Each year the tidal marshes of the Fraser River delta foreshore undergo a cycle of life and death which forms the basis of an intricate food web which on the one hand supports waterfowl along the Pacific flyway, and on the other supports the vitally important salmon fishing industry. Each spring the marshes emerge from what appears to be bare mud in the winter months. Waterfowl on their northward migration stop in these marshes to rest and feed on the stored materials within the rootstocks of the plants and on the invertebrates in the marsh area; snowgeese in particular use the rhizomes of the marsh vegetation (Burgess 1970; Burton 1977). The vegetation grows rapidly during the months of May and June and by mid July a dense, waist-high field of green stretches seaward from the dykes. The average production of the Fraser River foreshore marshes has been calculated as 4.9 tons of dry matter per hectare (Yamanaka 1975); this can be contrasted to the average hay crop in the lower Fraser Valley which yields approximately 3.8 tons per hectare. Marsh-hawks, bitterns and ducks co-habit and nest in these areas; smaller birds such as marsh-wrens, blackbirds, and shorebirds such as dunlins and snipe are plentiful; their songs and chattering bring a new aspect to the life of the marsh. Insects are numerous and offer some support to the bird life but as grazers their effect on the vegetation is very limited (Smalley, 1959). Of large animals only the occasional muskrat or racoon can be seen. By late summer the vegetation takes on a golden tone and, as it scenesces is easily pushed down by wind and wave action. Bacteria, fungi and possibly other microorganisms colonize the dead leaves and the decay accelerates. Numerous invertebrates feed on the decaying vegetation and its associated microorganisms. Tidal cycles cause the decaying vegetation and the associated microorganisms (in combination known as detritus) to be shifted around in the marsh and often out to sea; winds and waves break the material allowing for more rapid decay.
In the fall months the waterfowl again stop in the marshes on their way south. During fall and winter the summer's accumulation of vegetation is broken apart, fed on by microorganisms and invertebrates and shifted to the estuary where it eventually feeds fish such as the herring and salmon. By the end of the winter the marsh areas has largely been swept clean of surface organic material.

It is difficult to estimate how much of the Fraser tidal marshes have been lost due to human activity. Dyking has been the prime reason for loss of marsh land; this was done in the last century and early in this century so few records of previous marsh areas are available. Impending alienations to the Fraser river foreshore marshes include airport expansion, land fill, marinas, more dyking, river training (with a possible reduction of sediment and nutrient flow to marsh areas) and nearby port expansion (Roberts Bank).

It is the objective of this study to explain some of the features important in the cycle of the emergent vegetation. The major part of this study is concerned with the Brunswick Point marsh, near Ladner, B. C. Some of the habitat factors are discussed; the productivity of the marshes is considered; as is the fate of the aerial vegetation as detritus. The question of plant establishment, the importance of certain environmental variables, and possible successional roles are discussed in relation to transplant experiments. Some historical changes of the marsh are documented by means of aerial photographs, and in a final discussion, the ecological role of the marsh is developed as a combination of the factors considered in the study. The objectives of the study can be recapitulated as follows:

a) to describe the emergent marsh communities from Brunswick Point to the Roberts Bank Superport jetty;

b) to assess the net primary production of the dominant marsh species and to relate this to various environmental factors;
c) to study the decomposition rate of four prime species under quasi-natural conditions and under laboratory conditions, with regard to environmental variables; and

d) to discern successional patterns within the marsh and relate these to the success of transplanting various species into different environmental conditions.
2. LITERATURE REVIEW

The literature on wetlands of the world is rapidly growing, especially for wetlands associated with river deltas since these are among the most densely populated and intensively exploited areas in the world. The literature reviewed below is restricted to those articles which appear to be relevant to the Pacific Coast situation.

2.1 MARSH HABITAT

The marshes on the Pacific Coast of North America are distinct from marshes found elsewhere (Chapman, 1974). Salt marshes occur throughout the world on gently sloping or protected coastlines. On the eastern coast of North America, where the continental shelf slopes gently, there are large expanses of salt marsh. The rugged, exposed nature of much of the Pacific coast has limited the development of marshes to protected bays or river estuaries (MacDonald and Barbour, 1974). Chapman (1960) observes, "...they (Pacific coast marshes) appear to be built on a sand substratum; and they are interesting because the succession of the different communities developed on them with increasing height above sea level appears to be very simple, as compared with the complex development found on other salt marshes."

2.1.1 DEVELOPMENT

Marsh expansion in a very general way depends on sediment accretion and/or isostatic uplift, as the topset beds of sand and mud reach a level where plants can grow (Redfield, 1972). Motion of sand in some areas may inhibit plant growth though sufficient elevation exists (Redfield, 1971). Once pioneer species become established the roots and shoots serve as baffles,
which may bring about increased deposition of fine sediments carried by tidal and other currents (Pestrong, 1965). Once fine sediment is trapped by a root mat it is seldom freed by water movements (Ginsburg and Lowenstam, 1958). The influence of vegetation on sediment was particularly evident in a case where the presence of seagrass (presumably Thalassia testudinum) resulted in the formation of elongate mud banks 1.2 to 2.4 meters deep over a rock seabed, where, without plant intervention, uniform strata of sediments could be expected (Ginsburg and Lowenstam, 1958). Seagrasses are on occasion considered to be precursors to marsh development.

A grading of sediments occurs in the marshes with the coarsest sediments near the lower reaches of channels and fine sediments at the higher elevations, a result of decreased flow velocities (Pestrong, 1972). Pestrong (1972) demonstrated that considerably more sediment is moved into the marsh system by the flood tide than is removed by the ebb tide. Greatest accumulation occurs at the leading edge of the marsh, thus accounting for the gradual spread of the marsh onto adjacent sand flats (Pestrong, 1972). Eilers (1975) at Nehalem Bay, Oregon observed a great increase in the rate of accretion once the marsh reached an elevation near MHHW (Mean Higher High Water); MHHW occurs at approximately 4.1 m above chart datum at Roberts Bank. At this point the frequency and duration of tidal inundation was considerably reduced and as a result, little detrital vegetation was removed from the marsh. The inundation period was still long enough to create predominantly anaerobic soil conditions and thus decomposition was inhibited. Eilers recognized another major step in marsh development which he established at the 2.8 m above MLLW (Mean Lower Low Water) mark. At this point, tidal inundation becomes negligible. As a result, terrestrial invertebrates invade the substrate, litter decomposition increases and the soil develops terrestrial characteristics. The marsh eventually ceases vertical growth and becomes a seral climax (Chapman, 1974).
Redfield (1972) observed stratification of inter-tidal marsh substrates and attributed it to annual variation in sedimentation. Fibrous layers were formed by algal mats and *Spartina* fragments during the growing season. During winter, storms and a lack of vegetative cover resulted in increased sand deposition. The presence of vegetation stimulates the deposition of fine sediments. Kellerhals and Murray (1969) observed a similar phenomenon in Boundary Bay, British Columbia, where alternation of blue-green algal mats in summer and sand in winter produced "a varve-like stratification". The accumulation of sediment by the algal mats was sufficient to raise the elevation of the area to a point where vascular plants could colonize.

2.1.2 PLANT RELATIONS TO TIDAL REGIME

Tidal factors have received considerable attention in the literature because they are the most obvious environmental variables influencing the coastal marshes. W. F. Gagnon's (1903) investigation of the marshes in the Bay of Fundy concluded that the observed zonation reflected the individual species' abilities to withstand inundation. Johnson and York (1915) were the first to measure tidal limits and relate them to plant distribution. They concluded that tidal action was most significant in affecting transpiration abilities, gas exchange, and photosynthesis. Emergence-submergence ratios were calculated and a detailed list of plants and their habitats (type of substrate, upper and lower tidal limits and average tolerable submergence periods) were included. The presence of air "storage" tissue in some species was considered important in their ability to tolerate long periods of submergence.

A number of other studies have dealt with species distributions as determined by tidal regime: Nichols (1920), Conrad (1935), Penfound and Hathaway (1938) and Reed (1947). The general concensus is that tidal movement, with its associated submergence and emergence of marsh vegetation, is responsible
for controlling the vertical distribution of species. Associated factors are soil aeration, soil salinity, and type of substrate.

Chapman (1934) concluded, after calculating submergence and emergence times for various marsh areas and conducting levelling surveys, that the period of submergence was vital in controlling upper marsh species, while emergence controlled the lower vegetation.

Most of the research relating vegetation to tide levels is not directly applicable to the Pacific Northwest since the local vegetation composition is different from other North American marshes. Recent works by Eilers (1975) and Jefferson (1975) have dealt with vegetation comparable to that of the British Columbia marshes; included are some references to tidal relationships. Eilers (1975) computed inundation periods and discovered two discontinuities in the relationship of decreased submergence with increased elevation at Nehalem Bay, Oregon. He considered the region between .91 to 1.21 m above MLLW to be critical for marsh development and colonization. Carex lyngbyei Hornem. occurred the lowest in the intertidal zone extending down to .97 m above MLLW, while Scirpus maritimus L. was found immediately below 1.21 m and Triglochin maritima L., immediately above. The second elevation break occurred between 2.59 and 2.74 m and was considered the level of an 'upper transitional marsh'. Jefferson (1975) did not record elevations of plant communities, but did make note of a number of individual species ranges including Carex lyngbyei and Scirpus americanus Pers. which extended from 1.5 m above MLLW to 2.7 and 3.0 m above MLLW respectively.

The lack of uniform tidal base lines as well as varying tidal regimes between study areas make interpretation of tide levels and their effects on vegetation extremely difficult. In Canada, Chart Datum is the plane below which the tide seldom falls; it is periodically modified as tidal fluctuations dictate. In the United States, Chart Datum is represented by MLW (mean low water) and MLLW (mean lower low water) on the Pacific Coast (Chapman, 1960).
2.2 MARSH VEGETATION OF THE PACIFIC COAST

The floristics of west coast marshes have been poorly documented and those in their northern extremes have been especially neglected. The most comprehensive overview of Pacific coast marshes to date was produced by MacDonald and Barbour (1974). Working from floristic lists as well as detailed ecological studies where available, they formed a list of species distributions from 53 locations, ranging from Alaska to Baja, California. They recognized three groups of vegetation which changed with latitude; Alaska to northern California, central and southern California, and Baja, California. Diversity of marsh vegetation seemed to increase in a southerly direction and species which spanned a wide geographical range tended to occupy different marsh levels as they changed groups. For example, *Triglochin maritima* occurs in the mid-littoral zone in southern California, but colonizes the lower littoral further north. The area from Alaska to Point Conception in Northern California contains a fairly uniform flora. *Carex lyngbyei*, *Salicornia virginica*, *Triglochin maritima*, *Scirpus americanus*, *Scirpus maritimus*, and *Distichlis stricta* occur as common elements throughout this region. South of this area are the marshes of central and southern California, dominated by *Spartina foliosa* in the lower littoral and a diverse flora in the upper zones. Furthest south is the Baja California region where salt marshes grade into mangrove swamps.

The earliest work on Pacific coast marshes was concentrated in the California region. As these were classic papers and considered environmental features of interest to the Pacific Coast they are reviewed despite species differences. Purser (1942) studied the marshes of San Diego County, California. The results of the study are not directly applicable as only one of the species considered (*Distichlis spicata*) occurs in British Columbia.
Hinde (1954) investigated tidal relationships and species distributions in San Francisco Bay, and found that three main associations dominated by *Salicornia ambigua*, *Spartina leiantha*, and *Distichlis spicata* were controlled by tidal emergence and submergence.

Vogl (1966) discovered that *Spartina foliosa* dominated the lowest levels of the marshes at Upper Newport Bay in California. *Salicornia virginica* occurred interspersed with *Spartina foliosa* in the lowest reaches but also spread throughout the marsh zones being most prevalent in the mid-littoral. *Triglochin maritima* reached its lowest extent in the mid-littoral but was also most abundant there, tapering off as elevation increased. *Salicornia virginica* played a very important role in marsh development as it was the prime colonizer of mudflats, yet tolerated extremely variable environmental conditions and so occurred in even the uppermost marsh regions. Elevation was a prime determinant of vegetation distribution, especially in the mid-littoral zone, where small elevation changes reflected species preferences.

In the Pacific Northwest, marsh research was conducted by Jefferson (1975) and Eilers (1975). They were concerned with marshes in Oregon which contained many of the same species as British Columbia marshes, among which were *Carex lyngbyei*, *Salicornia virginica*, *Triglochin maritima*, *Scirpus maritimus*, *Scirpus americanus*, and *Scirpus validus*. Eilers observed that *Triglochin maritima*, *Carex lyngbyei* and *Juncus balticus* had wide elevation ranges while others such as *Salicornia virginica* were more limited in their distribution. Species occurring at upper elevations were generally more restricted in range than those occurring lower in the inter-tidal zone.

2.3 PRODUCTIVITY

A large literature exists concerning both salt marsh and freshwater marsh productivity estimates. It is now common knowledge that estuaries and
their associated marshes are extremely productive for a variety of reasons. Odum (1961) stresses two main factors responsible for the high productivity; the estuary acts as a "nutrient trap", and the tidal action supplies nutrients and oxygen while removing waste products. In addition the effect of freshwater contributions in terms of nutrients and aeration cannot be ignored in the estuary.

Keefe (1972) provided a comprehensive treatment of marsh production literature. High productivity was attributed to unique environmental factors to which the marsh species were adapted. Turner (1976) also summarized production literature with the aim of demonstrating that a north-south gradient existed in the production levels of Spartina alterniflora. Although a considerable amount of variation occurred within, as well as between marshes, he found productivity levels increased from north to south. An exhaustive summary of the production literature is beyond the scope of this study; the reader is referred to Keefe (1972) and Turner (1976) for their excellent summations.

Sedge wetlands occur commonly throughout the world, but they have received relatively little study. In so far as the productivity of the Fraser delta emergent marshes is concerned, the information obtained from other sedge wetlands is more directly applicable than that from salt marsh areas. The recent papers relating to Carex production will be briefly summarized.

