Biological And Geomorphological Classification Of Placentia Bay: A Preliminary Assessment

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BIOLOGICAL AND GEOMORPHOLOGICAL CLASSIFICATION OF PLACENTIA BAY: A PRELIMINARY ASSESSMENT

by

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ABSTRACT

Catto, N.R., R.G. Hooper, M.R. Anderson, D.A. Scruton, J.D. Meade, L.M.N. Ollerhead and U.P. Williams. 1999. Biological and Geomorphological Classification of Placentia Bay: A Preliminary Assessment. Can. Tech. Rep. Fish. Aquatic. Sci. No. 2289: v + 35 p.

This report provides preliminary biological and geomorphological classification schemes for Placentia Bay, Newfoundland. In addition, this study examines the degree to which the geomorphological regimes of the Bay affects the development of the biological communities. The region of the province studied encompasses the area from Point Crewe (western tip of the Burin Peninsula) to Point Lance (Avalon Peninsula).

The biological classification of Placentia Bay is based upon a three-fold hierarchical subdivision. The primary elements involved in the classification are oceanographic circulation, wave regime, freshwater influx (volume and consistency), effects of terrestrial influx, pack ice activity, geomorphologic and climatic regime, and anthropogenic influences.

Close relationships exist between the geomorphic regimes and the biological communities of Placentia Bay. In many locations, biological communities are dependent upon a specific combination of geomorphic and climatic factors for their habitat. Other biological communities, while less demanding in their requirements, flourish most effectively under particular geographic regimes. Although the biological communities vary in species diversity and populations, each community can be distinguished by the presence of critical or characteristic organisms.

Future research should involve the detailing of biological assemblages at shoreline areas representing sites that fit each of the geomorphic classifications of the Placentia Bay shoreline. Alternatively, specific locations along the shoreline could be selected for additional research and analysis.

RÉSUMÉ

Catto, N.R., R.G. Hooper, M.R. Anderson, D.A. Scruton, J.D. Meade, L.M.N. Ollerhead and U.P. Williams. 1999. Biological and Geomorphological Classification of Placentia Bay: A Preliminary Assessment. Can. Tech. Rep. Fish. Aquatic. Sci. No. 2289: v + 35 p.

Le présent rapport présente des systèmes préliminaires de classification biologique et géomorphologique de la baie de Plaisance (Terre-Neuve). De plus, on y détermine dans quelle mesure les régimes géomorphologiques de la baie influent sur le développement des communautés biologiques. La région étudiée va de la pointe Crewe (extrémité ouest de la péninsule de Burin) à la pointe Lance (péninsule d'Avalon).

La classification biologique de la baie de Plaisance repose sur une subdivision hiérarchique triple. Les éléments primaires de cette classification sont la circulation océanographique, le régime des vagues, l'afflux d'eau douce (volume et régularité), les effets des apports terrestres, l'activité du pack, les régimes géomorphologiques et climatiques et les influences anthropiques.

Il existe d'étroites relations entre les régimes géomorphologiques et les communautés biologiques de la baie de Plaisance. Dans de nombreux endroits, l'existence d'un habitat favorable aux communautés biologiques dépend d'une combinaison particulière de facteurs géomorphologiques et climatiques. Certaines autres communautés biologiques, quoique moins exigeantes, s'épanouissent beaucoup mieux dans des régimes géographiques donnés. Quoique les communautés biologiques varient par la diversité et les populations d'espèces, chaque communauté peut se distinguer par la présence d'organismes essentiels ou caractéristiques.

Il faudrait effectuer d'autres recherches sur les caractéristiques détaillées des assemblages biologiques dans les endroits de la région littorale qui correspondent à chacune des classifications géomorphologiques du littoral de la baie de Plaisance. On pourrait aussi choisir des endroits précis du littoral en vue d'y effectuer de plus amples recherches et analyses.

INTRODUCTION

In response to the growing public concern for impacts of oil tanker accidents on the marine environment, the Prime Minister of Canada appointed a Public Review Panel on Tanker Safety Spills Response Capability in June 1989. The Panel was mandated to review and evaluate: i) the measures currently in place to ensure the safe movement of oil and chemicals through Canadian waters, ii) Canada's ability to respond to marine spills of these products, iii) provisions for compensation for damages resulting from spills of oil and chemicals, and iv) Canadian legislation and international conventions which regulate the movement of vessels transporting oil and chemicals.

A major regional need in response planning for marine environmental emergencies is the provision of detailed sensitivity mapping for areas with high potential for such emergencies. One of the areas identified during the Public Review Panel on Tanker Safety Spills Response Capability to have a high potential for an oil-related environmental accident was Placentia Bay, Newfoundland. This elevated risk was due to the presence of an oil refinery at Come-by-Chance. Subsequent to the Panel Report, it has been decided that oil from both the Hibernia and Terra Nova oil fields will be shipped through a new transshipment facility at Whiffen Head, Placentia Bay. It is anticipated that, at peak production, there will be in excess of 350 tanker movements per year in Placentia Bay.

The Panel had found that there was a paucity of sound environmental data in Placenta Bay and recommended that a sensitivity map be prepared. In October 1991, a Treasury Board submission for "Response to Marine Environmental Emergencies (Brander-Smith)" was approved and the Department of Fisheries and Oceans (DFO) was funded to develop the map. One of the required products from this initiative was the establishment of biological and geomorphological classification schemes for Placentia Bay.

The purpose of this study is to provide preliminary biological and geomorphological classification schemes for the Placentia Bay, Newfoundland region, and to examine the degree to which the geomorphological regimes of the bay affect the development of the biological communities. The study area extends from Point Crewe on the western tip of the Burin Peninsula to Point Lance on the Avalon Peninsula (Fig. 1). This study represents an application of research concerning the coastal classification of Placentia Bay (Catto *et al.* 1997).

The report is divided into two principal sections. The biological communities of Placentia Bay are discussed initially. The communities are considered within a hierarchical framework of environments, ranging from the entire bay to consideration of specific representative sites. The second section of the report discusses the relationship of these biological communities to the geomorphic regions of Placentia Bay.

HIERARCHICAL BIOLOGICAL SHORELINE CLASSIFICATION OF PLACENTIA BAY

The biological classification of Placentia Bay is based upon a three-fold hierarchical subdivision. Further subdivision between the level of the major regions of Placentia Bay (second-order regions) and the individual local shoreline units would require evaluation at very fine map scales, in addition to extensive on-site investigation. The local scale units should be critically evaluated in detail, before decisions are made concerning the precise delineation of boundaries of the individual sub-areas.

The primary elements involved in the classification are oceanographic circulation, wave regime, freshwater influx (volume and consistency), effects of terrestrial influx, pack ice activity, geomorphologic and climatic regime, and anthropogenic influences. Although the communities vary markedly in the diversity of species and their populations, each can be distinguished by the presence of a limited number of critical or characteristic organisms.

PLACENTIA BAY

Placentia Bay is the arbitrary primary unit because of its differentiation as a large Newfoundland Bay. In terms of shoreline biology, it is a mixed transitional zone between the annually ice-dominated, largely ephemeral, heterogeneous shore biota of northeast Newfoundland and the conspicuously zoned, largely perennial communities which can develop where and when ice is not so overwhelmingly destructive. Hence, the scarcity of seasonal ice in Placentia Bay is critical to its existence as a distinct habitat for marine organisms. Ongoing changes in the timing, persistence, nature, and distribution of seasonal marine ice will have significant impacts on the biota of the region.

There are no sharp biological boundaries delineating Placentia Bay from neighbouring coasts. No marine species strictly endemic to Placentia Bay have yet been identified.

SECOND-ORDER SUBDIVISIONS

Within Placentia Bay, shoreline biological communities can be divided into five second-order subdivisions. These are related to oceanographic circulation, wave regime, freshwater inflow, and terrestrial effects.

a) Cape Shore

The Cape Shore is defined as the region extending from Cape St. Mary's to the northern tip of the Argentia Peninsula. This shore is dominated by northward-flowing ocean currents, which occasionally carry Labrador Sea pack ice into the bay. Summer sea temperatures remain relatively low throughout July and August, in contrast to the temperature rises which mark the more northerly parts of Placentia Bay. Winds are usually oriented onshore, especially during spring and summer. At these times, the shorelines are subjected to heavy surf, especially in areas where waves form breaking surf in coves, through interaction with shallow water depths. Hurricanes and storms wreak special havoc here. Fog is pervasive and has a major influence on shore biology.

This coastline is currently erosional in nature in most areas, with erosion occurring slowly along bedrock shores and very rapidly along major raised glacio-marine terraces (such as occur at Point Verde). Some of these shorelines contain substantial proportions of sand and silt, and clay is present in offshore areas. Seawater clarity is locally reduced by surf-suspended sediments. Erosion of this type of material is a controlling factor for many biological communities in this region.

This region has the lowest biological diversity within Placentia Bay. Few species are restricted to the Cape Shore. Productivity is high, primarily due to the high concentrations of nutrients carried by upwelling waters off Cape St. Mary's. High surf and the ubiquitous fog combine to foster marine life at much higher elevations on the shore than in the other second-order regions.

b) Northeast Placentia Bay

Northeast Placentia Bay includes the shores from Argentia Harbour to North Harbour. The biota along these shores is bathed by the same north flowing currents which influenced the Cape Shore, but the shores of northeast Placentia Bay are much more protected from surf and ice erosion by the highly convoluted and indented nature of the coast, with its countless shoals, headlands and small islands. Pack ice which is carried northwards into the outer part of Placentia Bay seldom survives transport north of Argentia.

The diversity of species is conspicuously higher than in the Cape Shore region, but it is still relatively low. No species are restricted exclusively to this area. Some zonation of perennial species occurs within protected habitat areas, such as embayments and sheltered coves. Productivity is relatively high (Hooper 1995), due to the nutrients and phytoplankton carried into this region, but is less than in the Cape Shore region.

c) Swift Current Estuarine Region

The Swift Current Estuarine Region is the northwest portion of Placentia Bay which is subject to major reduced salinity effects related to freshwater influxes from the Piper's Hole and other associated rivers. The exact position of the boundaries of this region are uncertain, due to annual fluctuations in weather that control the extent of landfast freshwater ice and the magnitude and timing of fluvial discharge. The boundaries may best be defined by the limits of landfast freshwater ice and/ or by the distribution of characteristic estuarine species. There are direct relationships between low salinity values and the suitability of the habitat for estuarine algae, invertebrates, and fish. A possible solution, then, could involve defining the estuarine limits to coincide with the limits of the distribution of smoltifying salmon parr. However, care must be taken to define the limits with sufficient latitude to accommodate yearly or seasonal variability.

The estuarine region generally is defined here to extend between North Harbour Point and Prowsetown, including Soundy Island, Woody Island, and Bar Haven Island. The extensive *Zostera* (eelgrass) communities are the most characteristic and diagnostic perennial biological feature. Saltmarshes are more frequent throughout the estuary than in the other second-order regions. Productivity is moderate. The freshwater entering this system is very low in nutrients, as it originates primarily from areas of acidic rock outcrop, but nutrients are recycled efficiently within estuarine sediments and nitrogen is fixed by estuarine cyanobacteria and anaerobic bacteria. The biological diversity of this region is (moderate) but no species are restricted exclusively to this area.

d) Northwest Placentia Bay

The northwest Placentia Bay region includes Merasheen Island, Long Island, the Ragged Islands archipelago, Isle Valen, Presque Harbour, Paradise Sound, and the adjacent mainland shores of Newfoundland. This is the relatively fog-free portion of Placentia Bay, where the more frequent sunshine can produce significantly higher seawater temperatures. Thus, the climate favours temperate species not found elsewhere in the bay. Sea surface temperatures can exceed values lethal to some cold-loving organisms, which are thus excluded from the shallows of the northwest.