Carex wetlands have been examined to determine their productivity and to relate the growth variables to certain environmental features. Bernard (1973) compared Carex wetlands for various latitudes and altitudes; those at high latitudes and high elevations had standing crops of less than 300 g/m² while in more favorable sites, standing crops ranged up to 1,000 g/m². Bernard (1973) also stresses the importance of overwintering shoots in the Carex wetlands. Shoots are initiated twice during the year, in spring and fall; those initiated in the fall overwinter as shoots and their contribution to the biomass should be taken into account in productivity estimates. In the same study,
Bernard discussed the translocation of labile chemical constituents into underground organs; the rate was approximately 1 g/m² per day beginning in July.

During August the underground biomass represented only 18 percent of the total biomass while in winter it rose to 74 percent. In a subsequent study (Bernard, 1974), the above and below ground standing crops were investigated in more detail. The below ground "standing crop" was the highest during winter and declined at a rate of 11 g/m² per day until mid-July whereupon it increased at a rate of 1 g/m² per day. An investigation of a Carex lacustris wetland (Bernard and MacDonald, 1974) indicated that shoots in his area lived for one year or less; shoots were initiated either in the fall or in the following spring and died in late summer. The number of shoots declined steadily over the summer from an initial count of 253 shoots per m² in May to 97 shoots per m² in October. The maximum above ground biomass in this area was 1,037 g/m²; the maximum daily production was estimated as 15 g/m² per day.

The growth rates of Carex wetlands are considerably lower than those of reed swamps (e.g. Typha and Phragmites stands) which in general have a net production of over 1,000 g/m² per year (Bernard, 1973), and growth rates exceeding 15 g/m² per day during the most rapid period of growth. These differences have been attributed to the increased amount of siltation these sites receive when compared to the Carex wetlands (Bernard, 1973 and papers quoted therein); the increased siltation presumably increasing the nutrient input. In New Jersey, Jervis (1969) recorded a production rate of 12 g/m² per day for Carex stricta; in a montane area, Carex rostrata had production rates of 6 g/m² per day (Gorham and Somers, 1973). In the Squamish River delta, B. C., Levings and Moody (1976) reported production of Carex lyngbyei as 1,323 g dry weight/m²; the greatest increase in standing crop occurred at the end of June with a growth rate of 22.9 g/m² per day. (The Squamish River carries a high suspended sediment load, 550 mg/l in 1974, the year of the study.)
Gorham (1974) reported a strong correlation between mean summer temperature and above ground biomass; the highest biomass yields came from low latitude, low elevation sites, which consequently had high summer temperatures.

2.4 DETRITUS

The pathway of energy flow from net primary production has been separated into the grazing food chain and the detritus food chain (Odum, 1963), the term detritus being widely accepted as meaning non-living plant or animal remains and the associated microflora. Macrophytes of coastal marine environments are not grazed to any extent; the large amounts of structural tissues (lignin and cellulose) in many of these species make them unpalatable to grazers (Odum, et al., 1972). Smalley (1959) found direct grazing in a marsh system to be less than 5 percent. Harrison and Mann (1975) observed that the high C:N ratio of eelgrass, greater than 20:1, made it a very poor direct food source (17:1 being the maximum for an adequate diet, Russell-Hunter, 1970); eelgrass detritus had C:N ratios of between 11:1 and 17.5:1, considerably improving its nutritive value. Similar studies for marsh vegetation have not been found in the literature.

The importance of detritus in shallow coastal waters has been extensively documented (a summary is provided by de la Cruz, 1965) and in the past two decades the processes involved have been explored in depth. Decomposition includes both mechanical and chemical action. In the high energy intertidal zone, physical forces play important roles in the breakdown and contribution of detritus to the sea. Harrison and Mann (1975) observed that microbial activity and leaching rates were increased as mechanical action reduced the size of Zostera (eelgrass) leaves. They also found that bacterial activity was proportional to the surface area of the particles. Upon death of the plant, there are rapid chemical changes in which autolysis may be of some importance. Odum
et al. (1972) have summarized these degradation processes for marsh vegetation. Soluble organic compounds, such as sugars, starches and organic acids may be lost by leaching as soon as the plant dies; losses of up to 25 percent (of initial dry weight) may occur in the first few days. Once the organic compounds enter into solution, there is a rapid increase in the associated bacteria and fungi, and a succession of these organisms as the various plant components become available for degradation. Mechanical fragmentation occurs continually due to physical factors and consumer action. Smaller particles usually have higher surface to volume ratios (Darnell, 1967), which allow a larger surface for colonization by micro-organisms (Odum and de la Cruz, 1967, Harrison and Mann, 1975).

A number of studies have explored the relationships between detritus and the associated microbial populations with the conclusions that microbial decomposition is the main agent for plant degradation (Burkholder and Bornside, 1957; Teal, 1962; de la Cruz, 1965; Darnell, 1967; Odum and de la Cruz, 1967; Fenchel, 1970, Gosselink and Kirby, 1974). Increases in protein are frequently recorded in association with the aforementioned microbial studies; these increases can be attributed to the loss of carbohydrates and the increase in the microbial biomass. In one study (Odum and de la Cruz, 1967), *Spartina* detritus had a protein content of up to 24 percent, compared with 6 and 10 percent in the dead and living grass respectively. The decomposition of proteins and soluble carbohydrates occurs more rapidly than that of crude fibre (Burkholder and Bornside, 1957). Leaching was determined to be the major agent in decomposition of eelgrass, accounting for up to 92 percent of the loss (Harrison and Mann, 1975). The effect of leaching does not seem to have been explored in marsh degradation. Estimates from laboratory and field studies (Burkholder and Bornside, 1957) conclude that (on a dry weight basis) about 11 percent of the yearly production of *Spartina* could be converted to bacteria.
While it was known for many years that bacteria and fungi played vital roles in the decomposition of detritus, and that detritivores fed upon these particles, the ecological significance of the interrelationships was not appreciated. Newell (1965) made a significant discovery to this end when he observed that the fecal pellets of *Hydrobia*, a detritus feeding snail, rapidly developed bacterial colonies resulting in an increase in the nitrogen of the system. He concluded that bacterial protein had been produced using atmospheric nitrogen. Fenchel (1970) supported this information when he observed amphipods feeding on detritus and found undigested detritus in their fecal pellets; the fecal pellets were devoid of microorganisms but were rapidly recolonized. The rapid recolonization was attributed to the presence of mucus on the pellet surfaces. He concluded the amphipods were important to the system in breaking apart detritus particles thus increasing surface area; and by using the microorganisms they actually stimulated regrowth of the microorganisms. Odum et al. (1972) similarly attributed the rapid breakdown of mangrove leaves in seawater to the activity of amphipods.

The fate of the detritus within the estuarine system is an interesting problem. Marsh grass contributions to the estuary vary with the amount of tidal flushing they experience. Teal, (1962) estimated that only 45 percent of a *Spartina* marsh in Georgia actually contributed to the estuary. Pomeroy (1977) concluded that 90 percent of vascular plant production in the Squamish River estuary entered the detrital food chain, and 49 percent of the particulate organic matter (largely from vascular plants) was exported to the estuary. Different size fractions of detritus may contribute in various ways. Large detritus particles may be broken down by detritivores and thus added into suspension; filter feeders may cycle suspended detritus into feces; suspended material may combine with other live or dead organic matter into larger clumps and then become deposited on the bottom. Odum et al. (1972) discuss the various facets of suspended or deposited detritus.
3. THE STUDY AREA

3.1 GENERAL DESCRIPTION

The study area located approximately 20 km south of Vancouver, British Columbia (Figure 1) is bounded by Canoe Pass, a part of the Main Arm of the Fraser River, to the north, the Roberts Bank Superport jetty to the south, the dyke to the east and the lowest lower low water tide level to the west. This area was chosen because it was relatively free from man-made disturbance. Impending alienations such as the hydraulic ditching of a section of the study area made the choice of location particularly important.

The remainder of the Fraser River foreshore marshes have been subject to major alterations. Iona Island is now the site of a major sewage treatment plant. Sea Island is the site of Vancouver International Airport and foreshore areas are subject to expansion of airport facilities. The Richmond foreshore has had river flow diverted from it by the Steveston jetty and recent suburban development has probably resulted in increased ground water discharge. The Westham-Reifel Island foreshore has experienced modifications such as dyking for agricultural land, the erection of river training walls and the use of marsh land to extend Reifel Refuge for waterfowl nesting habitat. These marshes are now considered secure from further modifications by virtue of their reserve status. Brunswick Point marsh is the southernmost of the Fraser foreshore brackish marshes. West of the Tsawwassen Indian Reserve is a true salt marsh occurring in what was probably a bay filled with long-shore drift material originating from Point Roberts, this source was cut off by the Ferry causeway in 1960 (Medley and Luternauer, 1976). This marsh has been the topic of much controversy between the Tsawwassen Indian Band who wish to dyke and fill it and the Federal Department of Environment, who maintain it is an important link in the estuarine food web (Hillaby and Barrett, 1976).
Figure 1: Aerial photo mosaic of the Fraser River Delta foreshore showing location of the study area. Major marsh areas are outlined.
The Brunswick Point marsh is presently a public hunting ground and is part of the 8,000 acre (Roberts Bank) Provincial Order-in-Council reserve Number 2374 for waterfowl management (Gates, 1967; Harris and Taylor, 1972), however, the reserve status is very tenuous as is indicated by the establishment of the Westshore Terminal facility on reserve land. The present port facility occupies some 150 acres (causeway and port) and has jurisdiction over a further 3,600 acres of intertidal flats (Pearson, 1972).

3.2 GEOLOGICAL SETTING

Current information suggests the development of the present Fraser River delta began approximately 8,000 years ago near New Westminster, at which time Pleistocene ice had disappeared and "post-glacial rebound was virtually complete" in the Fraser Delta (Luternauer, 1974).

Surveys of the surficial deposits of dyked lands indicate the occurrence of tidal flat deposits up to 30 m thick on the southern half of Sea Island and the western third of Lulu Island, the eastern two-thirds of Lulu Island being marsh accumulated sediments now overlain by peat bogs (Blunden, 1973). The Municipality of Delta is also underlain by thin floodplain or tidal flat deposits from .15 to 3.5 m thick. Recent palynological research indicates that Burns Bog in Delta Municipality may have at one time been a coastal marsh which subsequently developed into a sphagnum bog (R. Hebda pers. comm.). Kellerhals and Murray (1969) discuss the development of tidal flat to marsh community in an adjacent area (Boundary Bay). The present delta has been greatly altered by extensive dyking and urban and industrial development. The dyked lands are comprised largely of floodplain, channel and intertidal deposits. At the seaward side of the dykes lies a 6.5 km wide expanse of mainly unvegetated tidal flat which slopes seaward at 0.08° (Luternauer, 1974). The tidal marsh clings to the dykes in approximately a 1 km wide strip along 42 km of foreshore. The
growth of the Fraser Delta has occurred steadily over the past 8,000 years and few changes have occurred in the river passes because the delta is building into deep water (Blunden, 1973). Mathews and Shepard (1962) report that growth of the delta has progressed at a rate of about 9 meters per year. "Sturgeon Bank is covered almost entirely by sand-size sediment...", as is Robert's Bank which has, in addition, finer inshore sediments. "This seems to indicate that there is ample discharge of at least suspended sediment from the main channel of the Fraser River to Robert's Bank." (Luternauer and Murray, 1975). It has also been observed that due to prevailing currents there is a general northward trend for sediments discharged from the main channel (Luternauer, 1976).

Luternauer (1974) observed an anomalous occurrence in the sand-sized sediment to the north of the Westshore Terminal causeway in the form of a lobe of very fine sand and silt lying adjacent to the causeway. He suspects this may be due to fines settling out of water impounded by the causeway during an ebbing tide.

Sediment discharge past Port Mann located approximately 30 km from the mouth of the Fraser River, averages about 18,000,000 T annually, with about 80 percent of this occurring between mid-May and mid-July.

Local deposition may be substantial in some areas of the foreshore as in the case of Brunswick Point where an average deposition rate of 3.5 cm per annum has been noted (K. Fletcher pers. comm.). Mathews et al. (1970) have reported that either sediment compaction or tectonic down-warping result in a subsidence of approximately 1 cm per decade on the Fraser Delta.

3.3 THE LOCAL AQUATIC ENVIRONMENT

An estuary is a unique blend of fresh and salt waters, both influencing the biota in various ways. The following is a summary of the salient features of the river and ocean environments.
FLUVIAL ENVIRONMENT

The most characteristic feature of the Fraser River is the murky brown color of its downstream reaches. Draining an area of approximately 233,000 square km, the Fraser River has a high suspended sediment load (maximum of about 800 ppm) and a normal flow rate of 3 to 4 knots, reaching 5½ knots at freshet (Tabata, 1972). Studies done by the B. C. Research Council in the fall of 1971, reported by Benedict et al. (1973), indicated that dissolved oxygen levels were very high (at or near saturation) in the lower reaches of the Fraser River.

During the period of freshet, mid-May to mid-July, the mean monthly discharge of the Fraser River is in the order of 7,000 cu m/sec. Low discharges occur in late winter with minimum levels in the order of 800 cu.m/sec (March).

MARINE ENVIRONMENT

The Fraser River has a salt wedge estuary which characteristically has a large fresh water runoff. The fresh water flows out over more dense saline water which, in turn, is forced upstream in contact with the river bed forming a thin salt wedge, especially prominent during flooding tides (Pickard, 1970). The turbid fresh water spreads over salt water in a thin layer, very evident during periods of freshet; the salt wedge itself moves up and downstream in response to the amount of discharge and the tidal cycle. Mixing and flocculation occur in salinities between 0 and 15 o/oo (Waldichuk, 1967). Upwelling may occur in response to the seaward flow of fresh and mixed seawater (Waldichuck, 1952, 1957).

Although many factors are involved in creating the current patterns of the Fraser River estuary, wind seems to play a major role. Wind-generated waves cause vertical and horizontal mixing of fresh and salt water. The prevailing winds of the estuary are westerly with the strongest winds being northwesterly and southeasterly, although considerable variation occurs seasonally. During the summer a land-sea breeze pattern takes effect with the sea-breeze beginning in the mornings, reaching peak strength by the afternoon with wind...
speeds of 15 to 25 km/hr and dissipating by sunset. Land breezes at night are weaker, being in the range of 5 to 13 km/hr (Hoos and Packman, 1974).