The extreme geomorphological complexity of the shoreline and bathymetry results in extreme microhabitat diversity, with literally thousands of tiny beaches, coves, basins, and other features, especially in the Ragged Islands archipelago. The biological diversity in this region is extremely high, by any standard applicable to Atlantic Canada (Hooper 1995), and the region is much more diverse biologically than any other second-order region of Placentia Bay. Both seaweeds and phytoplankon, which thrive in the warm shallow waters in this region contribute to its high productivity. Pack ice is practically unknown in this area, but landfast ice forms in all sheltered locations.

e) Burin Peninsula

The Burin Peninsula region of Placentia Bay is biologically distinct from other regions. This distinction arises in response to a combination of physical circumstances. Oceanographic circulation involves considerable upwelling which keeps summer seawater temperatures cool, and the air foggy. Upwelling also provides nutrients which promote high primary production, especially in local situations. As a result of the presence of extensive shoal water, much of the primary production is due to seaweeds, in addition to substantial input from phytoplankton. Diversity is not as high as the previous sector. Headlands in this region are exposed to considerable wave energy, but the prevailing winds are offshore. Sea ice is very rare along this shore, although it has entered the region twice in recent years.

THIRD-ORDER (INTERTIDAL) BIOLOGICAL SHORELINE UNITS

The third-order units presented here represent a preliminary attempt at classification that is subject to further investigation, refinement, and debate. The classification is based on the scheme developed for the West Newfoundland Marine Sensitivity Atlas, which was prepared for the Environmental Science Research Fund. Many units are comparable, but it has proven necessary to develop new units to accommodate habitats which occur in Placentia Bay but are absent from western Newfoundland. For some purposes, an alternative classification scheme dividing the shoreline into three levels of biological communities based on tidal altitude (high, middle, and low) would be preferable. Each of these tidally-defined regimes could then be discussed independently. For this report, however, the subregions have been designated on the basis of key biological indicators.

a) Saltmarsh

Saltmarsh shores are high intertidal areas dominated by vascular vegetation, especially grasses and sedges. Typical examples are the *Carex* dominated regions of the Swift Current - Piper's Hole estuary. The marsh vegetation entraps sediment, and thus serves to stabilize these shores. Additional key genera include *Plantago, Triglochin, Glaux, Festuca, Arenaria,* and *Potentilla.*

The arrangement of the organisms in the Pipers Hole River salt marsh is represented in Figure 2. The area directly above the spring high tide level of the shore is occupied primarily by freshwater riverside vegetation. The most conspicuous indicator species are the shrub *Myrica gale* and the sedge *Juncus balticus.* Directly adjacent at the high tide level is a mix of grasses, including *Arenaria* and *Festuca,* and other vascular plants such as *Iris, Potentilla spp., Glaux, Triglochin,* and others. Less conspicuous, but still important, are a host of small microscopic algae including diatoms (especially *Navicula spp.*) and cyanobacteria (including *Rivularia* and *Phormidium*). Between the high water spring zone and the neap tide zone, the first obviously marine influence on the biota becomes apparent. Blue-green algae (cyanobacteria) cover extensive areas, where they are responsible for major quantities of nitrogen fixation. Diatoms, green algae, and brown algae also contribute to high primary production. This zone resembles a meadow because of the abundance of low grasses, especially *Festuca, Plantago, Ranunculus* and *Potentilla,* which are conspicuous flowering plants of this zone.

The saltmarsh vegetation is less abundant lower on the shore, due to shifting sediments and moving ice. Less stable areas are dominated by early successional species, especially the plantain, *Plantago maritima.*

Animals in this marsh are not usually conspicuous. Waterfowl and shorebirds should be making extensive use of this productive habitat, but activities related to the community of Swift Current and the presence of the Burin Peninsula Highway are believed to prevent this. Large numbers of insects and other invertebrates, including the snails, *Hydrobia* and *Littorina,* and *Gammarus* spp. occur here, but are not obvious to most observers (biting flies excepted!).

b) Eelgrass (Zostera)

Zostera is found in sandy, relatively sheltered lowshore locations. It is not quite as tolerant to freshwater influxes as is saltmarsh vegetation, although the two assemblages frequently overlap. A typical site is found inside Placentia Harbour. These areas are productive and shelter many important commercial species. Additional key genera include *Rhodophysema, Ahnfeltia, Crangon, Arenicola,* and *Cancer.*

At Swift Current (Fig. 3), *Zostera marina* forms meadows from just above the low tide level to about 3 metres depth from near the upper reaches of the Swift Current estuary, as far downstream as suitable sheltered sandy substrate occurs. The shallowest plants are exposed to freshwater on the falling tides and higher salinities as the flood tides peak. Deeper portions of the bed are not so salinity stressed, except during extremely high river flow periods. The sand surrounding the plant roots harbours a wide range of burrowing invertebrates, especially the softshell clam *Mya arenaria,* the lugworm *Arenicola marina,* and the sand shrimp *Crangon septemspinosus.* The leaves form an anchorage for numerous seaweeds including *Polysiphonia harveyi, Rhodophysema georgii,* and

Myrionema sp. Hydroids, bryozoans, and serpulids are among a number of animals which have also attached themselves.

Eelgrass beds are an important area for salmon, trout, and other fish. Not only are these important feeding zones, but they are also important resting areas where fish can acclimatize physiologically between life in freshwater and in the sea. These areas, therefore, are both ecologically and economically significant.

Eelgrass stabilizes the sediment in the Swift Current region. They typically anchor 30 to 50 cm of sand. Loss of these submarine meadows would lead to severe erosion problems. Eelgrass diseases, associated with pollution, have decimated American and European eelgrasses with very detrimental effects. As of yet, these problems have not arisen in Newfoundland.

c) *Fucus anceps Surf Zone*

Fucus anceps surf zone shores are typical of extremely exposed bedrock shores subject to essentially continuous surf and pervasive fog. A typical site is the Cape St. Mary's area, north and east of the bird sanctuary. Marine plants and animals colonize the rock faces well above the tidal zone. Pack ice damages these communities by damping wave energy, so that the raised communities do not receive the sea spray that they require. Additional key taxa include *Pilinia, Porphyra linearis, Audouinella purpurea,* and *Sphacelaria nana.*

The rocky headlands on the southern point of Buffet Island (Fig. 4) are almost continuously battered by long period surf which climbs up the large gullies on the steep bedrock faces. These shores are also bathed by heavy fogs for extended periods of the year. The result of this activity is the development of raised seaweed and animal zonation. Kelps, especially *Alaria* and *Laminaria digitata,* occur much higher on this shore than is usual in other Placentia Bay localities. The barnacles and seaweeds such as *Porphyra* that occur at other sites in the intertidal zone, here grow attached well above the high tide level. The seaweed *Fucus anceps* is restricted to this type of habitat.

d) *Seabird-Dominated Shores*

Seabird-dominated shores are typified by green to yellow-orange rock faces which are clearly visible from great distances seaward. The colours are the result of nitrogen loving algae and lichens which thrive in the seabird excrement (guano). The Cape St. Mary's bird sanctuary is the best example along the Placentia Bay shore, although less well-developed and smaller examples are widespread throughout the shoreline areas. Additional key genera include *Rosenvingiella, Prasiola, Xanthoria, Calothrix,* and numerous associated Cyanobacteria and insects.

Bird excrement subjects organisms to high levels of nitrogen and phosphorus compounds. These can be toxic to many organisms, as well as a source of considerable osmotic stress. Many organisms are thus excluded from these sites. Other organisms are not only resistant, but are able to use these chemicals as growth-promoting fertilizers, allowing these species to thrive. The colour of the seabird sanctuary at Cape St. Mary's (Fig. 5) is due mainly to the green algae *(Rosenvingiella polyrhiza,* *Rhizoclonium,* and *Prasiola)* and lichens *(Xanthoria).* These taxa are good indicators of this unit, as they are essentially representative of areas that are highly eutrophied. These plants serve as the food for numerous mites and insects.

e) *Ascophyllum* Rockweed Shores

These shores are dominated by extensive carpets of yellow-brown fucoid seaweeds growing on bedrock and stable boulder substrata. These beds require several years of biological succession to develop, so they cannot mature on shores which are regularly scoured by severe storms or marine ice. The inner Ragged Islands area is the best example in all of Newfoundland. Additional key organisms include *Chondrus, Chorda, Hildenbrandia, Phymatolithon lenormandii, Phymatolithon laevigatum, Fabricia sabella, Dynamena, Littorina obtusata, L. littorea, Flustrellidra, Polysiphonia lanosa,* and many more (Fig. 6).

The Ragged Islands area has hundreds of hectares of bright yellow shore, where everything is covered by dense beds of the "knotted rockweed", *Ascophyllum.* These beds have taken many years of succession to develop, with *Ascophyllum* essentially outliving its competitors and dominating by suppressing their recruitment with its shading canopy. There is a characteristic understory biota of *Chondrus, Phymatolithon, Verrcuaria, Hildenbrandia, Dynamena,* and *Fabricia* which depend on the rockweed blanket to protect them from temperature extremes, dessication, and competition. The lower limit of this zone was determined by competition with *Laminaria longicruris,* but this latter species has been dragged out by scallop fishermen, and had not yet recovered from this devastation at the time of these observations in 1994.

f) Capelin Spawning Beaches

Capelin spawn preferentially on wave-dominated, exposed fine gravel shorelines (Templeman 1966). These areas can appear biologically barren, because the constant movement of the substrata prevents development and establishment of conspicuous flora and fauna. In fact, these shorelines are marked by characteristic species of microscopic algae and invertebrates. Much of the food webs developed in these environments is supported by stranded seaweeds and animal remains, which are consumed either directly or *via* microbial decay pathways. In the early summer, capelin eggs and dead capelin form the main food supply. Numerous animals immigrate to capelin beaches to feed during the spawning and incubation season in June, when large numbers of breeding capelin spawn on the intertidal coarse sand and fine gravel substrata. Typical capelin beaches are located at Gooseberry Cove and Point Verde (Fig. 7), Cape Shore. The biological assemblage of capelin beaches has been poorly studied to date, but it is known to include *Navicula* and other motile diatoms, nematodes, burrowing crustaceans, insects, and fungi.

g) Temporary Intertidal Communities

Temporary intertidal communities form on rounded boulders that are stable in calm weather, but are unstable under storm conditions. Pocket beaches backed by steep cliffs often develop a biota of rapidly growing, ephemeral seaweeds and invertebrates that are removed by every storm. Typical sites are located along the southern shores of Merasheen and Red Islands. Typical taxa include *Pilayella, Ulothrix, Chorda filum, Ectocarpus,* harpacticoid copepods, and amphipods (Fig. 8).

The rounded boulders and coarse gravel roll whenever wave action is powerful, thoroughly removing all organisms. During calmer periods these substrata are colonized by a range of fast-growing opportunistic seaweeds and animals. Species present depend upon chance, the magnitude of the last scour, the duration since the last scour, and the season of the year. At any particular time, diversity is low, with very few species dominating.

h) Barachois Estuaries

Barachois estuaries are an important localized feature around Placentia Bay. A sedimentary bar isolates lagoon-like water bodies, marked by the development of dark tannin-coloured fresh water at the surface and higher salinity waters below. When the sediment bar has been built high by waves and river flow is relatively low, the lagoon is almost totally freshwater with runoff permeating through the bar (as occurs frequently at Ship Cove). Severe river flooding can breach the bar, leaving a passage for seawater to enter the lagoon on the flood tides. The barachois estuaries are biologically stressful sites, with low biological diversity and low productivity (Fig. 9). Seasonal changes are common. Many estuaries shelter sea-run trout or salmon. Plant growth is dominated by black coloured cyanobacteria, including *Phormidium, Oscillatoria, Calothrix,* and a few green algae species, including *Pseudendoclonium, Enteromorpha* and *Capsosiphon*.

i) Vertical Biological Zones

Vertical biological zones cover sheltered bedrock vertical cliff faces. Horizontal bands of lichens, seaweeds, and invertebrates form well-defined zones, commonly defined as characteristic in the biological literature. These vertical zones are most prominent along glaciated fjord walls, such as Paradise Sound, and along portions of the Ragged Island channels. Typical inhabitants include *Verrucaria, Hildenbrandia, Fucus spiralis, Lichina, Littorina saxatilis,* and *Mytilus*.

The outer margins of Best's Harbour, like several other areas in Placentia Bay, have vertical seaside cliffs that are protected from surf and pack ice. Vertical zonation of perennial species with tidal height is visually conspicuous (Fig. 10). The lack of wave action eliminates most of the variation in species distribution which is always observed at more exposed locations. The upper intertidal zone is marked by the lower limit of terrestrial crustose lichens and the appearance of marine lichens, especially *Verrucaria. Littorina saxatilis* is abundant in minor crevices in the upper zone and becomes more abundant slightly lower. Above the mid-tidal level is a barnacle zone dominated by *Semibalanus (Balanus) balanoides.* This zone may be shared with patches of the highshore seaweed *Fucus spiralis.* Most of the mid- to lowshore is occupied by a thick moustache of *Ascophyllum nodosum.* Lower on the shore, where space has been opened by herbivores or minor ice scour, are found other *Fucus* species and shorter lived plants such as *Sphaerotrichia.*

j) Rockweed Platforms

Rockweed platform exposed shores have an irregular rocky substrate which usually includes frequent tidepools. Typical sites are the Iona Islands, off Fairhaven, and the Green Islands. *Fucus edentalus, F. vesiculosus, Chondrus,* and other seaweeds are most abundant in protected microhabitats, while the most convex (most exposed) microhabitat is more barren with some lichens and *Littorina saxatilis.* The pools are dominated by *Chondrus, Fucus distichus,* and crustose seaweeds. The lower portion of the shore supports *Alaria, Laminaria, Palmaria,* and *Devaleraea.*

The Green Islands are exposed to much more wave action than the sites inside the Ragged Islands. Their substrate is mainly bedrock with irregular topography that includes many tidal pools. The plant and animal communities present are much more heterogeneous as a result of the combination of stresses (Fig. 11). Patches of *Ascophyllum, Fucus, Chondrus, Chordaria, Dictyosiphon, Pilayella, Mytilus, Semibalanus,* and many other species can all occupy discrete locations at the same tidal level. The pools' flora and fauna are similarly heterogeneous. Although some pool species (such as *Fucus distichus)* are restricted to pools at a particular level, there is no predictable pattern to determine which organisms will dominate specific pools.

k) Periwinkle Shores

Periwinkle shores are somewhat similar to the rockweed platform shores with respect to the abundance of intertidal fucoids and Irish moss (*Chondrus*), but the substrata can include boulders, cobbles, and fine gravel. The diversity of both plants and animals is lower and the low shore kelps are absent, being replaced by crusts and summer ephemeral beds of *Chordaria, Scytosiphon, Dictyosiphon, Pilayella,* and *Ectocarpus.* The differences in the low shore assemblages are caused by the depredations of herbivorous *Strongylocentrotus* and *Littorina,* which are controlled or precluded by storm waves in more exposed locations.

Moderately sheltered shores along Bar Haven Island (Fig. 12) have huge populations of the common periwinkle, *Littorina littorea.* These ensure that whatever heavy seaweed settlement occurs is always curtailed, leaving only scattered patches of weeds such as *Fucus vesiculosus.* The remaining cover on the shoreline rocks are crustose organisms such as *Ralfsia, Semibalanus, Verrucaria,* and other organisms resistant to grazing. Between the rocks are numerous nestling animals, especially polychaetes, nemerteans, amphipods, oligochaetes, and nematodes. Where sediments are suitable, *Arenicola* and *Mya arenaria* are present.

INDIVIDUAL FACTORS INFLUENCING BIOLOGICAL COMMUNITY TYPE

a) Pack Ice Scour

The direct effect of moving sea ice is the removal of attached species of plants and animals. The degree and specificity of scour mortality is dependent upon several factors. Some of the more important are considered briefly below.

Ice type ranges from loose unconsolidated ice crystals through pancake ice, new ice pans, rafted first year ice, multi-year ice, to pieces of glacial ice. The former are the softest and do the least inertial impact damage, but are composed of the sharpest small fragments. These commonly have an effect similar to thorough sand blasting on the substrata. Larger, harder masses of ice can cause impact damage to the more robust plants and animals, but may leave concave or otherwise sheltered microhabitats unscathed.

Slush and slob ice are most common in Placentia Bay. These ice types can occur anywhere in the bay following suitably cold air conditions, providing that water temperatures are already near or below 0°C. Formation of new pack ice has become an occasional problem in Placentia Bay in recent years. Its prevalence is highest along the Cape Shore, although during most years it is not present. Currents carry ice into the northeastern part of the bay, where it usually does not persist for long. Pack ice is very rare elsewhere in the bay, and multi-year ice is almost unknown. Icebergs are occasionally observed in the outer portions of Placentia Bay, but the incidence here is so low that the biological effects are very local and specific.

Duration and timing are extremely important in assessing the effectiveness of ice scour. Many of the plants and animals of Placentia Bay are opportunistic or ephemeral. Seasonal species, in particular, are likely to be decimated or, alternatively, to remain completely unscathed, depending upon the timing of ice scour episodes. Long durations of scouring increase the chances of individual species being killed. Duration also increases cumulative damage to marine species. The timing of ice activity is variable in Placentia Bay, ranging from January to May, with many years marked by totally ice-free conditions. The duration is usually brief.

Altitude or height of ice scour is more limited in Placentia Bay than along the northeastern shore of Newfoundland. In much of the bay, the most thorough scour occurs low in the intertidal zone. Higher shore zones are not often reached by the usually thin pack ice, while the lowest reaches are protected by buoyancy and the lack of thick rafted pressure ridge ice floes or iceberg bits. Thus, the intertidal zonation in Placentia Bay differs both from that reported in more temperate regions, and that prevalent along more ice influenced coasts.

b) Landfast Ice

Landfast ice or an icefoot protects shores from moving marine ice scour, and from the effects of extremely low air temperatures. The stability thus imposed allows the development of a multi-year biological succession, and the formation of perennial biological communities. Saltmarshes, eelgrass beds, and fucoid-rockweed beds in Newfoundland and Labrador depend upon this landfast ice protection.

The ice cover does stress these communities, however, as well as protecting them. Thick ice cover intercepts most photosynthetically-useful sunlight, so plants must survive extended periods of light deprivation. During ice formation, brine released by freezing seawater can subject biota to high salinities (in excess of 40 ppt). Once the ice is in place, it impairs mixing between seawater and freshwater. Therefore, a layer of freshwater usually develops below the ice, and ranges from a few centimetres to several metres in thickness. Species occupying these shores must be able to survive this osmotic stress.

c) Substrate Size

Substrate size in the Placentia Bay region is biologically important mainly because of its relationship to the stability of the environment. Fine clays and silts become suspended under relatively gentle wave and current action. Fine particulate material stresses life by smothering and shading. Gravel and boulders are churned by increasingly energetic surf, ice, and storms. Bedrock is only susceptible to stresses above the physical strength of the specific rock type. Newfoundland as a whole, and Placentia Bay in particular, are marked by an unusual predominance of stable rocky shores. This is largely related to the glacial history, and to ongoing geomorphological and sedimentological processes which remove less stable substrata. Habitats with fine sedimentary substrata are only common in sheltered locales.

d) Geochemistry

Geochemistry is relatively unimportant to most shore life. Seaweeds, in contrast to land plants, get their chemical input from the overlying water, which generally has little chemical relationship to the substratum. Areas underlain by limestone are the main exception to this relationship. Many plants and invertebrates are specifically adapted to burrow into carbonates, whether in the form of skeletal debris or limestone bedrock. Most calcium carbonate substrata in Placentia Bay are modern biogenous materials, rather than solidified Palaeozoic limestones.

e) Fog

Fog is a trademark feature of Placentia Bay. Fog influences shore life in several ways, of which the prevention of desiccation is the most important. The foggiest shores, such as the Cape Shore, have a conspicuously more diverse and abundant highshore and spray zone flora and fauna. When there is an extended fog-free period, these communities show signs of stress and mortality. Fog is less saline than seawater, so it causes some freshwater stress to the residents of the intertidal zone. Fog also reduces air temperature and slightly reduces irradiance.

f) Temperature

Temperature extremes can easily affect many organisms in this area which are near their biogeographic ecological limits. During especially hot summers, mortality of some of the 'coldwater' species has been noted. Freezing mortality has also been observed. Paradoxically, some local supercooled temperatures have been observed under Placentia Bay ice that are in excess of those developed under sea ice in arctic conditions. This supercooling develops as a result of the very heavy surf often experienced during severe winter storms. The motion keeps seawater in a liquid state at temperatures well below -2°C. "Southern" taxa such as *Callithamnion* are the most frequent victims. Non-lethal year-to-year temperature variations can also have a major influence on biological communities. Many species require particular combinations of photoperiod and temperature or degree-days to successfully reproduce. This is particularly conspicuous in certain seaweeds and invertebrates with very dissimilar sexual and asexual phases. Some of the organisms which were important members of shoreline communities during the 1970's were difficult or impossible to find during the cold years of the early 1990's. Revival of these communities is dependent upon relatively warm, mild summer conditions.

g) Seawater Chemistry

Chemistry of marine waters is generally uniform, with most elements and ions found in constant ratios to one another, and abundances varying only with salinity. In addition to these conservative components, however, a few chemical components are biologically utilized. These include the plant growth 'nutrients' such as silicates, nitrates, and phosphates. If any of the components (and / or other similar ones) becomes depleted, then marine productivity drops. Upwelling of deep seawater from below the photic zone is necessary to replenish the limiting nutrients. Upwelling is frequent off Cape St. Mary's and the Burin Peninsula, and very rare in northern Placentia Bay. During the summer, nutrients are more likely to be high in the foggiest portions of the bay and most limited in the northern reaches of the bay.

h) Anthropogenic Effects

Man-made effects on shores are varied. Sewage pollution and other organic problems such as fish wastes impair many shores in the direct vicinity of communities. Wharves, breakwaters, causeways, roads, and garbage disposal areas all alienate numerous shores. Fishing activities can have a major effect on adjacent shores, in addition to the species directly fished. Major industrial sites include the Come-by-Chance oil refinery, the Marystown shipyard, the former phosphorus plant in Long Harbour, and the former Argentia Naval Base. The 1968 effects from the Long Harbour operation are well known (Jaangard, 1970), and a survey of the geomorphic impacts of the Argentia operations has been undertaken by the Atlantic Geosciences Centre. The potential effects of ship traffic to and from Come-by-Chance could be much more profound.

GEOMORPHOLOGICAL - SEDIMENTOLOGICAL CLASSIFICATION OF PLACENTIA BAY

The geomorphological-sedimentological classification of Placentia Bay used in this report is determined by the biological classification outlined in the preceding section. Although a purely geomorphological classification scheme would result in divisions that were not identical with those resulting from a biological division, the differences between the subregions produced for Placentia Bay by application of the two systems are relatively minor. This degree of compatibility indicates that geomorphic and sedimentological parameters are responsible in large measure for controlling the distribution and development of the biological communities of the coastline of Placentia Bay. The possibilities of such integration on a more regional scale have been discussed previously by Kelletat (1989).

The coastal classification of Placentia Bay from a geomorphological - sedimentological viewpoint has previously been undertaken, and the results are described elsewhere (Catto *et al.* 1997). The summary of the geomorphic characteristics of the biological regions and subregions presented below is designed to be read in conjunction with the previously produced "Coastal Classification" report. Shore classes cited below are defined and discussed at length by Catto *et al.* (1997).