Wave action is minimized on the wide, gently sloping foreshore, as the greatest wave impact occurs at the delta front where large waves break. Smaller waves further inshore result in rippling effects on the sand flats. The mixing of salt and fresh water by winds may serve to moderate salinity extremes during flooding tides (Hoos et al., 1974).

3.4 MARSH VEGETATION OF THE FRASER RIVER ESTUARY

British Columbia marshes are among the most poorly documented in North America. The Fraser River, because of its proximity to a large urban centre and two universities, has the best understood tidal marshes in British Columbia, yet Mac Donald and Barbour (1974) state, "Descriptions of the Fraser River Delta marshes (49°N) have not been found in the literature." The information which does exist has not appeared in readily available publications.

Gates (1967) described some of the important marsh areas of the Lower Mainland in his discussion of wetland reserves. Burgess (1970) used aerial photographs to map and determine the extent of the Fraser River foreshore marshes. The areal extent was calculated as 1,512 ha, of which Brunswick Point comprised approximately 10 percent. He stated that plant species distribution was affected by tidal flooding, degree of drainage, and possibly salinity; upper and lower marsh levels were distinguished, they were separated usually by a rapid change in slope at approximately the 3.05 m tide level. *Carex lyngbyei* was the most dominant species in the upper zone (3.96 m to 3.05 m) while *Scirpus americanus* was dominant in the lower zone (3.05 m to 2.13 m). Burgess (1970) also estimated seed production of these species and concluded that *Carex lyngbyei*, *Scirpus validus* and *Scirpus americanus* were the most important food sources for ducks.
A summary of ecological relationships was produced by Becker (1971), with emphasis on the vegetation information from Burgess (1970). McLaren (1972) and Forbes (1972) described and produced generalized maps of the Fraser River estuary marshes. Wade (1972) discussed plant distribution along Sturgeon Bank and included a floral list. Harris and Taylor (1972) discussed human impact on estuaries and mentioned marsh vegetation as related to migratory waterfowl and Halladay (1968) considered marsh vegetation as related to bird hazards at Vancouver International Airport.

In discussion of "Biology of the Lower Fraser" Northcote (1972) emphasized fish distributions but relied on Forbes (1972) and McLaren's maps for vegetation information. He stated that, "Probably they (marsh areas) form an important habitat for various invertebrates and young fishes, including salmonids."

Hoos and Packman (1974), summarized environmental information available for the Fraser Estuary. Vegetation descriptions of marsh areas were derived from McLaren (1972) and Forbes (1972). Upland and bog vegetation of the delta is also discussed.

Taylor (1974) included in his report a special study by Entech Consultants (Sverre) commissioned by the Canadian Wildlife Service to evaluate the vegetation of Sea and Iona Islands. Sverre (in Taylor, 1974) distinguished three zones along the foreshore. Scirpus americanus yields from the most seaward zone were reported as being approximately 1.1 tons per hectare. (Other values were not given.) Seed production of Scirpus americanus was estimated and the values were considered low (5.1 percent of stems were reproductive) due to stress conditions caused by light attenuation during flooding by tides and intolerance of sewage effluent (Sverre in Taylor, 1974). Burgess (1970) reported the average percentage of reproductive stems (Scirpus americana) as 3.1 percent over the entire Fraser foreshore. It is difficult to assess the role of stress in seed production without further studies.
Yamanaka (1975) studied productivity changes across the Fraser River delta marshes. *Carex lyngbyei, Scirpus americanus* and *Scirpus paludosus* (maritimus) accounted for over 80 percent of the standing crop. An average dry matter yield was 4.9 tons per hectare (490 g per sq m) per year. In general, dry matter yield and diversity decreased with distance from the dyke. The highest dry matter yield was found in the marshes adjacent to the North Arm of the Fraser River with average values of approximately 1,700 g per sq m. Yamanaka attributes these high values to possible enrichment by sewage effluent.

Parsons (1975) analyzed a salt marsh at Boundary Bay. *Distichlis spicata* and *Salicornia virginica* were inhabitants of a low marsh which he classified as ranging between 4.3 m and 4.9 m above mean sea level (these values are probably above chart datum (o) rather than mean sea level {2.96 m}); the low marsh displayed high soil conductivity values. Upper marsh inhabitants consisted of *Distichlis spicata*, *Achillea millefolium*, *Juncus* sp., and *Grindelia integrifolia*. Hillaby and Barrett (1976) investigated the Tsawwassen salt marsh and described plant communities similar to those of Boundary Bay. Burton (1977) investigated rhizome use by snow geese in the Fraser foreshore area.

3.4.1 VEGETATION DESCRIPTION

The vegetation of Brunswick Point is representative of a brackish marsh. The area is situated on the interface of fresh water and marine environments and hence the vegetation not only exhibits a horizontal zonation, which is mainly influenced by tidal exposure, but also a gradation from brackish to marine species.

The number of species occurring in this marsh is relatively small, with the three major ones being *Scirpus americanus* Pers., *Scirpus maritimus* L., and *Carex lyngbyei* Hornem. (Figure 2). Other species common to the area but which usually occur in isolated patches are: *Triglochin maritima* L.,
Figure 2: Vegetation map of the Brunswick Point Marsh showing transect and sampling station locations.

Scientific names will be used throughout.

3.5 SELECTION OF SAMPLING SITES

Three transects (A, B, C) were selected in order to cover maximum marsh area. Stations along these transects were established 150 m apart. The objective was to sample both a salinity and an elevational gradient. Lines were established by choosing compass bearings prior to field work.

In addition to these transects, three shorter ones (M, D, E) were established further south in a narrow band of Triglochin/Scirpus marsh adjacent to the dyke (Figure 2). Stations D and E were on either side of an area disturbed by trenching and cable burial. Because of the limited vegetated area, sampling stations were established 50 m apart.
4. ENVIRONMENTAL FACTORS DEEMED IMPORTANT IN MARSH HABITAT

Introduction

An understanding of the habitat is of paramount importance in assessing the succession, productivity or even decomposition in a tidal marsh area. The tide is the most apparent phenomenon in this habitat; it controls not only the moisture, oxygen, temperature and salinity contents of marsh soils but it also determines the potential for photosynthesis because flooding reduces gas exchange and turbid waters reduce available light. The period that a plant is continuously flooded is of as great an interest as the cumulative daylight exposure, since both are limiting measures in their own right. Continuous flooding limits plant growth by waterlogging roots, imposing salinity stress in saline waters, and by reducing light availability.

A saline environment imposes physiological stresses on the vegetation. Osmotic stress is induced when the external water potential is lowered below that of the cell, thus causing "physiological drought". Nutrient deficiency stress is caused by the preferential uptake of sodium ions (which are in great abundance) over potassium ions. Hormonal stress is induced by salt stressed roots being inhibited in transport of hormone to leaves, eventually causing hormonal imbalance and resulting in the increased rigidity of cell walls which prevents their expansion. (Levitt, 1972; Waisel, 1972).

In the brackish environment the salinity levels are usually quite low, but they fluctuate in response to other environmental variables, this may impose stresses on plants which are not normally subject to extremes. In the Brunswick Point marsh, the substrate salinities vary on a daily basis according to tide heights, the duration of flooding and the amount of rainfall or evaporation. Over a longer term, the salinities are affected by the volume of river discharge.
Temperature may determine the rate of evaporation from the marsh surface, thus affecting salinity. The dark "mud flats" of the Fraser foreshore have low albedos; the mud absorbs a great deal of the incident radiation, and as a result there are high surface temperatures. Vegetation both absorbs radiation and increases the albedo thus controlling surface temperatures, reducing evaporation and thereby not affecting salinity.

Vegetation both influences and is influenced by the substrate in which it exists. An examination of depth profiles can lead to an understanding of these relationships.

4.1 TIDES

4.1.1 METHODS

Tides are a dominant feature of the marsh environment; vegetation zonation often reflects the relative abilities of the different species to tolerate inundation and emergence. A levelling survey was undertaken in February, 1977 in order to determine marsh elevations; a total of 62 spot elevations along the established transects were determined by using standard levelling techniques and equipment. Details of vegetation and notable surface features were relayed to the transit operator by means of portable two-way radios. The final corrected vertical and horizontal distances and other detailed information were later transferred onto a base map of the area.

In order to relate the marsh elevations to tidal oscillations, the observed tidal data from the recording station at Tsawwassen were obtained for the year 1976 from the Regional Tide Superintendent, Victoria, British Columbia. These hourly observations were interpolated to provide information regarding exposure and submergence periods for selected tidal elevations.
4.1.2 RESULTS AND DISCUSSION

Levelling enabled delimitation of contours which seemed to be critical for plant distribution. The lowest limit of plant growth within the surveyed portion of Brunswick Point marsh appeared to be 2.82 m; the Carex lyngbyei community appeared to reach dominance at the 3.05 m level and at the 3.35 m level. Other species such as Potentilla pacifica and Argrostis semiverticillata were found in association.

The greatest exposure in the growing season occurred during the months of April and May, when the 3.35 m level was exposed 64 percent and the 2.44 level was exposed 29 percent of the time. Table 1 shows the percentage exposure at the above mentioned elevations plus that of 2.44 m, representing unvegetated areas.

The greatest differences between the seasonal means and the maximum exposure periods were not constant with elevation; the 3.35 and 3.05 m levels had the greatest differences with 5 and 4 percent differences respectively, while the 2.82 m and the 2.44 m levels had only 2 and 1 percent differences. The mean daylight exposure for the growing season ranged between 46 and 66 percent for the vegetated areas. Figure 3 displays the relationship between exposure and elevation both overall and in daylight hours; a slightly curved relationship is apparent, more so for "daylight" than for total exposure. The mean exposure (total) ranges from 6.5 (27%) to 14.1 (59%) hours per day (Figure 4).

The level which limited most plant growth (2.82 m) was an exposure of 9.1 hours per day or approximately 38 percent. Exposure to daylight ranges from 3.5 (15%) to 7.7 hours (32%) (Figure 5). The actual number of hours exposed in daylight is greatest in June, a result of a fortuitous combination of the summer solstice with low tides occurring during the day. The 2.82 level is exposed 4.9 hours (20 percent of daylight hours). It is to be noted that these values are the yearly means; if the daylight exposure means are calculated for the growing season, April to September, the mean exposure would be
Table 1: Percentage Exposures During the 1976 Growing Season for Selected Elevations.

<table>
<thead>
<tr>
<th>Meters Above Chart Datum</th>
<th>2.44</th>
<th>2.82</th>
<th>3.05</th>
<th>3.35</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>28.9</td>
<td>39.2</td>
<td>49.3</td>
<td>64.0</td>
</tr>
<tr>
<td>May</td>
<td>28.4</td>
<td>38.3</td>
<td>47.3</td>
<td>62.8</td>
</tr>
<tr>
<td>June</td>
<td>28.6</td>
<td>37.5</td>
<td>46.0</td>
<td>58.6</td>
</tr>
<tr>
<td>July</td>
<td>26.6</td>
<td>35.9</td>
<td>43.0</td>
<td>54.7</td>
</tr>
<tr>
<td>August</td>
<td>27.4</td>
<td>35.5</td>
<td>44.4</td>
<td>55.8</td>
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<tr>
<td>September</td>
<td>26.9</td>
<td>36.7</td>
<td>43.4</td>
<td>58.3</td>
</tr>
<tr>
<td>24 Hour ×</td>
<td>27.9</td>
<td>37.6</td>
<td>45.4</td>
<td>59.2</td>
</tr>
<tr>
<td>Daylight ×</td>
<td>34.0</td>
<td>45.6</td>
<td>53.1</td>
<td>66.0</td>
</tr>
</tbody>
</table>

Table 2: Continuous Inundation Time for Selected Elevations. Means for 1976.

<table>
<thead>
<tr>
<th>Meters Above Chart Datum</th>
<th>2.44</th>
<th>2.82</th>
<th>3.05</th>
<th>3.35</th>
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</thead>
<tbody>
<tr>
<td>Mean maximum continuous inundation per day</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours</td>
<td>20</td>
<td>17.8</td>
<td>16.3</td>
<td>12.4</td>
</tr>
<tr>
<td>%</td>
<td>83%</td>
<td>74%</td>
<td>68%</td>
<td>52%</td>
</tr>
<tr>
<td>Mean maximum continuous inundation in daylight</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours</td>
<td>11.8</td>
<td>11.2</td>
<td>10.0</td>
<td>8.2</td>
</tr>
<tr>
<td>%</td>
<td>86%</td>
<td>81%</td>
<td>72%</td>
<td>59%</td>
</tr>
</tbody>
</table>
Figure 3: Mean daily exposure at selected elevations.
Figure 4: Seasonal distribution of mean daily exposure for selected elevations.

Figure 5: Seasonal distribution of mean daylight exposure for selected elevations.
as follows: for 2.44 m, 5.5 hours or 34 percent; for 2.82 m, 7.3 hours or 46 percent; for 3.05 m, 8.5 hours or 53 percent; and for 3.35 m, 10.6 hours or 66 percent of 16 hours (the average number of daylight hours for the growing season).

The period of continuous submergence was deemed to be important as it reflects the amount of waterlogging to which the substrate and plant roots are subjected. There was a four hour, or 16 percent difference in the maximum submerged period between the 3.35 m and 3.05 m tide levels; between the 3.05 and 2.82 m tide levels, the difference was only 1.5 hours or 5 percent (Table 2).

Comparison of marsh zonation and species vigour in different geographical areas would be very useful, such comparisons are very difficult to make, not only are there different base lines but there are also different tidal ranges between various locations. Tides do not rise and fall equally along a shoreline, even over relatively short distances; currents, winds and bottom configurations affect both tidal range and extremes. Although mean tide lines are established for areas, they are extrapolations from the nearest tide recording stations and do not fully reflect the on site situation. In marsh areas where even a 30 cm variation in elevation can produce distinct vegetation changes (Purer, 1942; Hinde, 1954; Chapman, 1960; Adams, 1963) the lack of precise tidal information can restrict the understanding of vegetation distribution.
Figure 6: Seasonal changes in interstitial salinity. Brunswick Point Marsh
Figure 7: Seasonal changes in salinity at 1 m and 20 m depths. Sandheads 1976.

Figure 8: Seasonal changes in salinity at Tsawwassen, surface and 1.5 m.
4.2 SALINITY

4.2.1 METHODS

Water samples were obtained from each of the sampling stations by removing a core of sediment (approximately 10 cm deep) and collecting the water which percolated into the core hole. Conductivity determinations were undertaken in the laboratory using a Guild Line Autosal; readings were converted to salinity values based on a computer-prepared conversion table. Water with values lower than 2.83 o/oo was considered to be fresh as the machine could not accurately detect differences below that level.

4.2.2 RESULTS AND DISCUSSION

Salinities, in general, increased as the distance from the river increased (Figure 6). The effect of the Fraser River freshet can be seen on transects A and B; after the onset of the freshet, the salinity values declined from approximately 5 percent to fresh values (i.e. less that 2.83 o/oo) where they remained for the rest of the growing season. This decline in salinity during the period of freshet can also be seen at depths off Sandheads and Tsawwassen (Figure 7 and 8) (see Figure 1 for locations). Salinities on transect C were slightly higher than on A or B with values fluctuating around 5 o/oo all summer but with considerably greater variation at the outer stations (C4 and C5) than at the inner ones. Transect M values were considerably higher than the preceding ones with values in the 10 o/oo range; highest values occurred in unvegetated areas. A paired-sample test between stations M1 (vegetated) and M3 (unvegetated) indicated that salinities at M3 were significantly higher than those at M1. The highest salinities were observed at transects D and E with values of between 10 and 20 o/oo. Again the highest values occurred in unvegetated areas.
Salinity variations can be attributed in general to the influence of environmental variables such as rainfall, evaporation, proximity to creeks and channels and the height of the previous tide. The results should be considered relative between sampling stations.

A pattern of higher salinities in unvegetated areas was observed; those areas with sparse vegetation also had higher salinities than areas with dense vegetation. High salinities were observed at stations C4 and C5 before the shoots and canopy developed when values became comparable with those of the inner stations. The high salinities in areas of sparse or no vegetation can probably be attributed to the higher temperatures and greater evaporation as a result of low albedos in unvegetated areas. Salinity interactions with vegetation will be considered in more detail in Sections 5.3 and 7.3.

4.3 TEMPERATURE

4.3.1 METHODS

During each sampling period, thermometers were inserted to depths of 8 cm and 15 cm at each sampling station. Temperatures, time of measurement, substrate and vegetation conditions (e.g. wet or dry, dense or sparse) were recorded.

4.3.2 RESULTS AND DISCUSSION

Unvegetated areas showed greater variations than vegetated surfaces, as can be seen by the great discrepancies between 8 cm and 16 cm temperatures early in the growing season when little or no vegetation cover had yet developed, e.g. transects A and B (Figure 9).

In areas of sparse cover the temperature differences between surface
Figure 9: Seasonal fluctuations in substrate temperature. Brunswick Point marsh at 8 cm and 16 cm depths.
and depth was considerable throughout the season. The temperature of unvegetated or sparsely vegetated areas varied more closely with daily maxima while densely vegetated areas were more closely associated with daily mean temperatures.

The effect of temperature on vegetation is probably most dramatic in the temperature differences between the air, substrate and seawater (Figure 10 and 11). As an example, in June there was a difference of 8°C between seawater and marsh substrate means, and a 7°C difference between the mean maximum air temperature and the seawater temperature. The rapid change in temperatures between the exposed and the inundated marsh environments must impose considerable stress on the vegetation. This stress is possibly reflected in the lowered productivity of marsh vegetation at higher latitudes (see Section 2.3). The differences between seawater and ambient air temperatures may not be as great in southern regions but discussions of this factor have not been found in the literature. It would be useful to know if the cardinal and threshold temperatures for wetland sites are similar to those used in studies of the distribution of terrestrial vegetation.

4.4 SUBSTRATE AND UNDERGROUND BIOMASS

In order to assess substrate characteristics, pits were excavated in each of the major plant communities. This proved to be a very difficult operation because of the high water table in the marsh; the pits began filling with water while digging progressed. Three layers of root density could be discerned in each profile; the top 30 cm (approximately) were densely rooted with variable amounts of aerial materials mixed in; (values ranged from 10 to 50 percent organic material); the middle 30 cm were sparsely rooted (2 to 20 percent) but with a lot of decaying organic material present; the lowest layer reached (0 to 10 percent) showed live roots only in the case of Triglochin maritima, decaying remnants of other species were visible under T. maritima in the profile.
Figure 10: Seasonal changes in substrate temperatures (8 cm and 16 cm depths). Brunswick Point marsh.

Figure 11: Seasonal variations in temperature;
  a) monthly mean air temperature
  b) monthly mean air temperature
  c) seawater temperatures at 1m depth.
Visually Estimated Rooting Density
with Depth of Several Marsh Communities

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>S. americanus</th>
<th>S. maritimus</th>
<th>C. lyngbyei</th>
<th>T. maritimus</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 30</td>
<td>20</td>
<td>10</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td>31 to 60</td>
<td>10</td>
<td>2</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>61 to 90</td>
<td>3</td>
<td>0</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

Photographs illustrate the profiles of four communities from Brunswick Point marsh (Figures 12 to 16).

Moody and Luternauer (in preparation) undertook a more detailed study of plant-sediment relations along the Fraser River foreshore and examined rhizome fragments in order to discern successional patterns as evidenced in the layering of the sediments. A very successful but labor intensive technique was used in which plexiglass tubes (7 cm in diameter) were forced to a depth of 1 meter into the marsh substrate. (See also Section 9.1).

During regular biomass sampling, a hand auger was used to remove short cores (10 cm x 15 cm) from each sampling station at the beginning of the growing season. In order to separate root and sediment components washing was attempted with a rotating screened drum into which two sprays of water were directed. This proved unsuccessful in removing any sediment beyond the surface layer. Next, the cores were manually washed and broken apart to expose the interior portions to water spray. This method was more successful than the previous one but the results were extremely variable. Even though the roots had been washed until they appeared "clean", ash content varied from 38 to 82 percent and the results were not considered valuable enough to merit such a labor intensive, time consuming operation.
Figure 12: Sediment profile of a *Scirpus americanus* community.

Figure 13: Sediment profile of a *Scirpus maritimus* community.
Figure 14: Sediment profile of a *Scirpus maritimus* community which is being invaded by *Triglochin maritima* roots.

Figure 15: Sediment profile of a *Triglochin maritima* community. A varying of sediments is apparent.
Figure 16: Sediment profile of a Carex lyngbyei community.
Textural "ratings" for each sampling station (see section 3.5) are in progress by research personnel at Agriculture Canada and may be obtained on request.
5. PRODUCTIVITY

Salt marshes have been claimed among the most productive habitats in the world (Odum, 1961). Detailed investigations of marsh productivity have been carried on for decades on the eastern North American seaboard, but very little productivity assessment has been undertaken on the west coast until recently. Brackish marsh systems have been especially neglected. Yamanka (1975); the first major study of marsh productivity on the Fraser foreshore, contributed yield estimated for the Fraser marshes but did not attempt to follow temporal changes. The present study in part was intended to examine the productivity of one particular marsh over the course of one growing season.

5.1 METHODS

A 50 cm by 20 cm (0.1 m$^2$) rectangular quadrat was used for vegetation sampling. This size has been established as the most appropriate size for similar vegetation types (Eilers, 1975). The quadrat location was randomly (by means of a "shut eye, over the shoulder" randomization) chosen in the vicinity of each sampling station. All of the vegetation rooted within the quadrat was clipped at the soil surface with a battery powered, grass clipper. Three replicates were obtained from each sampling station (15 stations in total), during each sampling period (9 in total), for a total of 405 samples during the growing season. Samples were placed in plastic bags, tagged and transported to a refrigerator upon completion of field sampling.

In the laboratory, samples were separated into component species, and the number of reproductive and vegetative stems enumerated. Ten stems were chosen at random and measured for total length and stem diameter twice during the study period, (May and August). In order to remove sediment from leaves, (see Levings and Moody, 1976) the plant material was placed in fine mesh bags and
washed in a Hoover washer (Model 0610) for 4 minutes, rinsed and spun dry. Samples were then transferred to paper bags, labelled and dried in a forced air oven at 105°C for 48 hours. The samples were cooled, weighed, and ground in a Wiley Mill, the station samples (3) were pooled for each date and subsampled. Portions were ashed using standard ash determination procedures (A.O.A.C) in a muffle furnace at 550°C. Nitrogen analyses (micro-Kjeldahl) were performed on the aforementioned subsamples.

5.2 RESULTS

5.2.1 STANDING CROP

Of the dominant species in the Brunswick Point area, Carex lyngbyei was the most productive, peak phytomass (above ground) averaged over all sites was 909 g/m². dry weight in July. Scirpus maritimus peaked in August with an average weight of 565 g/m². Scirpus americanus, while occupying the greatest area in the Brunswick Point marsh, was the least productive with a peak mean of 397 g/m² occurring in July (Figure 17). The S. americanus and S. maritimus shoots were initiated approximately two weeks later than the C. lyngbyei shoots. C. lyngbyei displayed rapid, steady growth in the period from mid-May to a peak in mid-July, succeeded by a fairly rapid decline. The growth strategies of C. lyngbyei can be separated into two distinct patterns (Figure 18). The stations furthest from the dyke experienced a rapid growth, reaching a peak in mid-July, then declining equally rapidly. Inner areas were on the average not as productive, but paralleled the growth of the outer stations until mid-June when the inner growth proceeded in a slower rate to reach a peak in August with a rapid decline thereafter. The infrequency of sampling late in the growing season may mean that the peak standing crops actually occurred earlier or later than on the sampling dates.
Figure 17: Comparison of seasonal distributions of standing crop weights for three species

Figure 18: Comparisons of seasonal distribution of standing crop weights:
   a) Carex lyngbyei at Stations A1, A2, B1, 2, 3
   b) Carex lyngbyei at Stations A3, B4
   c) Scirpus paludosus at all stations
   d) Scirpus americanus at all stations
5.2.2 SHOOT COUNTS

The mean number of vegetative *C. lyngbyei* shoots declined steadily through the season, beginning with 1,250 shoots per square meter at the beginning of May, and declining to 770 shoots by the end of September (Figure 19). Reproductive shoot counts peaked at the end of May, with 130 shoots per square meter and showed a steady decline thereafter; since the vegetative portion was also declining, the percentage of reproductive shoots remained at a level of about 11 percent from May until July.

5.2.3 SHOOT MEASUREMENTS

Shoot lengths and diameters, which were measured in May and August are shown as frequency distributions in Figures 20 and 21. In May, shoot length frequencies ranged between 10 and 50 centimeters; reproductive shoots were fewer but closely approximated the pattern of the vegetative shoots. By August the vegetative shoot lengths ranged between 60 and 200 cm, the shoot sizes being much more varied than before; the range of reproductive shoot lengths was between 50 and 110 cm. In other words, in May, there appeared to be no differences in the lengths of reproductive and vegetative shoots; by August the reproductive ones tended to be shorter than the vegetative. The vegetative shoot diameters did not appear to be changed from May to August but while the May reproductive shoots were comparable in size to the vegetative, the August diameters had experienced a decline.

A Newman-Keuls test of significance for overall shoot lengths and diameters is summarized in Table 3. Station B3 had the greatest mean shoot length; Station B4 had the shortest mean shoot length. These stations are only 150 meters apart but have an elevation difference of approximately 0.8 meter. Station C1 had the greatest mean stem diameter; it occurred 0.5 meter above the smallest stem diameter at A3.
Figure 19: Seasonal changes in vegetative and reproductive shoot numbers per square meter of *Carex lyngbyei*.
Figure 20: Frequency distribution of Carex lyngbyei shoot lengths.

a) Reproductive
b) Vegetative
Figure 21: Frequency distributions of Carex lyngbyei shoot diameters.

a) Reproductive
b) Vegetative
Table 3: Newman - Keuls Multiple Range Test for Significant Differences between Means for Carex lyngbyei Shoot lengths and Diameters

<table>
<thead>
<tr>
<th>Shoot Length (cm)</th>
<th>Ranks of Species Means</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ranked Species Means</td>
<td>52.59</td>
<td>56.52</td>
<td>56.94</td>
<td>59.13</td>
<td>60.15</td>
<td>63.58</td>
<td>69.35</td>
<td>76.62</td>
<td></td>
</tr>
<tr>
<td>Conclusion (P=0.05)</td>
<td>B4</td>
<td>A3</td>
<td>A1</td>
<td>C1</td>
<td>A2</td>
<td>B2</td>
<td>B1</td>
<td>B3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
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<th>Shoot Diameter (cm)</th>
<th>Ranks of Species Means</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<td>Ranked Species Means</td>
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<td>3.45</td>
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<td>3.55</td>
<td>3.63</td>
<td>3.83</td>
<td>3.87</td>
<td>4.22</td>
<td></td>
</tr>
<tr>
<td>Conclusion (P=0.05)</td>
<td>A3</td>
<td>A2</td>
<td>B2</td>
<td>A1</td>
<td>B4</td>
<td>B1</td>
<td>B3</td>
<td>C1</td>
<td></td>
</tr>
</tbody>
</table>
5.2.4 RELATIONSHIPS WITH ENVIRONMENTAL FACTORS

The mean phytomass for each station (for all the sampling dates) showed definite trends when compared to the elevation above chart datum. In both Carex lyngbyei and Scirpus maritimus the standing crop increased as the elevation increased. (Figure 22). In comparing the shoot length of C. lyngbyei with elevation there was a similar trend of longer shoots with higher elevations (Figure 23). The basal diameters of C. lyngbyei stems measured twice during the growing season were also plotted against elevation; no visible trends were observed.

An interesting relationship was observed when comparing C. lyngbyei mean stem length. In essence, the areas of greater biomass had longer stems. Although this relationship deserves further investigation, it could prove to be a rapid method of estimating the standing crop of an area (e.g. if the mean stem length was 115 cm, the standing crop would be approximately 1,000 grams per square meter) (Figure 24).

The number of reproductive C. lyngbyei shoots showed a strong relationship to elevation; the number of shoots declined as the elevation increased (Figure 25). An examination of the percentage of reproductive shoots indicated the shoots followed a normal distribution.