PLACENTIA BAY

As a geomorphic entity, Placentia Bay is marked by its relatively deep bathymetry and its exposure to southwesterly winds and currents. The bay entrance is unrestricted by any topographic or bathymetric obstacles, allowing waves unrestricted access to the region.

The climate of Placentia Bay is classified as mid-boreal (modified Köppen-Geiger Dfb). The region is marked by relatively short, cool and wet summers (normally, the driest and hottest month is August), with moderately mild, wet winters, long springs, and relatively short autumns (Banfield 1981). Daily mean temperatures in Placentia (Fig. 1) are approximately -4°C in January and 16°C in July. Mean annual precipitation is approximately 1300 - 1400 mm, of which 15-25% falls as snow. Freezing drizzle is common, with an average of 35 hours per year.

The low summer temperatures and abundant precipitation combine to produce a perhumid moisture regime and an excess of soil moisture, keeping soils saturated throughout most of the year. Snow cover persists for approximately 140 days in wooded areas, but snow is removed rapidly from exposed coastal zones. Fog is common: Argentia (Fig. 1), the foggiest weather station in Canada, averages 206 days / year with at least 1 hour of fog. The annual total of sunshine is approximately 1500 hours, one of the lowest totals in the country. Ice foot development has commonly occurred along all sediment beaches during the winters of the past five years (Catto 1994).

Wind patterns vary seasonally at Placentia, and along the Placentia Bay shore. Easterly winds prevail during the summer, and southwesterlies dominate during the winter. Throughout the bay, however, winds may originate from any point of the compass at any time of the year. The southwesterly winds generally bring warm, moist air to the region from the surface of the Gulf Stream, but are also associated with many of the major storms during the summer and autumn. Northeasterly winds, which are responsible for much of the storm modification of beaches along Conception and Trinity Bays and the open Atlantic Southern Shore of the Avalon Peninsula, are generally ineffective agents of shoreline modification in Placentia Bay. Diurnal onshore and offshore winds are common in most embayments.

The glacial history of the Avalon and Burin Peninsula regions differs substantially (Henderson 1972, Tucker and McCann 1980, Grant 1989, Catto and Thistle 1993, Catto 1994, Catto 1998). The Avalon Peninsula was not overridden by glacial ice from central Newfoundland, but supported its own independent glaciers. Avalon Peninsula glaciers flowed radially outward from centres throughout the peninsula and isthmus. Ice divide migration, coalescence, and development of separate ice caps during deglaciation have produced a complex assemblage of glacial features. At present, ice flows from more than 25 separate sources scattered throughout the Avalon Peninsula have been recognized through geomorphological, sedimentological, and petrographic analysis (Catto 1993, 1998; Catto and Thistle 1993).

Placentia was glaciated by ice moving westwards and westnorthwestwards from St. Mary's Bay during the Late Wisconsinan, beginning 30,000 - 25,000 years ago. Local diversion of flow around Castle Hill and other obstructions, and initial flow southward along the bay shoreline, are indicated by erosional landforms and striations (a good example is present behind the Visitor Centre). Esker complexes are present along Northeast Arm and Southeast Arm, indicating that subglacial water flowed from the east. These complexes terminate in a large fan delta at Point Verde (southwestern side of the harbour). Gravel aggregate from this fan delta is currently being mined for the St. John's market.

The Burin Peninsula was glaciated both by local ice and by glaciers which originated in the Middle Ridge area of Newfoundland, southwest of Terra Nova National Park (Tucker and McCann 1980, Grant 1989). Recent research by suggests that the Burin Peninsula was glaciated during the Late Wisconsinan, in addition to several pre-Late Wisconsinan events. The entire peninsula was covered by Late Wisconsinan ice (unpublished data).

Sea levels in Placentia Bay have undergone a series of changes since deglaciation (Catto 1993, 1994; Catto and Thistle 1993; Liverman 1994; Shaw and Forbes 1995). Initially, sea levels were approximately 5-20 m higher than present around the bay, due to the effects of glacioisostatic depression emanating from the much larger Laurentide glacier to the northwest in Labrador. The small ice caps on the Avalon Peninsula and the central Newfoundland ice caps were not capable of producing significant glacioisostatic deformation. Higher sea levels carved erosional benches and deposited gravel terraces at elevations between 5 m and 20 m above sea level. The elevations of the raised sea levels increase systematically from south to north (Catto 1993, Catto and Thistle 1993, Liverman 1993, 1994).

Subsequently, sea level fell around the Placentia Bay coast, dropping below present during the early Holocene, approximately 9,000 B.P. The presence of submerged estuarine and deltaic sediments southeast of Swift Current, at the northwestern head of Placentia Bay indicates that sea levels stood as much as 20 m below present levels in the northern part of the bay (John Shaw, Atlantic Geoscience Centre, pers. comm.). Along the Cape Shore south and north of Placentia town, ^{14}C dated terrestrial peat deposits indicate that sea levels were at or below present throughout the mid-Holocene (Catto 1993). Similar deposits are present along the southern Burin Peninsula (Grant 1989). All of these sites represent exposed seacoast locations, where trees are currently unable to grow and peat cannot form or accumulate. The decline in sea level can be attributed to a reaction from glacioisostatic overcompensation.

During the past 1300 years, sea levels have continued to fluctuate, in response to ongoing isostatic adjustment. At Ship Cove, south of Placentia, sea level rose to at least ± 1 m above present c. 1340 B.P. (Boger and Catto 1992, 1993a, 1993b). Drowned forests and peat at Biscay Bay Brook (east of Trepassey) and at numerous locations on the Burin Peninsula indicate that sea levels have risen in the past 1000 years. Archaeological evidence from the site of Fort Frederick, adjacent to the lift bridge, and evidence from elsewhere along the Avalon Peninsula coast suggest a rate of sea level rise on the order of 4-7 mm per year during the past 270 years. Evidence of enhanced erosion along many Placentia Bay beaches suggests that transgression is currently occurring.

SECOND-ORDER REGIONS

a) Cape Shore

The Avalon Peninsula contains several areas of rolling uplands, interspersed with small plateaux regions. The peninsula is included within the Atlantic Uplands of Newfoundland physiographic division, which in turn is a part of the Appalachian Region. Along the Cape Shore, the rolling uplands are aligned northeast-southwest, producing the relatively straight coastline marked by few embayments and short, steep-gradient rivers. The scarcity of deeply indented embayments, in contrast to the Conception Bay shore, indicates the alignment of physiographic ridges and bedrock units parallel to the coast. The inland area east of Placentia Bay is a gently rolling plateau. Maximum relief is approximately 275 m, in the Beaver Pond Hills.

The Avalon Peninsula is underlain by moderately to very resistant Hadrynian (latest Precambrian) sandstones, siltstones, and shale, most of which have been metamorphosed (King 1988). Small areas of volcanic rocks, primarily basaltic, and volcaniclastic rocks formed by explosive volcanic eruptions during the Precambrian are also present. Sedimentary limestones, sandstones, and red shales of Eocambrian, Cambrian, and Ordovician age crop out along the southern part of the Cape Shore. The strata have undergone folding and faulting during several orogenic events in the Palaeozoic. The dominant structure consists of NNE-SSW trending doubly plunging folds, with tight crests and steep angles, cut by WSW-ENE trending normal faults at acute angles (King 1988).

The bedrock strata alignment, combined with the small-scale normal faulting, controls the development of the coastline. The absence of major embayments allows northward-flowing currents to traverse the length of the Cape Shore without significant interference. Onshore winds impact the small embayments, barachoix estuaries and lagoons, and areas of exposed bluffs of Quaternary sediment severely, causing coastal erosion at localities such as Point Verde. Current rates of erosion at Point Verde approximate 1 metre per year (Catto and Thistle 1993; D. Liverman, Newfoundland and Labrador Department of Mines and Energy, pers. comm.). During the October 1992 storms, Placentia remained unaffected. Northeast winds travel from landward in the Placentia region, and hence seldom cause coastal modification. Southwesterly winds, especially during August and September, are more effective agents of geomorphology. Sediment plumes are apparent in the offshore waters during July and August, but often bypass the nearshore areas and the barachoix zones. Sediment transported by the offshore currents is dominantly sand and silt.

The steeply-sloping bedrock shoreline is marked by deep nearshore bathymetry in all areas except for isolated embayments. This allows waves to break at the shoreline in cliffed areas, and near the shore in all embayments except Big Barasway and Placentia Roads. The influence of the offshore currents in the nearshore and shoreline zones, especially the cold Labrador Current derived waters, contributes to low biological diversity and high productivity.

The most commonly encountered subregions within the Cape Shore region are eelgrass shores, *Fucus anceps* surf zones, seabird-dominated shores, capelin spawning beaches, and barachoix estuaries.

b) Northeast Placentia Bay

The geomorphology of Northeast Placentia Bay is controlled by differential resistance to frost heaving of the northeast-southwest striking, doubly plunging folded Hadrynian metasedimentary bedrock. The strongly folded bedrock controls the development of harbours and embayments, producing the deeply indented coastline. The rock strata are similar in their resistance to erosion to those of the Cape Shore, but the differences in tectonic deformation are sufficient to create a very different style of coastline. Faulting is also present in most of the major embayments, in particular at Long Harbour, Fox Harbour, and Southern Harbour.

In contrast to the northern part of the Cape Shore, glacial sediment is rare south of Little Harbour along Northeast Placentia Bay. Striae and roches moutonncées suggest that two small ice caps developed along the height of land on the isthmus, near Colliers Brook and Tickle Harbour Station, and expanded into Placentia and Conception Bays. Later centres developed near Great Pinchgut, Chapel Arm, and Little Harbour.

North of Little Harbour, the sediment exposed along the Trans-Canada Highway is texturally finer (75 % fine sand / silt matrix), and is pink or red. This glacial diamicton was derived from the granitic terrain west and north of Swift Current, at the head of Placentia Bay, and from preexisting marine sediment in the bay north of Long Island. Ice from the Middle Ridge Centre to the northwest flowed south through the inlets at Swift Current, North Harbour, and Come-by-Chance, crossed Placentia Bay and the isthmus, and flowed northeast out Trinity Bay (Catto and Thistle 1993, Catto 1998). Pebbles derived from Late Proterozoic granitoid intrusions from the Piper's Hole - Swift Current area, transported by this glacier, are found on the northern part of the isthmus, and at Heart's Delight, New Perlican, and New Chelsea along the eastern shore of Trinity Bay.

The north-flowing currents largely bypass the major inlets of the northeast coast. Complex local patterns characterize current flow in most embayments, and the majority of the sediment is transported by shorenormal waves and density current flows. The absence of pack ice along the shorelines allows for reworking of the beaches on the open shoreline and in the outer parts of the embayments throughout the year, but local brash ice forms in most sheltered embayments by late February.

The geomorphic regime thus differs substantially between the seasonally sheltered, locally-influenced heads of the embayments, and the exposed regions of the open coast and embayment mouths. For most embayments, the exposed regimes extend 5 km landward of the exposed shoreline. Shallowly-indented embayments are essentially parts of the exposed shoreline.

The most commonly encountered subregions within the northeast Placentia Bay region are eelgrass shores, capelin spawning beaches, temporary intertidal communities, rockweed platforms, and periwinkle shores.

c) Swift Current Estuarine Region

The Swift Current estuary and the associated embayments are developed along faults and bedrock contacts associated with the Precambrian (Hadrynian) and Cambrian granites, granodiorites, and other plutonic igneous rocks (Colman-Sadd *et al.* 1990). Relief is relatively high in the inland regions, to a maximum value of 361 m a.s.l. at Toby's Lookout, west of Swift Current. These rocks have been repeatedly fractured along a series of orthogonal northwest-southeast and southwest-northeast joints and faults, producing the strongly aligned embayments and leads of the region. Minor outcrops of Cambrian sandstones and sandy limestones are present in the North Harbour region, but contribute little to the overall geomorphology.