The mean number of C. lyngbyei shoots seemed to be a correlation between the distance from the river and the number of stems; A3, the closest station to the river had the largest number of stems; B4 was next with the second largest number while A2 and B3 were about equal; B1, the station furthest from the river had the lowest stem count (Figure 26).

The mean rate of growth (g/m²/day) is shown of individual stations over time (Figure 27). In general, transect B had the greatest rate of growth, reaching a mean of 21 g/m²/day by the beginning of June; transect A followed a similar pattern but reached a maximum of 17.5 g/m²/day. Transect C exhibited
Figure 22: Regression of standing crop on elevation for *Carex lyngbyei* and *Soirpus maritimus*.

Figure 23: Regression of shoot length on elevation for *Carex lyngbyei* in May and August.
Figure 24: Regression of standing crop on stem length for Carex lyngbyei.

Figure 25: Regression of stem number on elevation for Carex lyngbyei.
Figure 26: Mean number of shoots of Carex lyngbyei at different elevations above chart datum.
Figure 27: Seasonal changes in growth rates for *Carex lyngbyei* at different stations.
an entirely different pattern; C1 which had a mixture of Carex lyngbyei and Scirpus maritimus showed a peak in growth at the beginning of June, as did transects A and B; after June the growth dropped to zero and then showed a second, but lower peak in July. This drop in growth cannot be attributed to sampling variability as it is uniformly evident in all of the stations of transect C with the exception of C5. The stations with the most rapid growth rates were A2, B1 and C1, with maximum rates at least 5 g/m²/day above the other stations at each transect.

5.2.5 NITROGEN

Nitrogen analyses revealed a general trend of decrease with time (Figure 28). Peak nitrogen levels were reached at the beginning of May (a mean of 2.75%) and then declined rapidly until July (mean of approximately 1%); a slow decline after this resulted in a final mean nitrogen of 0.67 percent. A Newman Keuls test of significance indicated that all C. lyngbyei station means were significantly different (Table 3). Upon converting the nitrogen percentage to yield values (Figure 29) the decline in nitrogen yield (g/m²) with elevation became apparent. The percentage nitrogen also showed a decrease with elevation (Figure 30) though not as pronounced as the yield decrease. During the period of peak biomass nitrogen yields were in the order of 5 to 10 g/m²; the only notable exception was Station C1 where high biomass and high nitrogen combined to produce a yield of 19 g/m² (Figure 31).

5.2.6 SUMMARY OF YIELD VARIABLES

Table 4 summarizes the Newman Keul multiple range test results for each of the dominant species, C. lyngbyei, S. maritimus, and S. americanus, for each of the main yield variables. Station B1, nearest the dyke, had the greatest mean biomass, significantly different from the other stations, as was A1 with the
Figure 28: Seasonal changes in nitrogen content of Carex lyngbyei. Means of all stations.

Figure 29: Regression of nitrogen yield on elevation for three species at all stations.
Figure 30: Changes in nitrogen content of three species (combined) with elevation.

Figure 31: Seasonal changes in nitrogen yield for Carex lyngbyei at various stations.
### Table 4: Mean Yields of *C. lyngbyei*, *S. maritimus* and *S. americanus*

#### Carex lyngbyei

<table>
<thead>
<tr>
<th>Station</th>
<th>n</th>
<th>Weight</th>
<th>#Stems</th>
<th>#Repr.</th>
<th>#Veg.</th>
<th>%Repr.</th>
<th>%N</th>
<th>Wt/Stem</th>
</tr>
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<tbody>
<tr>
<td>A1</td>
<td>21</td>
<td>401.9 d</td>
<td>951.4 c</td>
<td>136.7 a</td>
<td>814.8 c</td>
<td>14.9</td>
<td>1.62 c</td>
<td>0.53 bc</td>
</tr>
<tr>
<td>A2</td>
<td>21</td>
<td>528.5 bc</td>
<td>1025.0 c</td>
<td>79.1 b</td>
<td>945.7 bc</td>
<td>8.9 bc</td>
<td>1.43 e</td>
<td>0.59 bc</td>
</tr>
<tr>
<td>A3</td>
<td>21</td>
<td>533.6 bc</td>
<td>1560.0 a</td>
<td>90.0 b</td>
<td>1470.0 a</td>
<td>6.2 c</td>
<td>1.42 f</td>
<td>0.35 c</td>
</tr>
<tr>
<td>B1</td>
<td>21</td>
<td>660.8 a</td>
<td>849.0 c</td>
<td>55.2 b</td>
<td>779.0 c</td>
<td>6.8 c</td>
<td>1.69 b</td>
<td>0.90 a</td>
</tr>
<tr>
<td>B2</td>
<td>21</td>
<td>525.3 bc</td>
<td>905.7 c</td>
<td>60.5 b</td>
<td>845.2 c</td>
<td>6.6 c</td>
<td>1.79 a</td>
<td>0.66 b</td>
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<td>B3</td>
<td>21</td>
<td>595.1 ab</td>
<td>1030.0 c</td>
<td>63.3 b</td>
<td>966.2 bc</td>
<td>7.1 c</td>
<td>1.62 d</td>
<td>0.60 bc</td>
</tr>
<tr>
<td>B4</td>
<td>21</td>
<td>464.9 cd</td>
<td>1223.0 b</td>
<td>138.1 a</td>
<td>1085.0 b</td>
<td>11.3 b</td>
<td>1.39 g</td>
<td>0.43 bc</td>
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L.S.D. 81.1 144.9 34.8 140.2 3.14 0.002 0.18

#### Scirpus maritimus

<table>
<thead>
<tr>
<th>Station</th>
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<th>#Stems</th>
<th>#Repr.</th>
<th>#Veg.</th>
<th>%Repr.</th>
<th>%N</th>
<th>Wt/Stem</th>
</tr>
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<tbody>
<tr>
<td>C1</td>
<td>6</td>
<td>556.7 a</td>
<td>423.3 a</td>
<td>13.3 b</td>
<td>410.0 a</td>
<td>2.77 c</td>
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<td>1.04 b</td>
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<tr>
<td>C2</td>
<td>9</td>
<td>626.9 a</td>
<td>392.2 a</td>
<td>71.1 a</td>
<td>322.2 a</td>
<td>17.6 a</td>
<td>0.97</td>
<td>1.64 a</td>
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<tr>
<td>C3</td>
<td>9</td>
<td>188.7 b</td>
<td>226.7 b</td>
<td>27.8 b</td>
<td>198.9 b</td>
<td>9.30 b</td>
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<td>0.82 b</td>
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<tr>
<td>M1</td>
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<td>507.3 a</td>
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<td>6.1 bc</td>
<td>0.71</td>
<td>1.48 a</td>
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L.S.D. n.s.

#### Scirpus americanus

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<tr>
<th>Station</th>
<th>n</th>
<th>Weight</th>
<th>#Stems</th>
<th>#Repr.</th>
<th>#Veg.</th>
<th>%Repr.</th>
<th>%N</th>
<th>Wt/Stem</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4</td>
<td>18</td>
<td>265.7 a</td>
<td>803.9 a</td>
<td>387.8 a</td>
<td>416.1 a</td>
<td>43.9</td>
<td>1.93</td>
<td>0.46</td>
</tr>
<tr>
<td>C5</td>
<td>18</td>
<td>173.6 b</td>
<td>423.9 b</td>
<td>201.7 b</td>
<td>222.2 b</td>
<td>42.4</td>
<td>1.84</td>
<td>0.50</td>
</tr>
</tbody>
</table>

L.S.D. 52.3 172.0 98.7 87.4 n.s. n.s. n.s.
lowest yield. Station A3 had the largest number of stems, significantly different from the next largest, B4, which was significantly different from the other C. lyngbyei stations. Station A3 also had the largest number of vegetative stems; A1 and B4 had the largest numbers of reproductive stems. Station B1 had the "heaviest" individual stems.

For S. maritimus, Station C3 had significantly lower values than other stations for mean biomass, mean number of stems and mean number of vegetative stems; C2 had the highest percentage of reproductive stems. No significant differences were found in the nitrogen contents.

Station C4 in all cases had higher yield variables than C5 when significant differences were found; the species at these stations was S. americanus.

5.3 DISCUSSION

A variety of measurements were taken to assess productivity; attempts were made to relate these values to environmental variables which may influence plant production. Phytomass increased with elevation for both Carex lyngbyei and Scirpus maritimus, with the difference being more dramatic for S. maritimus. S. americanus was not included in the assessment due to a lack of elevation data for its zone of occurrence. Associated with these differences were changes in stem densities and sizes; the C. lyngbyei vegetative and reproductive stem numbers decreased as the elevation increased but stem lengths and diameters increased with elevation. For S. maritimus, the number of vegetative stems increased with increasing elevation but the number of reproductive stems decreased. The smallest percentage of reproductive stems occurred at the highest elevations. The task of interpreting these variations in growth is a very difficult one as the results may be due to any combination of environmental variables which cannot be measured in unison to give a stress or benefit factor.
The increased production with increased elevation possibly reflects the inhibition of photosynthesis due to silty waters. The fact that transect A, in general, had a lower productivity may reflect river influence; in essence transect A may be considered as occurring lower in the intertidal zone than it actually does, and is more subject to river flow and silt loading. In Oregon (Eilers, 1975), *C. lyngbyei* has been found to be a primary colonizer in the tidal marsh, extending lower than either *S. americanus* or *Triglochin maritima*; it extended down to 0.97 m above MLLW which is roughly equivalent to 2.27 m above chart datum in the Fraser foreshore area. Other species grew to 1.21 m (lower limit) which is equivalent to 2.51 m in the Fraser area. Biomass in Oregon was also found to be higher than in the Fraser River marsh areas; for *S. americanus* the net primary production was calculated as 609 g/m²/year; *C. lyngbyei* was separated into two forms, the tall yielding a mean of 1,746 g/m²/year and the short, a mean of 875 g/m²/year. The *C. lyngbyei* studied at the Brunswick Point marsh would probably fit into the tall category. The distinction of tall and short forms was also observed by Levings and Moody (1976) in the Squamish River estuary.

The outer marsh areas seem to display a different pattern of growth to that of inner areas. During early spring a "flush" of vegetation is apparent near creeks and close to the river (Figure 33). It is possible that this rapid growth is due to nutrient enrichment in these areas as well as warmer temperatures from the flooding water. Valiela and Teal (1974) noted that marsh sediments were very efficient at removing nutrients from water; hence, "...creek bank sediments would be supplied with more nutrients than high marsh sediments." In addition they found that enrichment experiments with urea in upper marsh areas resulted in vegetation resembling that of low marsh areas, again suggesting the rapid absorption of nitrogen by sediments. Growth was rapid in the outermost areas of Brunswick Point marsh, reaching a peak before other areas and also declining rapidly. The more frequent tide and wave action in the
Figure 32: Tall form of *Carex lyngbyei* as sampled in Brunswick Point.

Figure 33: Color infrared photograph of early *Carex lyngbyei* growth along channel banks. Red indicates actively growing vegetation.
lower marsh areas may be important in the rapid removal of senescent vegetation.

Growth rates in May were very high, and were comparable to those of the Squamish marshes (Section 2.3). These high values were previously attributed to high siltation rates and nutrient input.

The decrease in reproductive material with elevation is an unusual pattern. Jeffries (1971) noted that under conditions of high intraspecific density stress or under conditions of high salinity, flowering did not occur in *Plantago maritima* or *Triglochin maritima*; he concluded that under stressful conditions the plants tend to reproduce vegetatively and live longer. He also observed that many plants in salt marshes did not flower frequently. Vogl (1966) found that constant inundation inhibited flower stalk production in *Spartina*.

The observations of *C. lyngbyei* flowering frequently in lower marsh elevations (more stressful situations) seem to disagree with previous patterns. *S. maritimus* on the other hand follows the established pattern and is sexually more reproductive at higher elevations. The pattern exhibited by *C. lyngbyei* could reflect nitrogen enrichment at lower levels as discussed earlier, which tends to stimulate inflorescence production, or it may reflect increased competition at the higher marsh levels.

Reproductive shoots showed earlier senescence (in *C. lyngbyei*) than did vegetative shoots; leaf tips began to yellow after seed set, indicating a mobilization and translocation of cell constituents (Langer, 1972); reproductive stems were shorter and slimmer than vegetative stems in August.

The "vegetative frequency" distributions indicate there may be a difference in the shoot lengths of those initiated in the fall and those initiated in the spring. This relationship bears further investigation. Since the number of shoots declined through the growing season, the possibility exists that shoots initiated in the fall may reach senescence earlier and die. No records were kept of dead stems or leaves found on the marsh surface since with the heavy sedimentation in the area, they were quite rapidly buried and difficult to spot.
increased elevation seemed to elicit a response characterized by taller, thicker and fewer stems in *C. lyngbyei*. The shorter, slimmer, and denser stems at lower elevations and at sites close to the river could be attributed to stresses in these locations attributable to increased inundation and higher silt loads. *C. lyngbyei* may also be limited by the presence of totally fresh water.
6. DETRITUS

It has long been recognized that marshes contribute very little to the estuarine ecosystem by way of the grazing food chain (Smalley, 1954); most of the abundant vegetation produced in these areas is decomposed and washed into the marine environment (Pomeroy, 1977). The role of detritus has been extensively explored in salt marsh systems in other areas of the world but little attention has been paid to the brackish marsh communities and the fate of their production. The examination of litter bag loss and in vitro decomposition is a preliminary step to understanding the detrital part of the marsh system.

6.1 DETRITUS - FIELD CONDITIONS

6.1.1 METHODS

The relative decomposition rates of four species of marsh plants (Carex lyngbyei, Salicornia virginica, Triglochin maritima and Scirpus maritimus) were determined by enclosing 25 g plant samples in nylon mesh bags (25 cm x 25 cm). Two mesh sizes (1 mm and 0.5 mm) were used to determine the effect of the apertures on litter loss. Dried plant material was placed in the mesh bags and bag openings were closed by heat sealing. The mesh bags were stapled to 8 foot (244 cm) lengths of wooden studs ("two by fours"): these were attached by polyethylene ropes to wooden stakes driven into the sediment at 8 foot (244 cm) and 10 foot (305 cm) tide levels on either side of the Westshore Terminal jetty. The binding ropes were allowed enough slack (approximately 15 cm) to allow the bags to rise off the mud at high tides. This was to simulate natural conditions of detritus shifting in the marsh and to keep the bags from clogging with mud. The bags were set out in October, 1976 and recouped in January, 1977). After removal from the field the bags were washed, then dried in a forced air oven at
60°C for 24 hours. The contents were weighed; invertebrates were separated from the vegetation, counted and weighed; and the net weight of vegetation was determined. Nitrogen analyses, (micro-Kjeldahl) were performed on subsamples of the dried vegetation from which the amphipods had been removed.