Glacial sediment is present along the Swift Current embayment, and in the major embayments in the vicinity. The sediment was derived from the granitic highlands to the north and northwest (Middle Ridge area), and is dominated by coarse-grained diamicton and glaciofluvial sand and gravel. The estuary is dominated by kame deposits of glaciofluvial sand and gravel, formed when the retreating glaciers stood in elevated marine waters at the head of the inlet. Reworking of these deposits proceeded during the early Holocene, as sea levels fell steadily to more than 15 m below present c. 9000 B.P. (Liverman 1993, 1994; Shaw and Forbes 1995). These readily erodable deposits provide a source of sediment for the construction of offshore, nearshore, and shoreline bars and spits.

The shallow waters of the area are a consequence of the distribution of the glacial and glaciofluvial deposits, and the post-glacial fluctuation of sea level. The period of low sea levels during the early Holocene resulted in the construction of deltas, terraces, and meandering fluvial landforms, all of which are now submerged and provide sediment platforms suitable for the establishment of salt marshes and eelgrass communities. Although other parts of the bay had a similar sea-level history, none had the combination of ample supplies of sediment and deep embayments necessary for deltaic development and sediment bank accumulation.

Currently, sea level is rising throughout Placentia Bay. As sea levels continue to rise in the Swift Current estuary, glacial sediment deposited at higher elevations will undergo reworking. Previously submerged banks will become submerged under deeper water, resulting in the elimination of reworking of these sources. Overall, the net effect of rising sea level will probably be to diminish the available supply of sediment in the system. The current rate of sea level change, however (3-7 mm /year), is not sufficiently large to cause serious problems in the immediate future.

Investigations of salt marshes in other regions of Atlantic Canada (Jennings *et al.* 1993), in Maine (Kelley *et al.* 1988), and in Britain (Allen 1990a, 1990b , French 1993) have extensively examined the impact of sea level rise on marsh evolution. The effects of changing sea levels on salt marshes have generally been evaluated in macrotidal or high mesotidal environments. The northwestern arm of Placentia Bay, and the Come-by-Chance estuary to the north-northeast, are under the influence of low mesotidal -high microtidal regimes. Changes in sea level are thus unlikely to effect major changes in the tidal regime in the immediate future. Under a continuation of the present climate, the accumulation of detrital materials and sediments in the salt marshes and eelgrass subregions of the Swift Current Estuary is likely to proceed at a sufficient rate to mitigate the effects of sea level rise. Hence, the rising sea level will not cause a significant change in the character of these subregions. The embayment is sufficiently sheltered to preclude the possibility of enhanced storm wave activity due to rising sea levels.

The most commonly encountered subregions within the Swift Current estuary are salt marshes and eelgrass shores.

d) Northwest Placentia Bay

Northwest Placentia Bay, encompassing the major islands, Paradise Sound, and Presque Harbour, is marked by strong wave-dominated conditions on open shorelines, low energy zones in lee areas, and limited (locally non-existent) pack ice influence. The complex nature of the shoreline, with its intricate pattern of embayments, leads, coves, and variations in relief, is primarily due to the variations in rock type and the complex history of folding and faulting.

Each of the major islands is composed of a different rock type (Colman-Sadd *et al.* 1990), and hence each varies from its neighbours in geomorphic terms. Merasheen Island and the Ragged Islands, composed of Hadrynian basaltic and rhyo-dacitic volcanic rocks and metamorphosed silica-rich sandstones and shales, are marked by relatively high relief (284 m on Merasheen), steep cliffs, and non-indented shorelines reflecting the NNW-SSE trending joints, faults, and folds. Small indentations result from faults aligned WNW-ESE. Long Island, in contrast, is dominated by turbidite beds of alternating sandstone and shale, which are relatively non-resistant. Consequently, Long Island has generally lower relief than Merasheen and is divided at several locations by east-west trending valleys. Some of these valleys sever the island completely, and the bedrock segments are linked by tombolos. These trans-island valleys serve to funnel wind energy during southwesterly or northeasterly storm events. The impacts of storms thus differ considerably along the length of Long Island (especially along the lee side). Along Merasheen Island, in contrast, the effect of any particular storm is generally similar along one side of the island, but the impact on opposite sides of Merasheen Island differs substantially. The Ragged Islands are in the lee of Merasheen for almost all common wind directions, except from those winds which originate directly from the south-southwest.

Red Island is composed of the youngest rock in the Placentia Bay region, granites of Devonian and Mississippian age (Colman-Sadd *et al.* 1990). These rocks fracture along orthogonal joints, but formed after some of the faulting episodes recorded in the Precambrian sediments. The orthogonal jointing pattern gives Red Island its essentially equantic perimeter, marked by steep (but relatively low) cliffs and its rolling interior. The granites break down into orthogonal blocks, producing beaches dominated by equantic blocks rather than the discose clasts which characterize the other beaches in the Placentia Bay region. Similar effects of preexisting rock fracture patterns and characteristics on beach pebble shape have been observed by several researchers (e.g. Dobkins and Folk 1970, Matthews 1983, Waag and Ogren 1984). These beaches thus respond differently to storm and wave events than do others throughout the bay, and the clasts are not well shingled. The western fringes of Red Island are mantled by older Cambrian and Ordovician sedimentary rocks, locally metamorphosed where they are in contact with the younger granites. These shorelines are less resistant to erosion than are the granitic areas, but their somewhat sheltered position on the western fringe of Red Island limits their susceptibility to wave attack.

The mainland areas of northwestern Placentia Bay, including the Paradise Sound area, also display different rock types. Along the eastern side of the Paradise Fault, Hadrynian marine sandstones and shales (similar to those of Merasheen and Jude Islands) are present. This coastline is marked by steep cliffs and few embayments. West of the Paradise Fault, more acidic volcanic rocks crop out along the coast from Sound Island southwest to Marystown. Deep embayments are common, and are generally aligned northeast-southwest. The offshore island areas buffet the waves from southeasterly storms, and to some extent interfere with southwesterly storms as well. This coastline thus is generally marked by less storm modification than the exposed Cape Shore and the eastern side of Merasheen Island.

Current flow varies significantly throughout the region. Overall, the net direction of longshore drift is to the southwest, although local complexity is the hallmark of many coves and the Ragged Islands archipelago. The scarcity of pack ice and the limited amounts of onshore ice make these coastlines more susceptible to year-round modification by waves than other regions of the Placentia Bay coast.

Subregions commonly encountered within the northwest Placentia Bay region include *Ascophyllum* rockweed shores, temporary intertidal communities, vertical biological zones, rockweed platforms, periwinkle shores, and seabird-dominated shores.

e) Burin Peninsula

The Burin Peninsula in geomorphic terms can be divided into two regions. The northeastern segment, from Marystown to Little St. Lawrence, is dominated by Precambrian (Hadrynian) basaltic and andesitic volcanic rocks (Colman-Sadd *et al.* 1990), which are relatively resistant to weathering. These rocks have undergone faulting and ancillary folding, with the tectonic fabric trending northeast-southwest. Associated orthogonal faults and joints aligned northwest-southeast are also present. As a result, this segment of the Burin Peninsula coastline is marked by complex, deeply-indented embayments such as Mortier Bay, Little Mortier Bay, and Burin Harbour. The area is thus geomorphically similar to the Marystown-Paradise Sound segment ofNorthwestern Placentia Bay. An areally restricted granitic shoreline, similar to that of Red Island, is present in the St. Lawrence area.

Beach development in this region is influenced by its more exposed position, however, as the peninsula is open to the full fetch of all southerly storm and wave systems. Energy levels here are generally higher than those marking the coastline northeast of the Baine Harbour-Rushoon area. Coarse gravel barachoix and spits are present in some regions. The prevalence of offshore winds in local situations, however, limits the effectiveness of normal waves in modifying the shorelines.

The westernmost segment of the Burin Peninsula, from Little St. Lawrence to Point May, is marked by less resistant Cambrian and Ordovician sedimentary rock, and thick deposits of glacial and other Quaternary sediment. This coastline is thus more susceptible to erosion, and the sediment supply available for beach construction is much greater. Local beaches dominated by limestone clasts are present, with the relatively cold waters facilitating dissolution (cf. Leonard and Cameron 1981). In this region, sandy beaches are more common than in other areas of the Placentia Bay shore. Constructional features, such as tombolos and barachoix, are more abundant here than in other regions. Shoreline currents tend to flow westward, although local exceptions are present in embayments and adjacent to headlands. Shoals are common, due to the friable nature of the sedimentary bedrock. Individual embayments are less pronounced than in the eastern Burin or northern Placentia Bay, as the rocks' resistances to erosion are more uniform. West of Lord's Cove, faulting is aligned north-south, producing north-south aligned embayments which contrast with the northeast-southwest alignment dominant elsewhere in Placentia Bay. The absence of deep embayments, however, precludes the development of extensive salt marshes similar to those of the Swift Current Estuarine region. Areally-restricted salt marshes and eelgrass communities are present in some regions, however.

The western Burin Peninsula is exposed to all waves originating from the south, and is rarely influenced by marine ice. Landfast ice is rarer here than along the Cape Shore, but local occurrences have been observed within the past three years. Consequently, the shoreline is wave-dominated, and the geomorphic suite of features reflects the importance of wave action along the coast. Individual major storm events, along with the tsunami of 18 November 1929, have had significant impacts on the coast. The high storm frequency and constant exposure to wave action, however, mean that this coast is perpetually evolving, and the landforms created by individual events seldom persist unmodified for long.

Subregions encountered along the Burin Peninsula include periwinkle shores, rockweed platform shores, temporary intertidal communities, capelin spawning beaches, eelgrass shorelines, and salt marshes.

THIRD-ORDER SUBREGIONS

a) Saltmarsh

Saltmarsh zones are marked by sediment accumulation. These zones can only develop in low-energy areas, where sediment supply is moderate (but not so abundant as to cause burial of the vegetation), and where water circulation is adequate to allow *Carex, Plantago, Festuca,* and other genera to flourish. In the geomorphically-based "Coastal Classification of the Placentia Bay Shore" (Catto *et al.* 1997), these regions were classified as shore class 23 (Estuary and fringing lagoonal). Some areas of the Come-by-Chance bouldery tidal flat (shore class 24) also support salt marshes. These areas are marked by organic detritus and mixed clastic sediments, primarily fine sand and silt. The Swift Current Estuary, and the head of the Bay De L'eau estuary, are examples of this subregion.

Salt marsh development is affected substantially by the formation of sea ice. Extensive icing can generate erosion, both during the formative and break-up stages (Dionne 1989). Slow breakup during the spring inhibits marsh growth and recovery, but rapid breakup is usually associated with high wave energies and long wavelength events (eg. Squire 1993), both of which are unsuitable for marsh plant development. The best developed marsh zones of the Placentia Bay coast are present in regions marked by both relatively low energy conditions, and lesser ice influence. The Swift Current estuary fulfills both of these conditions. In other areas, such as the Burin Peninsula, sea ice is less prevalent, but energy levels are frequently higher than in the sheltered estuarine region. Along the Northeast Placentia Bay shore, relatively low energy levels favourable for extensive salt marsh development are counterbalanced by the prevalence of icing along the shorelines.

b) Eelgrass

Eelgrass communities require a greater degree of salinity, with less fluctuation and fresh-water influx. These subregions are frequently found in association with salt marsh communities, but may also occur separately. In areas where salt marshes have been partially abandoned by tidal action, eelgrass communities cannot develop. Conversely, in localities marked by coastal erosion and / or rising sea levels, eelgrass borders salt marsh zones and would be expected to expand landward in response to rising marine waters.