6.1.2 RESULTS

The nylon mesh bags became quite brittle during the course of the study, and as a result, split along the edges (especially where heat sealed) which resulted in the complete loss of 37 percent of the bags. Another 21 percent of the bags yielded unreliable results due to small breaks in the bags.

The litter bags were returned to the field after the first set of observations were recorded. Plans for further monitoring were halted when a heavy winter storm resulted in the loss of all the litter bags.

Despite the lack of observations repeated over time and the loss of replicates, the comparative data between species and stations, and different mesh sizes reveal trends.

Table 5 shows the percentage of detritus remaining after 103 days in the field. C. lyngbyei and S. maritimus had the greatest amounts remaining, with 52 percent each (mean of all stations and mesh sizes for each species). S. virginica had 19 percent of the initial material remaining but T. maritima, the most easily degraded of the four species, had only 12 percent of the initial weight present.

A model 1 single factor analysis of variance (Zar, 1974) was undertaken and a test of significance (Newman-Keuls) performed to compare the mean weights of species enclosed in mesh bags. The results indicate that for each mesh size there were four discrete populations with no means being equal (Table 6).

The means were ranked from 1 - 4 (smallest to largest) with T. maritima and S. virginica being 1 and 2 respectively for both mesh sizes. S. maritimus
Table 5: Percent of Initial Dry Weight of Plant Material Remaining After 103 Days (Species means)

<table>
<thead>
<tr>
<th>Sites</th>
<th>Carex</th>
<th>Scirpus</th>
<th>Triglochin</th>
<th>Salicornia</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>10N 1mm</td>
<td>54</td>
<td>44</td>
<td>8</td>
<td>12</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>0.5mm</td>
<td>62</td>
<td>53</td>
<td>18</td>
<td>(20 est.) 38</td>
</tr>
<tr>
<td>10S 1mm</td>
<td>55</td>
<td>38</td>
<td>8</td>
<td>18</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>0.5mm</td>
<td>55</td>
<td>59</td>
<td>13</td>
<td>(20 est.) 37</td>
</tr>
<tr>
<td>8N 1mm</td>
<td>55</td>
<td>54</td>
<td>8</td>
<td>15</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>0.5mm</td>
<td>44</td>
<td>53</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>8S 1mm</td>
<td>51</td>
<td>55</td>
<td>10</td>
<td>16</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>0.5mm</td>
<td>44</td>
<td>57</td>
<td>16</td>
<td>23</td>
</tr>
<tr>
<td>Mean 1mm</td>
<td>54</td>
<td>48</td>
<td>8</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5mm</td>
<td>51</td>
<td>56</td>
<td>16</td>
<td>22</td>
</tr>
</tbody>
</table>
Table 6: Newman-Keuls Multiple Range Test for Significant Differences Among Mean Weights of Detrital Material Remaining After 103 Days in Mesh Bags

<table>
<thead>
<tr>
<th></th>
<th>0.5 mm Mesh</th>
<th></th>
<th>1.0 mm Mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ranks of Species</td>
<td></td>
<td>Ranks of Species</td>
<td></td>
</tr>
<tr>
<td>Means</td>
<td>1</td>
<td>Means</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Ranked Species</td>
<td>3.66</td>
<td>Ranked Species</td>
<td>1.91</td>
</tr>
<tr>
<td>Means (g)</td>
<td>5.21</td>
<td>Means (g)</td>
<td>3.56</td>
</tr>
<tr>
<td></td>
<td>12.50</td>
<td></td>
<td>12.36</td>
</tr>
<tr>
<td></td>
<td>13.90</td>
<td></td>
<td>13.18</td>
</tr>
<tr>
<td>Conclusion (P = 0.05)</td>
<td></td>
<td>Conclusion (P = 0.05)</td>
<td></td>
</tr>
<tr>
<td>Species</td>
<td>T. maritimus</td>
<td>Species</td>
<td>T. maritima</td>
</tr>
<tr>
<td></td>
<td>S. virginia</td>
<td></td>
<td>S. virginica</td>
</tr>
<tr>
<td></td>
<td>C. lyngbei</td>
<td></td>
<td>S. maritimus</td>
</tr>
<tr>
<td></td>
<td>S. maritimus</td>
<td></td>
<td>C. lyngbei</td>
</tr>
</tbody>
</table>
had the highest weights for the 0.5 mm mesh, while *C. lyngbyei* was highest for the 1.0 mm mesh.

A paired-sample t test was used to compare the mesh sizes within each species resulting in no significant differences for any species with the exception of *T. maritima* which indicated a highly significant difference in weight loss between mesh sizes at the 5 percent level.

To test for differences between the four locations, a model 1 two factor analysis of variance (Zar, 1974) was used. In all cases the hypothesis that the weight of detritus at each location was equal was accepted. As expected the species effect proved to be highly significant.

Table 7 shows the nitrogen content of the detritus of various species at the different stations. A paired-sample t test was used to compare initial nitrogen values with those occurring in the detritus bags after 103 days. *C. lyngbyei* detritus in all cases (except of 8N, 1 mm mesh) had significantly greater nitrogen levels than the original plant material. *S. virginica* and *T. maritima* both had significantly lower nitrogen values than the original material, however for the *T. maritima* this only applied to the 1.0 mm mesh.

Amphipod (probably *Anisogammarus pugettensis*, pers. comm. C. D. Levings) counts are recorded in Table 8. *C. lyngbyei* appeared to be the most attractive species for amphipods at all locations. "8 S" appeared to be the best location for large amphipod numbers while "10 N" was the least favorable. As expected, the smaller size mesh resulted in fewer amphipods per bag at all locations and for all species. The 0.5 mm mesh may have been too small for amphipods to enter with ease and the presence of more easily accessible detritus nearby (1 mm mesh) may have confounded the effects.
Table 7: Percent Nitrogen Content of Detritus at Transplant Sites

<table>
<thead>
<tr>
<th>Site¹</th>
<th>C. lyngbyei</th>
<th>S. maritimus</th>
<th>T. maritima</th>
<th>S. vírginica</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>SE</td>
<td>N</td>
<td>X</td>
</tr>
<tr>
<td>8N 0.5 mm</td>
<td>.93</td>
<td>.06</td>
<td>2</td>
<td>.55</td>
</tr>
<tr>
<td>1.0 mm</td>
<td>.83</td>
<td>.25</td>
<td>2</td>
<td>.48</td>
</tr>
<tr>
<td>8S 0.5 mm</td>
<td>1.01**</td>
<td>.09</td>
<td>2</td>
<td>.64</td>
</tr>
<tr>
<td>1.0 mm</td>
<td>.93*</td>
<td>-</td>
<td>1</td>
<td>.69</td>
</tr>
<tr>
<td>10N 0.5 mm</td>
<td>.81*</td>
<td>.02</td>
<td>2</td>
<td>.73</td>
</tr>
<tr>
<td>1.0 mm</td>
<td>.83*</td>
<td>.02</td>
<td>2</td>
<td>.57</td>
</tr>
<tr>
<td>10S 0.5 mm</td>
<td>.95*</td>
<td>.08</td>
<td>2</td>
<td>.54</td>
</tr>
<tr>
<td>1.0 mm</td>
<td>.93*</td>
<td>.03</td>
<td>2</td>
<td>.52</td>
</tr>
<tr>
<td>Initial</td>
<td>.58</td>
<td>.08</td>
<td>7</td>
<td>.65</td>
</tr>
</tbody>
</table>

* Denotes significance at p <0.05
** Denotes significance at p <0.01

¹ Locations are shown in Figure
Table 8: Number of Amphipods (X of detritus bags for each species at each station)

<table>
<thead>
<tr>
<th>Site</th>
<th>Carex</th>
<th>Scirpus</th>
<th>Triglochin</th>
<th>Salicornia</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10N 1mm</td>
<td>21</td>
<td>11</td>
<td>3</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>0.5mm</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10S 1mm</td>
<td>39</td>
<td>41</td>
<td>33</td>
<td>11</td>
<td>31</td>
</tr>
<tr>
<td>0.5mm</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>8N 1mm</td>
<td>45</td>
<td>17</td>
<td>19</td>
<td>12</td>
<td>23</td>
</tr>
<tr>
<td>0.5mm</td>
<td>8</td>
<td>8</td>
<td>0</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>8S 1mm</td>
<td>62</td>
<td>34</td>
<td>48</td>
<td>45</td>
<td>47</td>
</tr>
<tr>
<td>0.5mm</td>
<td>20</td>
<td>17</td>
<td>5</td>
<td>2</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1mm</td>
<td>42</td>
<td>26</td>
<td>26</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>0.5mm</td>
<td>8</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
6.1.3 DISCUSSION

The detritus bags were placed at four different locations with the intent of exploring the effect of tidal inundation and salinity on decomposition. At the 2.44 m tide levels the detritus bags were submerged for 17.5 hrs per day while at the 3.05 m level detritus bags were submerged for an average of 13.1 hours per day. Salinities varied by 5% between the river influenced north side and the more marine south side of the jetty.

The 4.4 hours of increased submergence at the 2.44 m tide level were expected to have some effect on decomposition rates; however the analysis of variance for location effects showed no significant differences. While the amount of detritus was not affected by location the number of amphipods were, with larger numbers occurring at the lower elevations. Mesh sizes also probably limited the number of amphipods by restricting entry, as the large mesh size always contained more amphipods than the small mesh, regardless of species or location.

The mesh sizes did not play significant roles in degradation of species other than T. maritima. In this species losses from the 1 mm mesh bags were significantly greater than from the 0.5 mm mesh. This species is quite fleshy and becomes brittle when dry. It is probable that mechanical degradation occurs very rapidly in this species and hence losses due to mesh size are far more important than in the other species with more resilient leaves and stems.

S. maritimus stems had developed central woody cores by the end of the growing season; surrounding the core was a fleshy sheath. The removal of the fleshy material probably occurred quite rapidly with a gain, and then a loss in nitrogen content as the microfauna was removed by amphipods and wave action. The detritus left in the bags contained very little fleshy material; portions of the woody cores of stems were abundant. Nitrogen content was significantly different from that of the initial plant material.
S. virginica detritus was significantly lower in nitrogen than the initial tissues, as can be expected with only 19 percent of the material remaining, that remaining presumably being the most difficult to degrade; material left in the bags was mainly structural tissue. The material which is more easily broken down has a higher nitrogen content as testified also by the loss of this material and a lower nitrogen value in the 1 mm mesh bags for T. maritima. The material remaining in the bags was mainly the structural remnants of flower stalks.

C. lyngbyei did not show any differences between mesh sizes; evidently its resiliency, especially when wet, resists mechanical breakdown. C. lyngbyei, after 103 days in the detritus bag, could barely be distinguished from the initial plant material; sections of leaves and stems were readily apparent although considerable fragmentation had occurred. The fact that C. lyngbyei had the most material remaining of all the species indicates its importance as a slow releaser of nutrients. It is the only species with nitrogen values significantly greater than the initial; therefore we can assume a rich bacterial population and this appears particularly attractive to the amphipods which occur in their greatest numbers with C. lyngbyei. The amphipods which inhabit the detritus bags may increase nitrogen content with their feces as described in Section 2.4.

6.2 LABORATORY CONDITIONS

6.2.1 METHODS

Dead standing C. lyngbyei, T. maritima and S. maritimus stems and leaves obtained from Brunswick Point marsh in September, 1976 were oven dried (at 105°C), ground and screened to eliminate particles larger than 2 mm. Twenty-four replicates (1 gram each) for each of the three species were incubated in 250 ml erlenmeyer flasks with 100 ml of filtered seawater (obtained from the Roberts Bank area, having a salinity of approximately 18 o/oo) and 1 ml of a
Figure 34: In vitro decomposition of three species; changes in the percent remaining over time.
marsh mud suspension. Aeration and mixing were maintained by mounting the flasks on a continuously rotating shaker (at a slow speed). The flasks were incubated at 12°C in a dark chamber (to prevent photosynthesis) for a maximum of 27 days. Three replicates of each species were removed from the chamber at 3-4 day intervals, dried at 60°C, cooled in a desiccator and weighed on an analytical balance. Dried replicates were excluded from the remainder of the study. Three controls were prepared without any vegetation to determine the total salt content of the medium.

6.2.2 RESULTS

The results of the in vitro decomposition of marsh vegetation are shown in Figure 34. Residues, minus salts, are plotted as percent of initial dry matter. The graphy displays a rapid loss of vegetation during the first 6 days; a lost of between 50 and 56 percent for S. maritimus and T. maritima, respectively. Variability within species replicates, (coefficient of variation) was less than 4 percent at all times. The relative values of the species were remarkably consistent, with T. maritima being the most easily degraded but with S. maritimus and C. lyngbyei following parallel patterns throughout the experiment.

After day 6 the declining trend reversed and a gradual build-up in the amount of detritus occurred until day 23, whereupon the detritus underwent a 30 percent increase in four days. Final results indicated that C. lyngbyei and S. maritimus flasks had a dry matter content of between 85 and 90 percent of the initial dry weight; T. maritima flasks contained 67 percent of the initial dry weight (Figure 34).
6.2.3 DISCUSSION

Previous in vitro decomposition studies have extensively dealt with the microbial populations developed during decomposition. This type of analysis was beyond the scope of this study. The purpose of the laboratory study was to complement the detritus bag results and assess the relative decomposition rates of three marsh species. The lack of microbial population analyses makes any results, other than the relative rates, very difficult if not impossible to interpret.