Eelgrass subregions are associated with estuarine areas (shore class 23), and are also found in association with ponds and inlets present along the landward sides of narrow sand flats (shore class 20), gravel and sand flats (shore classes 16 and 17), on the lower energy, lowshore zones of gravel flats (shore classes 13 and 14), and in the Come-by-Chance area (shore class 24). Placentia Harbour, developed behind a gravel flat but with moderately strong circulatory currents, is a typical site for an eelgrass community. Energy levels must be sufficiently low to allow sand to accumulate and remain, but must also be sufficient to allow water circulation and preclude mud accumulation. Eelgrass communities developed behind sediment flats require circulation of low-energy currents, and thus cannot develop in barachoix ponds which are completely isolated by contiguous barriers from the influence of open oceanic waves and water flow. Eelgrass communities are also affected adversely by icing events and high energy conditions, but are less sensitive to these disturbances than are the salt marshes.

c) Fucus anceps Surf Zone

These zones develop along exposed bedrock shores, usually marked by steep cliffs (shore class 3) or narrow rock platforms (shore class 2). Some areas with very narrow gravel beaches at the base of rock cliffs (shore class 6) or on narrow rock platforms (shore class 5) also support *Fucus anceps* communities. The Cape St. Mary's area north of the bird sanctuary is a typical site, but others are present throughout Placentia Bay (e.g. along Paradise Sound).

The importance of sea spray for the maintenance of the communities means that areas with significant pack ice accumulation are unsuitable for community development. In the northwestern, northeastern, and Burin Peninsula regions, the general absence of significant pack ice accumulation limits this problem, allowing the *Fucus anceps* communities to develop unhindered. Along the Cape Shore, however, recent increases in the frequency of pack ice intrusion and ice foot development have hindered the maintenance of the communities. The health of these communities, therefore, can be taken as a guide to changes in the frequency, duration, and intensity of pack ice and landfast ice foot development.

d) Seabird-Dominated Shores

Seabird-dominated shores are defined as those which have significant bird populations (and hence sufficient bird excrement) to permit the growth of calcareous-requiring lichen (such as *Xanthoria sp.)* on the rock faces. These shorelines are readily recognizable by the characteristic orange and yellow lichens, and by the high concentrations of cyanobacteria (blue-green algae).

Geomorphically, these areas can develop in any location with exposed bedrock that is heavily utilized by seabirds. The shore classes involved include the wide rock platform of Copper Island (class 1), narrow rock platforms (class 2), rock cliff areas (class 3), rock platforms and cliffs associated with gravel beaches (classes 4, 5, and 6), and finer sediment beaches associated with rock cliffs (shore classes 12 and 15). Any exposed rock face, including individual large boulders, is sufficient to permit the establishment of lichens, cyanobacteria, and the insect communities associated with nutrients provided by seabird excrement.

Lateral variation along rocky coasts is common throughout Placentia Bay, as along many rock-bound shorelines throughout the world (eg. Trenhaile 1987, Nott 1990, Jones and Williams 1991, Scott and Johnson 1993). Transitions between geomorphic regimes are matched by transitions between seabird-dominated, *Fucus*-dominated, and vertically zoned biological communities, and between these communities and the pocket beach areas. Such subregions can be analysed individually, but are perhaps better considered as elements in a continuum.

e) Ascophllyum Rockweed Shores

Ascophyllum requires stable bedrock platforms or boulder substrata for development, and cannot develop in shoreline situations marked by high wave and storm energies or extensive landfast ice development. The fucoid seaweed thus cannot develop on the exposed areas of the Cape Shore, the eastern shore of Merasheen Island, or the exposed shorelines of the northeastern area of Placentia Bay. Bedrock platforms in areas marked by lower energy, less frequent storms, and limited ice cover (some areas within shore classes 2, 4, 5, 7, 8, and 11) support such communities.

The inner (eastern) shorelines of the Ragged Islands, adjacent to the sheltered western Merasheen Island shore, support well-developed carpets of *Ascophyllum.* This area is sheltered from the prevailing winds by Merasheen Island, and no major gaps in Merasheen correspond with the western shoreline facing the centre of the Ragged archipelago. Sediment beaches developed on the Ragged Islands' eastern shores (in particular, King Island), appear from airphoto analysis to be somewhat more stable than similar beaches present along more exposed shorelines. These areas, therefore, possess the necessary quiesence to allow the rockweed communities to develop and flourish.

f) Capelin Spawning Beaches

Capelin spawning requires fine gravel and /or coarse sand beaches with gentle to moderate slopes, or sediment flats. Energy levels are moderate, although the beaches may be subjected to isolated severe storms and ice foot development. The texture and configuration of these beaches and flats may change markedly throughout the course of a year, or from year to year, as indicated by repeated observations on several capelin spawning beaches throughout all of the regions of Placentia Bay. The texture of the beaches may be theoretically unsuitable for capelin spawning at various times throughout the year, but the repeated changes in sediment texture and configuration often result in the development of suitable sedimentary and geomorphic conditions during the summer spawning season. This high degree of fluctuation is common to many wave-dominated systems throughout the world (eg. Carr *et al.* 1982, Ekwurzel 1990, Greenwood and Osborne 1991). These beaches are classified within shore classes 9 (sand and gravel beach with rock cliff), 13 (wide gravel flat), 14 (narrow gravel flat), 16 (wide sand and gravel flat), 17 (narrow sand and gravel flat), and locally 18 (steep sand and gravel beach).

The most critical variables involved are the precise texture and slope of the beaches. The definitions of textural subdivisions are thus critical to the assessment of the beaches as capelin spawning terrains. In geological or sedimentological terms, "gravel" is defined as all materials of granule size or coarser, ranging from 2 mm diameter to the largest boulders, following the Wentworth-Udden textural classification system of 1898 - 1922. Clasts between 2 mm and 1 / 16 mm (0.0625 mm) are defined as "sand". Thus, a "gravel" beach could theoretically be composed entirely of granules, or entirely of boulders, or have a textural assemblage of a variety of gravel classes. A beach, in order to be considered as a sand-dominated system, must have a volumetric majority of clasts of grain diameter < 2 mm. Many beaches considered suitable for capelin spawning, such as Gooseberry Cove (shore class 13) and southern Ship Cove (shore class 13 /15), are thus classified as gravel beaches and contain very small proportions of sand (especially after storm events).

g) Temporary Intertidal Communities

Temporary intertidal communities develop on boulders which are subject to remobilization and movement during extreme storms. Isolated pocket beaches along shorelines exposed to high energy events, such as those along the southern shore of Merasheen Island (shore class 6) may support such communities. Other localities include some examples of gravel beaches developed along narrow rock platforms (shore class 5).

Beaches which contain significant quantities of sand generally are not subject to repeated high energy events frequently enough to allow the temporary intertidal communities to form. Seasonal ice foot development and onshore migration of pack ice prevent intertidal communities from developing during the winter and spring, but their temporary nature means that the communities can be re-established on suitable sites when the shoreline becomes ice-free. Thus, seasonal icing is not a major factor controlling the distribution of these communities.

h) Barachoix Estuaries

Barachoix estuaries develop along shorelines where the barachoix are sufficiently developed to restrict (but not completely prohibit) interchange of marine and fresh water. Barachoix inlets may temporarily be closed by storms or longshore drift, but influx of marine water through channels is necessary to prevent stagnation and to maintain salinity levels at values either approximating those of the nearshore areas of Placentia Bay, or at slightly higher levels. The estuarine areas are subject to less marine influence than the subregions marked by eelgrass communities.

Along the Cape Shore, a barachoix estuary is present on the landward side of the Ship Cove barachoix. The outlet at Ship Cove is open periodically throughout the summer and early fall, sometimes opening and closing on a daily basis. The estuary develops a vertically stratified profile when the barachoix remains closed for several days, marked by ferric-rich tannin freshwater derived from inland boggy areas overlying dense, saline waters impounded in the lagoon. Periodic flushing of the lagoon occurs when the outlet opens, allowing migration of sea trout, salmon, and other anadromous species and preventing the development of a permanent halocline.

These barachoix estuaries are thus characterised by the temporary establishment of haloclines, alternating with periods of total mixing of marine and fresh waters. Basal water velocities are relatively low in comparison to fresh water velocities, which inhibits mixing during most periods. The estuaries thus fluctuate between conditions of moderate stratification (with a fresh surface water layer) and totally mixed conditions. These variations in salinity and water temperature combine to produce a stressful biological environment.

i) Vertical Biological Zones

Vertical biological zonation occurs along steep bedrock cliffs which are not subject to high wave energies, frequent severe storms, or extensive icing. These areas are thus absent from the Cape Shore and are uncommon in Northeast Placentia Bay, but are frequent along areas such as western Merasheen Island, parts of the western shore of Long Island, the sheltered leads and channels of the Ragged Islands archipelago, and Paradise Sound. Cliffs along the deeply indented embayments of the northeastern part of the Burin Peninsula also support these vertically zoned communities. Local variations are common along the rocky shorelines of Placentia Bay, as is common along most rocky shorelines (Trenhaile 1987, Scott and Johnson 1993). These subregions are classified within shore classes 3, 6, and 9.

j) Rockweed Platform

Irregular rocky shorelines, without steep cliffs extending to the waterline, support rockweed platform communities. These communities develop on narrow rock platforms (shore class 2), and less frequently on rock platforms with thin, discontinuous sand or mixed sand and gravel cover (shore classes 7, 8, and 11). Rockweed platforms are also likely to exist on the northwest shore of Copper Island, the only wide rock platform area (shore class 1) identified in Placentia Bay. Tidal influence is generally evident in the shorelines of this subregion, and hence the environments are marked by relatively limited wave and storm activity and influence. Ice foot development must also be restricted to allow these communities to flourish.

k) Periwinkle Shores

Periwinkle communities develop on rock platforms which are overlain by thicker and more laterally extensive sediment cover (shore classes 4, 5, 7, 8, and 11). Wave energy may be slightly lower along these coastlines in comparison to the rockweed platform areas, as indicated by the accumulations of thicker and finer sediment on the rock basement. Periwinkle shores are present along the beaches developed on the rock platforms of Woody, Davis, and Dick's Islands.

l) Other Subregions

Non-biological subregions mark relatively few areas of the Placentia Bay shoreline. Generally, these subregions correspond to restricted geomorphic areas of high sediment flux, or areas where thick successions of unconsolidated and unstable sediment preclude the establishment of stable biological communities. In the Placentia Bay region, these subregions include the sand-dominated area of eastern Lance Cove (shore class 10); wide sand flats (shore class 19) of the Lance Cove and Flat Island areas; steep, unstable sediment beaches (some examples of shore classes 15, 18, and 21); and the mudflat area at Calmer (shore class 22). All of these subregions are areally restricted, and represent minor zones within the Placentia Bay region.

CONCLUDING REMARKS

The discussion above has indicated the close relationships which exist between the geomorphic regimes and the biological communities of the Placentia Bay region. Many biological communities are dependent upon a specific combination of geomorphic and climatic factors for their habitat. Others, while less demanding in their requirements, flourish most effectively under particular geographical regimes.

Further analysis would entail detailing the biological assemblages at each of the shoreline areas recognized through the previously undertaken geomorphic classification of the Placentia Bay shore (Catto *et al.* 1997). Alternatively, specific locations along the shoreline could be selected for further research and analysis.

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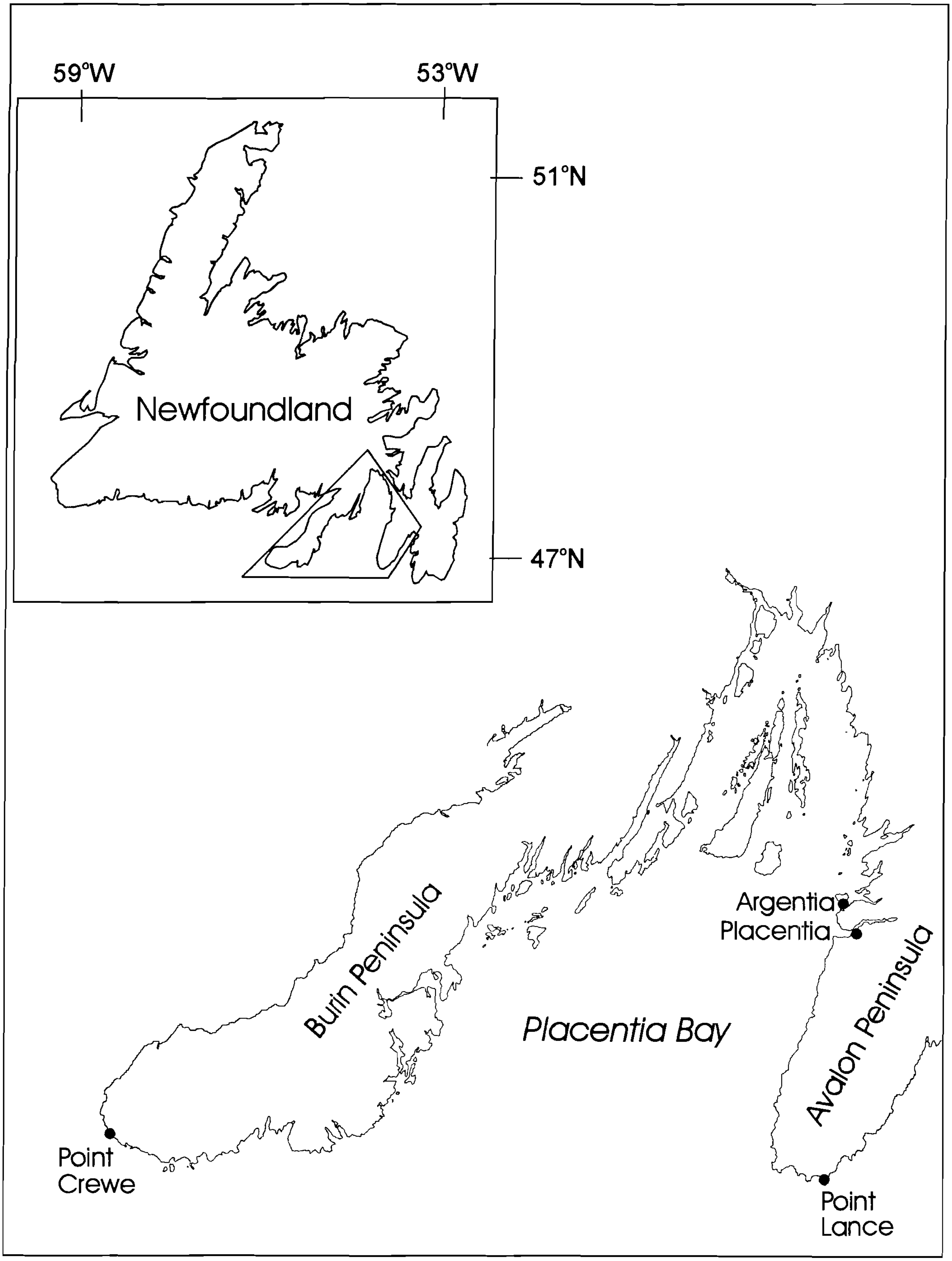