The results indicated that the relative decomposition rates between field and laboratory experiments were fairly comparable. *T. maritima* was the most easily degraded of the three species; *C. lyngbyei* and *S. maritimus* shared very similar patterns but with 5 to 7 percent more material remaining at any time than did *T. maritima*. In the field, after 103 days, the difference between *T. maritima* and *C. lyngbyei* was in the order of 40 percent.

Decomposition progressed much more rapidly in the laboratory than in the field. The litter bags which contained whole leaves and stems of the various species had lost approximately 50 percent of the initial material by 103 days in the field. In the laboratory the same amount of loss occurred in the first 6 days; a large portion of this loss can be attributed to rapid leaching of the finely fragmented materials. The unusually high values reached at the end of the experiment may have in part been due to some undetected systematic error. The comparison of field and laboratory results demonstrates the importance of mechanical breakdown in the decomposition of these marsh plants.
Introduction

The transplanting of vegetation was undertaken to answer two prime questions; what are the factors limiting the vegetation to its present boundaries and, is the establishment of the vegetation in unvegetated areas a feasible project?

The use of transplants is a time proven technique of experimentally demonstrating adaptation, as in the investigation of ecotypes (Clausen, et al., 1940; McNaughton, 1974). A classic technique has been to place ecotype clones in a standard garden and to observe differences which persist despite the uniform environmental conditions. A modification of this technique (Clausen, et al., 1948) involves reciprocal transplants of species to various environmental conditions. The limitations of the standard garden technique can be eliminated by the varied environment transplants (Heslop-Harrison, 1964).

Transplant experiments, until recently, have been used to a very minor extent in assessing marsh habitats. Stalter and Batson (1969) produced the first published account of attempts to explore habitat factors by means of transplantation in North America; the planting of tide lands for the purposes of land reclamation and harbor protection had been undertaken earlier in Europe (Ranwell, 1967). A transplant study, done by Mooring et al. (1971) explored the ecological relationships associated with tall and short varieties of Spartina alterniflora.

Recent research in marsh transplants has been directed to the problem of reestablishment or colonization of disturbed or altered tidal flats rather than to the problem of determining which environmental factors a plant is adapted to (e.g. Woodhouse, et al., 1974); Seneca, 1974). An example of this approach was undertaken at Miller Sands on the Columbia River estuary where a dredge spoil island was planted with natural marsh species. Although final results have not
been published, Carex lyngbyei and Deschampsia caespitosa proved to be especially successful transplants (Dredged Material Research, 1976).

The transplantation of four local species of marsh vegetation in the southern Fraser delta foreshore is the first attempt to relate species to various environmental factors in a British Columbia tidal marsh.

7.1 TRANSPLANTATION METHODS

Transplant sites were chosen adjacent to the Westshore Terminal causeway. The area afforded a variety of environmental conditions within easy access (Figure 35). The 2.44 m and 3.05 m tide levels were chosen to represent normally unvegetated 2.44 m and vegetated 3.05 m tide flats. Due to the recent construction of the causeway (in 1969) vegetation had not colonized the transplant area at the start of the study; however, during the period of the study, colonization occurred on both sides of the jetty (T. maritima on the north side, S. virginica on the south side) close to the 3.05 m transplant locations. The transplant locations included sites on either side of the jetty to consider probable salinity differences which occurred between the river-influenced water to the north and the more marine water to the south.

The transplant program was initiated in March of 1976. Tide tables were used to determine the specific time each elevation was to be exposed and then at that time, marking the water's edge with a wooden stake. These locations were later cross checked using observed tide data with the time of exposure. Sixty-four 20 cm³ centimeter blocks of marsh vegetation, representing four species (Carex lyngbyei, Scirpus maritimus, Triglochin maritima, and Salicornia virginica) were removed from Brunswick Point marsh (near Stations B2 and M1) on March 20, 1976. The blocks were placed in plastic bags and stored in a cool area overnight until the next low tide. Transplant locations were selected at random from 64 possible sites at each location. Holes were excavated in
Figure 35: Location of transplant sites at Roberts Bank.
TRANSPLANT SCHEME
(not to scale)

B Scirpus maritimus
C Carex lyngbyei
S Salicornia virginica
T Triglochin maritima

Roberts Bank Superport
Figure 36: Transplant plugs in situ at site "10S". 
(Photo)

Figure 37: Monitoring of transplanted vegetation: stem counts and measurements. 
(Photo)
preparation for the cores, and the excavated sediments removed from the immediate area to maintain the existing elevation. The plugs of vegetation were planted and their positions recorded. Figure 37 shows the transplant scheme. In addition to the four transplant sites, the aforementioned species were transplanted to different nearby sites within their own communities (four replicates of each species) to determine the "shock" effect of the transplanting techniques.

Periodic monitoring of the transplant sites was undertaken. Stem counts and measurements were taken, and observations made on the plants' vigour (Figure 38). Vigour was ranked on a scale of 0 - 5 (Table 9) based partially on stem numbers and dimensions, as these related to the original communities on the Brunswick Point marsh; and partially on subjective estimates. Salinities were measured periodically by collecting water samples and analysing them on a Guild Line Autosal and substrate temperatures were recorded from depths of 8 and 16 cm.

7.2 RESULTS

For all species, the best growth was observed at the "10N" transplant sites. In general, growth declined with higher salinities and lower elevations. Table 9 illustrates the ranked mean growth values for each species and location.

*S. maritimus* grew best of all the species. Station "10N" had the greatest growth rate and expansion; as evidenced by stem counts closely approximating those of similar elevations at Brunswick Point. Stems measured up to 60 cm tall and 7 mm thick. By 1978, two of the cores had expanded almost four-fold and had virtually closed a one meter wide gap between them. Stations "10S" and "8N" were very similar in the amount and type of growth in 1976, although one core at "8N" was able to expand while those at "10S" did not. Stem counts in these areas were in the range of 25 - 50 percent of those at Brunswick Point and measured 18 - 50 cm tall and 8 mm thick. By the spring of 1978, two cores
Figure 38: Transplant Scheme
Table 9: Ranked Mean Vigour of Transplant Sites, 1976 & 1977

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>10N</th>
<th>10S</th>
<th>8N</th>
<th>8S</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>Scirpus maritimus</td>
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<td></td>
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<tr>
<td>/76</td>
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<td>3.25</td>
<td>3.0</td>
<td>1.5</td>
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<tr>
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<td>3.25</td>
<td>2.5</td>
<td>0.75</td>
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<tr>
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<td></td>
<td></td>
<td></td>
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<td>1.75</td>
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<td>2.8</td>
</tr>
<tr>
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<td>1.5</td>
<td>0.5</td>
<td>0.25</td>
<td>1.4</td>
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<tr>
<td>Triglochin maritima</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>/76</td>
<td>3.75</td>
<td>3.0</td>
<td>0.75</td>
<td>0</td>
<td>1.8</td>
</tr>
<tr>
<td>/77</td>
<td>2.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Carex lyngbyei</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<tr>
<td>Total</td>
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<td>2.6</td>
<td>1.5</td>
<td>0.6</td>
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<tr>
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<td>3.5</td>
<td>1.2</td>
<td>0.75</td>
<td>0.25</td>
<td></td>
</tr>
</tbody>
</table>

Rank | Characteristic
---|-------------------
0   | Vegetation absent
1   | Barely alive or declining
2   | Static
3   | Slight growth
4   | Healthy growth
5   | Lush expansion
at "10S" were eliminated probably due to heavy sediment deposition. The poorest growth in this species occurred at "8S" where most of the stems showed little development. Stem counts were approximately 25 percent of those at Brunswick Point; with stem lengths and diameters ranging from 12 - 39 cm and 3.4 - 5 mm respectively. No reproductive shoots were observed at any location.

In the transplant situation, *C. lyngbyei* thrived best at Station "10N". Two cores planted at this site had expanded by the fall of 1976, and continued growth in 1977. One core which had lost several of its shoots by July, 1976 had greatly increased the density of shoots by October, and continued growth in 1977. Stems at this location were around 40 cm tall, with a density of roughly half that of a comparable elevation at Brunswick Point. All of the *C. lyngbyei* plugs had disappeared by July, 1976 at Stations "10S" and "8S". At "8N", this species survived until the fall of 1976, having experienced declining numbers throughout the season (with about 5% of the expected number of shoots in July as compared with Brunswick Point marsh) and then disappearing completely by 1977. Stem heights in this location reached a maximum of 8 cm in the first year. *C. lyngbyei* did not reproduce at any stations.

*S. virginica*, thrived at the "10N" location and showed some expansion and healthy green growth. "10S" showed similar growth with the exception of a reddish hue on some shoots, indicating possible stress. In both cases, at the 2.44 m tide levels, *S. virginica* survived until the fall of 1976, but with red shoots and weak growth. During 1977, three of four cores at each location disappeared and the remaining ones appeared very weak in the spring of 1978.

*T. maritima* also experienced its best growth at "10N". Less vigorous growth was apparent at "10S", there was one reproductive stem at each of the 3.05 m sites in 1976. Leaf lengths ranged from 22 - 26 cm and 28 - 32 cm at "10S" and "10N" respectively. At "8N", stem density was about half of that at "10N", while at "8S" the species did not survive. By 1977, *T. maritima* had disappeared at "8N" and had but two remaining units at "10S" both of which
disappeared by 1978 as did one of the weaker cores at "10N". Curiously one of the T. maritima cores at "8N" contained S. maritimus rhizomes as well. In April, 1976, one S. maritimus shoot became apparent, and in July, 7 stems had appeared while the original T. maritima shoots had disappeared.

Observations indicated that the physical effect of transplanting was negligible as intra-community transplants were all successful and the transplanted cores were indistinguishable from the rest of the community by July, 1976. However, the transplants in this case were all placed into previously vegetated areas and there may have been a substantial contribution from the vegetated areas around the plug in "filling in" the disturbed site.

Salinities varied seasonally but maintained about a 5 o/oo difference between the north and south sides of the jetty. Salinities were measured from interstitial water which was in abundant supply at each station except for "1ON". The more rapid drainage in this area may have been important in the transplant success.

Changes occurring following the summer of 1976 revealed that winter storms affected transplant success. Particularly at "10S", there was a heavy accumulation of silts (up to 15 cm.deep) over top of the transplanted material, probably inhibiting growth in all remaining cores. Areas of erosion were also apparent, especially at the "10N" site were in some instances, roots and rhizomes were exposed.

In a two year period S. maritimus cores at "10N" had expanded to about four times their original transplant size. At "10S" half of the cores were buried by silt, "8N" still had 3 intact cores, the one which disappeared being the one with only 1 stem. Similarly, the only surviving S. maritimus core at "8S" was the one with the largest number of shoots initially (4).

S. virginica had appeared to be quite well established at both "10N" and "10S". It, too, was lost from two cores and in the remaining two was severely impaired by sediment deposition. Of the "8" sites only one
Salicornia virginica unit remained alive at each location as of April, 1978 and continued growth was doubtful.

C. lyngbyei continued healthy growth at "1ON" in those cores which had previously shown good growth and expansion, but was eliminated from all the other sites.

7.3 DISCUSSION

One of the major problems with transplanting rhizomatous material within cores of sediment is the inability to assess the exact amount and nature of materials transferred. For example, initial stem counts of C. lyngbyei at "1ON" ranged from 11 to 32 shoots. Undoubtedly the amount of material transferred plays an important role in the eventual success of the transplant. In isolated instances where one core out of four has failed while the others have done well, it is possible to attribute this failure to insufficient root material in the core (e.g. "B16", "T7", "T10"). In other cases, the original transplanted material has disappeared and has been replaced by a different species, presumably because there was root material from more than one species present and not because of fortuitous seedling establishment. It is interesting to note the species changes which did occur in two such instances: "C3" (Carex lyngbei) had 11 shoots initially which were taken over by T. maritima stems in July, 1976 at "1ON"; at "8N" a T. maritima plug which was observed to have one S. maritimus shoot initially was eventually taken over by S. maritimus with T. maritima disappearing completely. Although these occur as isolated instances it is interesting to speculate about successional relationships as a result. Jeffries (1971) reports growing Plantago maritima and Triglochin maritima both separately and in mixed stands. Triglochin maritima growth was greatly reduced in the presence of Plantago maritima. Jeffries observes that:

"Much of the variation which has been observed in salt marsh plants may be
more closely linked to the adverse effects of interference from nearby plants than to the influence of the edaphic factors as such. Apparently in light of competition the plant most suited for the environment can overtake the one which initially appeared dominant; therefore in the *C. lyngbyei* plug "C3", *T. maritima* was more suited to the environment at "10N" and similarly *S. maritimus* appeared to be more suited to "8N" than *T. maritima*.

The varying amount of root and shoot material in the plugs, plus the different types of growth, made stem counts unreliable; hence a system of ranking the growth according to its apparent vigour was established. In terms of overall success, *S. maritimus* was the most tolerant of all environmental conditions with a mean growth value of 3.2, then *S. virginica* with 2.8, *T. maritima* with 1.8 and *C. lyngbyei* showing the least success with a rank of 1.1 (see Table 8 for rank characteristics).

Placing each station in perspective "10N" was most successful with an average rating of 4.2, "10S" with 2.6, "8N" with 1.6 and "8S" with 0.6.

Substrate characteristics and nutrient limitations were not explored, but tide levels and salinity values indicate that a high intertidal brackish zone is more easily colonized than high intertidal high salinity or both low tidal locations. In this context it should be noted that "8S" was the least favorable location for plant growth in any species.

In summary it may be stated that: a) "10N" was the most successful transplant location, presumably because of the combined "high" elevation and low salinity. The declining order of success by location was "10N", "8N", and "8S"; b) *Scirpus maritimus* must be deemed the most successful species having undergone a fourfold expansion in two years of growth (at "10N") while tolerating conditions at all sites to varying degrees; c) *Salicornia virginica* was the next again with the greatest success obtained at "10N" but growth occurred at all other stations; d) *Carex lyngbyei* did well at "10N" but did not survive at any other location; and e) *Triglochin maritima* did well in the first year.
at both "10S" and "10N" locations but had declined considerably by the spring of 1978.
8. HISTORICAL CHANGES OF THE BRUNSWICK POINT MARSH

Historical charts and aerial photographs were used to assess the changes occurring in the Brunswick Point area from 1827 to date. These changes are important in determining successional patterns and predicting responses to habitat modifications. The foreshore environment may seem static in terms of a human life span but in terms of geological history is actually a very dynamic system.