Fig. 1: Study Location

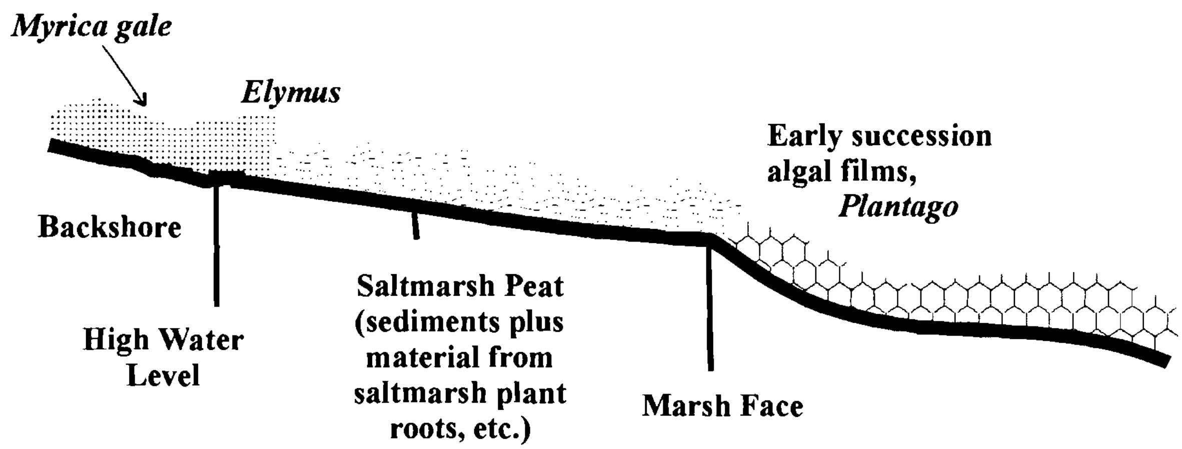

Fig. 2: Piper's Hole Salt Marsh, Schematic Diagram

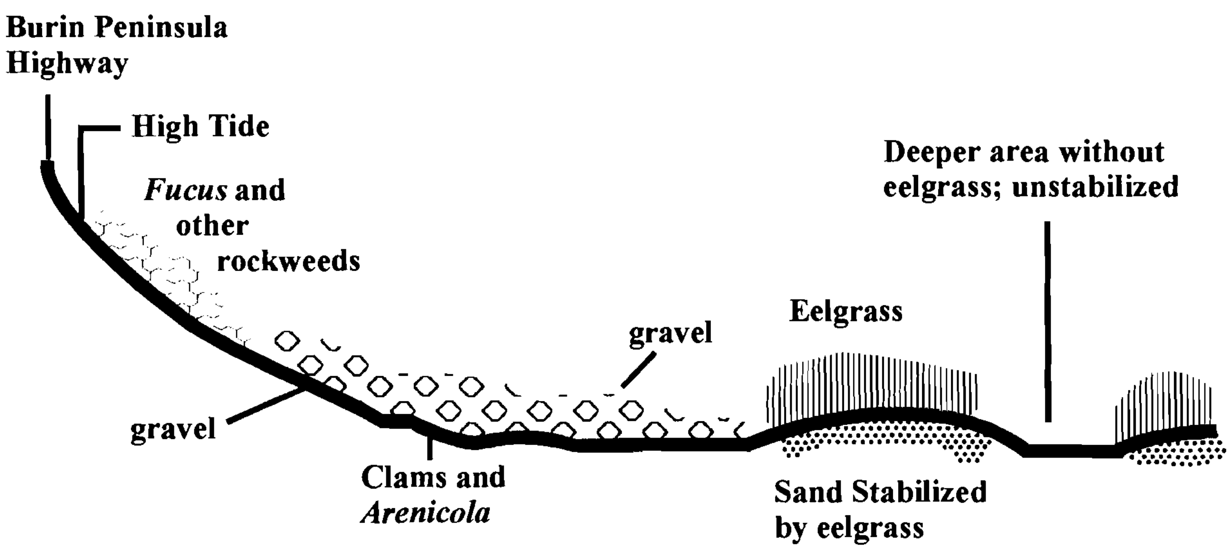

Fig. 3: Swift Current Eelgrass Bed, Schematic Diagram

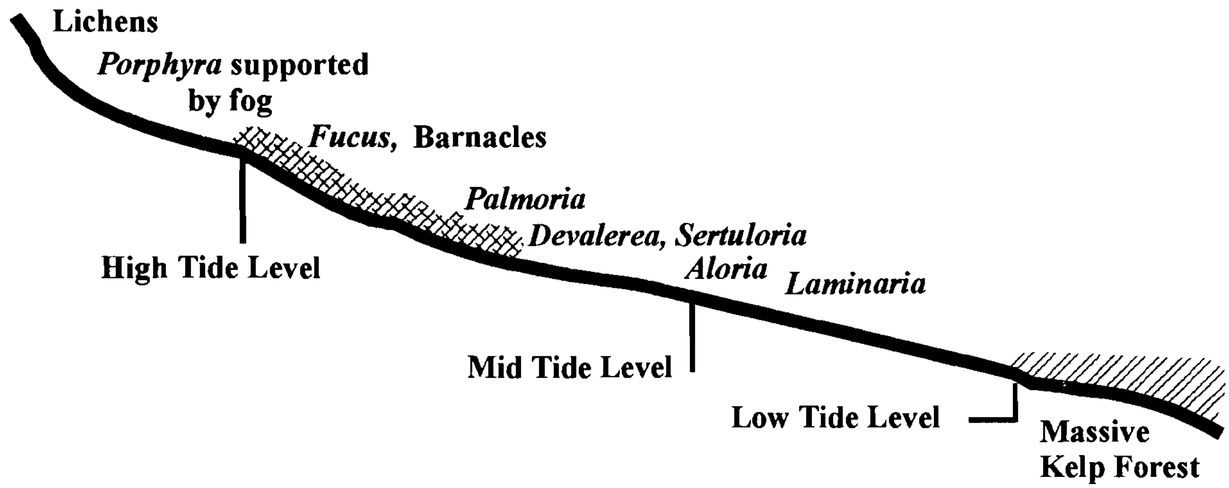

Fig. 4: Buffet Island, Schematic Diagram

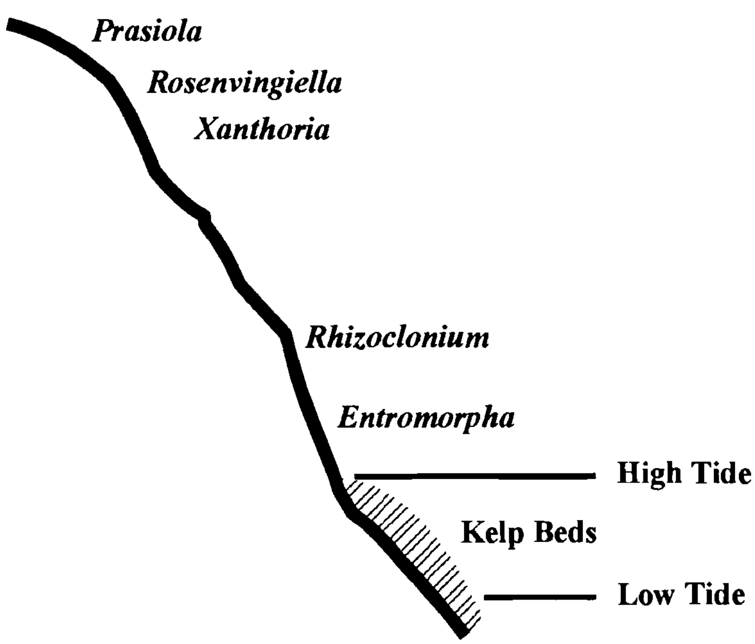

Fig. 5: Cape St. Mary's Bird Sanctuary, Schematic Diagram

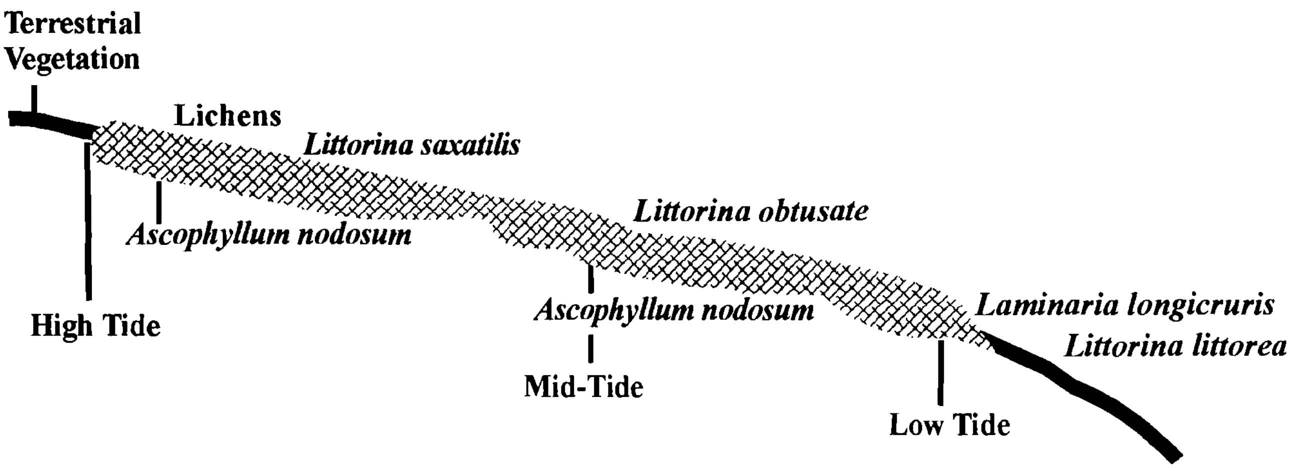

Fig. 6: *Ascophyllum* Rockweed Shore, Schematic Diagram

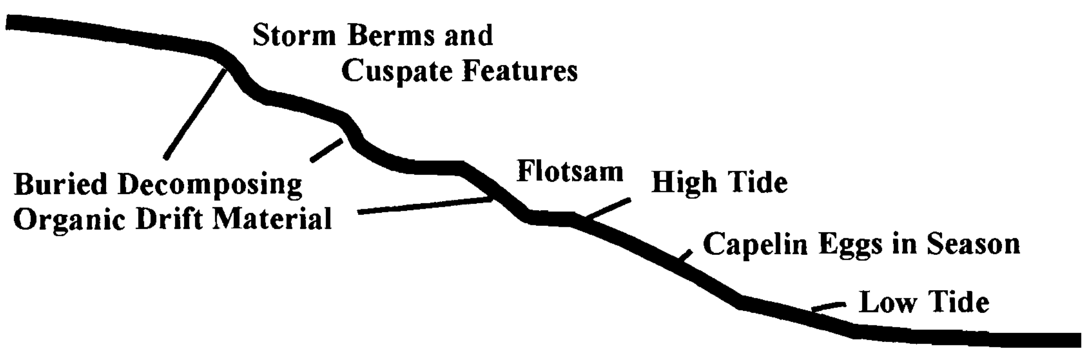

Fig. 7: Point Verde Capelin Beach, Schematic Diagram

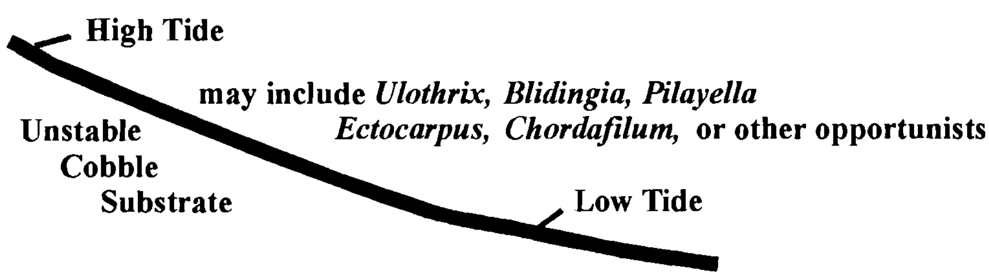

Fig. 8: Temporary Intertidal Community, Schematic Diagram

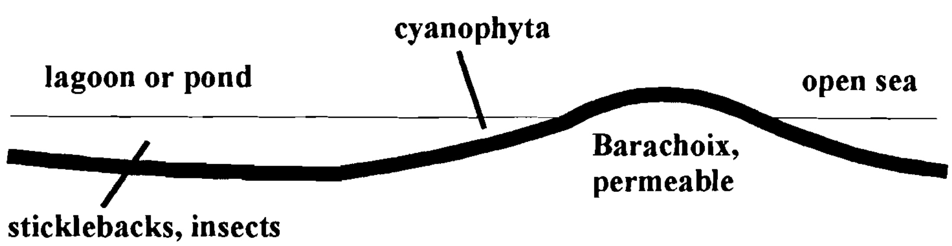

Fig. 9: Barachois Estuary, Schematic Diagram

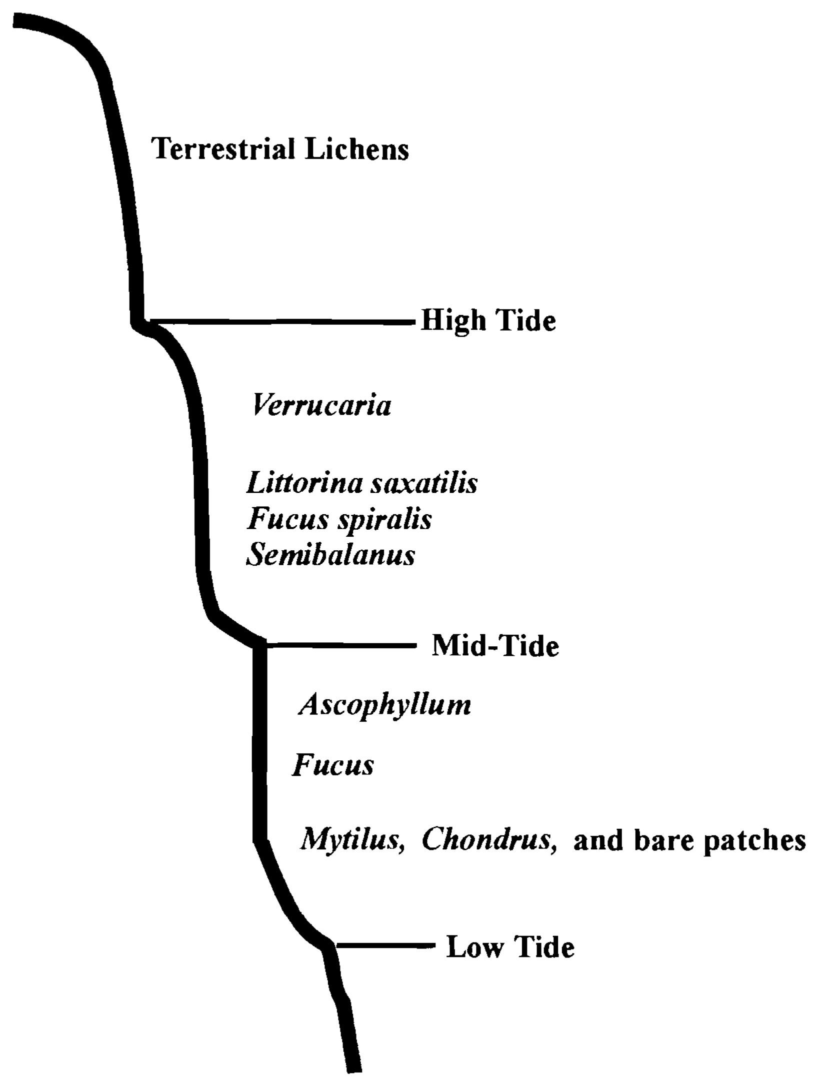

Fig. 10: Best's Harbour, Vertical Biological Zonation, Schematic Diagram

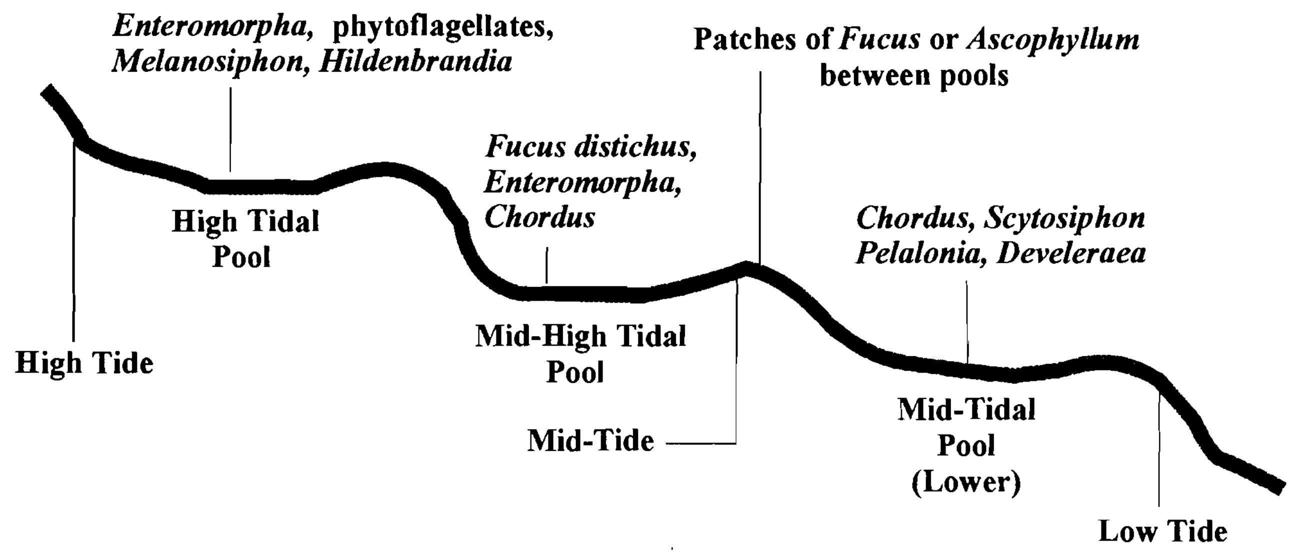

Fig. 11: Green Islands Rockweed Platform Community, Schematic Diagram

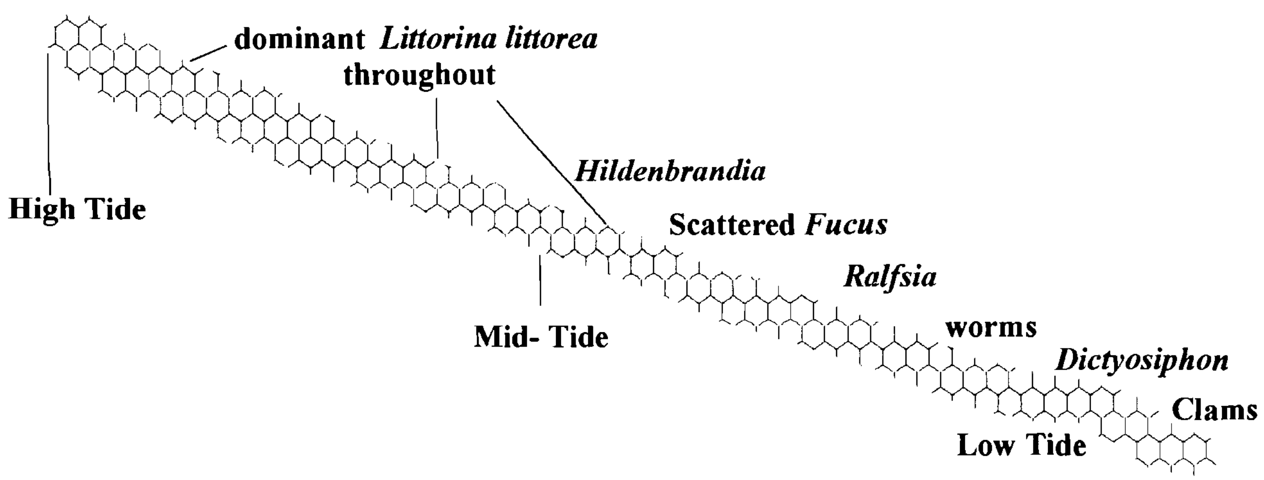

Fig. 12: Periwinkle Shore, Bar Haven Island, Schematic Diagram