A hydrographic chart (Figure 39) depicts the location of the Main Arm of the Fraser River as it was in 1827. The South Channel flowed south then east and eventually emerged far south of the present Canoe Pass. The emergence of the South Channel at this location may have been important to the establishment of the Tsawwassen Salt marsh. By 1860 (Figure 40) the South Channel had altered its course and assumed the present location of Canoe Pass. Marshes are not indicated in these charts, however, if the foreshore of Westham Island as shown in 1827 (Figure 39) did have a marsh bordering it, then the flow of Canoe Pass would have cut through the foreshore marsh separating it into the Westham Island and the Brunswick Point marshes.

The earliest available aerial photography for the study area (Figure 40 and 41, 1932) indicates that an area of marsh which appeared to lie on a line with the former shoreline of the large Westham Island had been dyked. Brunswick Cannery (to be used as a reference point) had been established at the edge of the marsh. The areal extent of Brunswick Point marsh in 1932 was 74 ha of which Carex lyngbyei occupied 21 ha (see Figure 43, 1975 for comparison). S. maritimus appeared to be colonizing an embayment immediately to the south east of the marsh. By 1938 little change had taken place (Figure 42) in the areal extent or distribution of marsh species.

By 1948 a sand bar, roughly 90 ha in area had appeared west of the marsh (Figure 42), possibly as a result of the 1948 flood (A1 Tamburi pers. comm.).
Figure 39: Hydrographic chart dated 1827, showing the main arm of the Fraser River.
Gulf of Georgia
Figure 40: Hydrographic chart dated 1860, showing the main arm of the Fraser River.
Figure 41: Photo number A4527 (29) dated September, 1932. Brunswick Cannery is indicated by a white dot.

Figure 42: Photo number A5984 (21) dated June, 1938. Brunswick Cannery is indicated by a white dot.

Figure 43: Photo number A37170 dated June, 1975. Brunswick Cannery is indicated by a black dot.
Although no vegetation had colonized the area, the shape was very similar to the vegetated area of the Brunswick Point marsh in 1969 (Figure 45). By 1948, further dyking of the high marsh area had occurred, but marsh expansion between 1938 and 1948 had resulted in a net increase of 2 ha. Much of this growth had occurred in the aforementioned embayment as a result of *S. maritimus* expansion. *Carex lyngbyei* had retreated in an area south east of the new dyke; the dyking probably resulted in higher salinities and lower sediment and nutrient supplies to the area, creating an unfavorable habitat for *C. lyngbyei*.

An oblique photo (Figure 46) of the sand bar area at the forefront of the Brunswick Point marsh in 1949 shows the area still unvegetated; a similar photo (Figure 47) taken in 1976 shows the sand bar covered with predominantly *S. americanus*.

By 1966 the marsh had assumed its present shape (Photos taken between 1949 and 1966 are either at too high water or not available). The *S. americanus* community formed on the 1948 sand bar appears to have been gradually extending southward; the 1976 extent of the marsh was approximately 170 ha (Figure 2).
Figure 44: Photo number X156C (19) dated June 5, 1948.

Figure 45: Photo number 39422B (Pacific Survey Corporation) dated 26 July, 1969.
Figure 46: Photo number BC 822 (29) dated June 20, 1949.

Figure 47: Photo taken August 26, 1976.
9. SUCCESSION

Although the environmental factors controlling the marsh are very complex, the basic ones affecting marsh succession are probably the depth of water and the lack of aeration; the successional trend is towards the accumulation of sediment, raising the soil to a higher level in the tidal range, and eventually lowering the water table.

Competition is one of the key factors of succession. The process of succession begins when a pioneer species is able to colonize a bare substrate. In the tidal marsh area, a pioneer must be able to tolerate a mobile, frequently inundated habitat. Salinity is quite variable in the brackish environment and along with the type of substrate, whether sand or silt, is probably a prime determinant in the establishment of pioneer species. Once the pioneer species has established, it alters the environment; water movements are slowed down resulting in increased silt deposition; organic matter is added to the "soil"; temperature extremes are attenuated; evaporation is decreased. The modified environment permits the establishment of other species which are probably better adapted to the environment than the original colonizer.

As observed by Chapman (1974), the marshes on the Pacific Coast of North America have very simple successions. This is particularly true in the case of the Fraser River delta marshes which have been subject to extensive dyking of mature marsh areas and hence only have pioneer and building stages present with their rather limited floristic components. The pioneer species along the foreshore are usually 'Scirpus maritimus and Scirpus americanus; 'Scirpus maritimus occurs in sparse monotypic stands on very silty substrates, while Scirpus americanus is usually found on sandy substrates in fairly dense monotypic stands. An examination of cores obtained from various communities in the Fraser area (Moody and Luternauer, in preparation) revealed that Scirpus
amerianus had in all instances colonized on sandy substrates. Deposited sediments in the established Scirpus americanus community were mainly comprised of silts and often there was a change in species to Scirpus maritimus after the deposition of silts. The dynamic nature of these colonizers was revealed in the frequent instances of one species present in one layer, being "overtopped" by the other species only to return to the original species again.

Jefferson (1975) developed an elaborate scheme of succession for Oregon coastal salt marshes (Figure 48) while many parallels occur between British Columbia and Oregon marshes, they are difficult to compare primarily because vegetation distribution is so intimately tied to tidal relationships and no real basis of comparison exists (Section 4.1) between tides at various locations. Jefferson differentiated between those communities formed on silts and those formed on sands, although the patterns are similar to those of the Fraser marshes, Jefferson noted that Scirpus validus was a successor to C. lyngbyei. In the Fraser foreshore marshes, S. validus is very often found among S. americanus communities in silty patches which develop after the community pioneers on sand (Moody and Luternauer, in preparation). The distribution of S. validus seemed to be restricted to areas with a heavy influx of fresh water and a low elevation. Similarly T. latifolia occurred in large patches along the Fraser River foreshore, in areas with fresh water influx but occurred only in small patches amid other marsh species as remnant patches or possibly in response to ground water discharge in some areas.

An important role in the succession of the Fraser foreshore marshes is played by Triglochin maritima; it often occurs amid S. maritimus stands forming elevated hummocks which coalesce and eventually eliminate the S. maritimus community. (See 4.4) Pits dug in a S. maritimus, T. maritima mixture (Figure 14, Section 4.4) indicated that areas which appeared to be S. maritimus at the surface had T. maritima roots in the deeper layers. These roots originated in the T. maritima mounds and had spread to the S. maritimus hollows. T. maritima
Figure 48: Species succession in Oregon coastal salt marshes (from Jefferson 1975: p. 85).
showed a great capacity for elevating the marsh surface by a large build up of roots in the surface sediment layers. The evidence from the transplant experiments (Section 7) suggests that *S. maritimus* is more tolerant of inundated conditions than *T. maritima*; the build up of sediments by *T. maritima* roots creates an environment in which *T. maritima* can successfully compete with *S. maritimus*. Remnants of *T. maritima* stands are often found within the *C. lyngbyei* community. Pits dug in the *C. lyngbyei* also indicated portions of *T. maritima* roots below the *C. lyngbyei* roots. From this evidence it may be deduced that *T. maritima* is indeed a forerunner to the *C. lyngbyei* community. Jefferson (1975) observed that this pattern did occur in Oregon as a portion of the much more complex successional scheme (Figure 48).

Eilers divided the Nehalem marsh (Oregon) into four zones; the edge marsh, which had an actively shifting margin (occurred up to approximately the 3.00 m level when considering the tide regime of the Fraser), the low marsh, 3.00 to 3.35, the transitional marsh 3.35 to 3.75 m, and the high marsh 3.75 to 4.08 m. In the study of Brunswick Point, it was noted that *S. americanus* and *S. maritimus* occurred up to approximately the 3.00 m tide level (in some cases extending further); *C. lyngbyei* became dominant from 3.00 m to 3.35 m in the low marsh and had mixtures of other species in the transitional marsh at 3.35 to 3.75 m (using the divisions of Eilers 1975). The zones determined by Burgess (1970) in general agree with these divisions (Section 3.4). All high marsh areas in the Brunswick Point area are now agricultural land, located east of the dyke. A summary of successional relationships is presented in Figure 49 - 57.
In the southern Fraser Delta foreshore the succession of marsh vegetation can be depicted as follows:

Figure 49: Blue green algae colonize the tide flats, often forming a solid carpet of vegetation which effectively binds the surface sediments together.

Figure 50: *Scirpus maritimus*, a pioneer vascular plant, is able to colonize the stabilized mud flat, either by seed or by vegetative expansion. Following establishment is a period of fairly rapid vegetative growth which results in a patchy distribution of the colonizers.
Figure 51: *Scirpus americanus* also occurs as a colonizer but is more often found on sandy substrates.

Figure 52: Colonization can also occur as the result of "rafting" of established material which has broken away from the edge of a drainage channel or the front of the marsh.
Figure 53: A characteristic pattern of tidal flat colonization is a contagious series of clumps which eventually coalesce.

Figure 54: The clumped pattern is apparent in the Triglochin maritima community in which T. maritima occurs as elevated clumps while Scirpus maritimus fills in the hollows between. The T. maritima hummocks eventually coalesce to form a higher marsh surface, up to 15 cm above the pioneer community. The photograph depicts this community prior to spring growth.
Figure 55: The raising of the marsh surface serves to decrease the period of inundation. The vegetation draws water from the substrate and this, combined with evaporation, results in a drying of the substrate.
Figure 56: Marshes are dynamic systems. The photograph depicts a *C. lyngbyei* community which had its habitat altered by dyking prior to 1948 (see Section 8). Only remnant clumps of *C. lyngbyei* remain and erosion is gradually eliminating those.

Figure 57: A healthy *C. lyngbyei* community, in contrast to the degrading one described above, has a uniform marsh surface, drained by deeply incised tidal channels.
10. SUMMARY AND CONCLUSIONS

Specific features of the marsh environment, higher plant production and habitat have been discussed in each section. It is difficult to place so many variables in perspective; however, a general understanding of how such a marsh system functions and what the pertinent variables are is essential before proceeding to more detailed studies. A detailed investigation of the ways in which these factors interact with the vegetation was beyond the scope of this study.

Brunswick Point marsh is a brackish marsh subject to both tidal inundation and river discharge. The distribution of vegetation responds to these influences in that each species is limited in its lower extent by the amount of inundation it is able to tolerate. Tidal inundation, combined with silt laden river flows may reduce the photosynthetic potential of plants occurring low in the intertidal zone.

The upper extent of the marshes on the Fraser River foreshore is limited by the extent of dyking; the high marsh areas which in Oregon Eilers (1975) found to be most productive have, in the Fraser Delta been converted to agricultural land. The high marsh areas are significant in the development of the marsh into a terrestrial system as organic material is incorporated into the substrate; in the low marsh areas most of the production is exported into the estuary (Eilers, 1975).

The observations and results from the detrital aspects of this study indicate there is a slow release of nutrients from the marsh; each species contributes at its own rate. Soft, fleshy stemmed vegetation such as T. maritima, S. americanus, and S. virginica breaks down readily and disappears rapidly from the marsh surface; more resistant species, such as C. lyngbyei and S. maritimus offer a slower release of nutrients which are available when the easily degraded materials have been used up.
Transplantation studies and historical and present observations indicate that a simple succession occurs in the Fraser River foreshore emergent marshes where precursors such as *S. maritimus* or *S. americanus*, alter their habitats enough, to allow a more complex marsh flora such as *S. validus*, *T. maritima*, *C. lyngbyei*, and *Potentilla pacifica* to grow.

The marsh is a sensitive system as can be seen from rapid changes occurring after minor environmental modifications. In conclusion it may be stated that, although significant modification of the Fraser River foreshore marshes has occurred, those areas of the marsh which contribute most significantly to the estuarine system are virtually intact and are expanding.

The major conclusions of this study may be summarized as follows:

1. Marsh elevations in relation to tides played an important role in vegetation distribution; little plant growth occurred below the 2.82 m (above chart datum) level in the main portion of the Brunswick Point marsh. *Carex lyngbyei* became dominant at the 3.05 m level and graded into a mixed community at the 3.35 m level. The upper limit of marsh growth is limited by dyking.

2. The Fraser River moderates salinity in the Brunswick Point marsh; lowest salinities occur during freshet. Salinity is influenced by the density of vegetation probably as a result of reduced temperatures and evaporation in densely vegetated areas.

3. The peak aboveground phytomass averaged over all sites, for each species was:

   - *Carex lyngbyei*: 909 g/m²
   - *Scirpus americanus*: 397 g/m²
   - *Scirpus maritimus*: 565 g/m²
4. *C. lyngbyei*, occurring near the river and drainage channels, experienced the most rapid growth in spring reaching an apparent peak in July and declining thereafter.

5. Standing crops increased as elevation increased for both *Carex lyngbyei* and *Scirpus maritimus*.

6. The number of reproductive shoots in *C. lyngbyei* decreased as elevation increased.

7. Shoot density, for *C. lyngbyei* was negatively associated with distance from the river.

8. Nitrogen content for all species reached a peak in May with an overall mean of 2.75 percent.

9. The growth rate of *Carex lyngbyei* was very high at all stations in the Brunswick Point marsh; the values were comparable to those of the Squamish River Delta marshes.

10. Of the four species tested *T. maritimus* decomposed most rapidly in litter bags.

11. *C. lyngbyei* was least readily decomposed but had the highest gammarid amphipod counts of all the plant species enclosed in litter bags.

12. Laboratory conditions confirmed the relative decomposition rates of *T. maritima*, *C. lyngbyei*, and *S. maritimus* as determined by litter bags.
13. *S. maritimus* was the species which best survived transplanting under the conditions of the trials.

14. A relatively high elevation site with low ambient salinities was most conducive to transplant success.

15. Aerial photographs and hydrographic charts indicate that the Brunswick Point marsh has undergone a series of dramatic changes over the past 150 years and has more than doubled in areal extent during the past 50 years.

16. A simple pattern of succession occurs in the Brunswick Point marshes with *S. americanus* and *S. maritimus* occurring as precursors, followed by *T. maritima* and *C. lyngbyei.*
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