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Marine and Estuarine Riparian Habitats and Their Role in Coastal Ecosystems, Pacific Region

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Abstract

This paper is an assessment of the fish habitat significance of a particular ecotone of the marine and estuarine shoreline in British Columbia- locations where aquatic habitat at higher tides merges into terrestrial habitat. Scientific data on these supralittoral areas, frequently called the "marine riparian" by managers are scarce in Pacific region. Habitat and ocean managers are dealing with uncertainty when assessing these areas in relation to forestry, urban development, and other industrial activities. There is evidence showing that unvegetated beach substrate in the marine riparian is used as spawning and incubation habitat for sandlance and surf smelt. Marine riparian is also recognized as rearing and migratory habitat for juvenile salmonids. Preliminary studies conducted at two locations in the Strait of Georgia in February and March 2001 showed that a variety of arthropods are potentially available as fish food from intact marine riparian habitats. The functional importance of marine riparian is likely to be related to food production, temperature regulation, wave energy absorption, and provision of structure as well as indirect ecological value. As an interim measure, based on the sparse available literature, we recommend that a site specific approach be taken to buffer zone widths to manage the marine riparian. Gravel, sand, or cobble beaches may be most susceptible to erosion and sediment sloughing from land, depending on backshore conditions. We also advise a careful review of the rationale, efficacy, and performance of the setback distances proposed in Clayoquot Sound and Puget Sound. Several focused research projects are recommended.

Résumé

Ce document est une évaluation de l'importance en tant qu'habitat du poisson d'un écotone particulier du littoral marin et estuarien de la Colombie-Britannique, soit les endroits où les habitats aquatique et terrestre se rencontrent à marée haute. Les données scientifiques sur ces zones supralittorales, que les gestionnaires appellent souvent la « zone riveraine marine », sont rares pour la région du Pacifique. Les gestionnaires de l'habitat et de l'océan doivent composer avec l'incertitude lorsqu'ils évaluent ces secteurs en relation avec le développement urbain ainsi que les activités forestières et industrielles. Selon certaines observations, les plages exemptes de végétation dans la zone riveraine marine servent de frayères et d'habitats d'incubation pour le lançon et l'éperlan argenté. On sait aussi que la zone riveraine marine est un habitat d'alevinage et de migration pour les jeunes salmonidés. Des études préliminaires réalisées en février et en mars 2001 à deux endroits dans le détroit de Georgie ont montré que divers arthropodes pouvaient servir de nourriture pour le poisson dans les habitats riverains marins intacts. L'importance fonctionnelle de la zone riveraine marine est vraisemblablement liée à la production de nourriture, à la régulation de la température, à l'absorption de l'énergie des vagues, à la structure qu'elle offre ainsi qu'à sa valeur écologique indirecte. En nous fondant sur la documentation très limitée sur le sujet, nous recommandons, comme mesure provisoire, de gérer la zone riveraine marine en adoptant une démarche propre au site en ce qui concerne la largeur des zones tampons. Selon les conditions de l'arrière-plage, les plages de sable, de gravier et de galets peuvent être très sensibles à l'érosion et à des effondrements de sédiments. Nous recommandons également un examen minutieux de la justification et de l'efficacité des distances de recul proposées dans la baie Clayoquot et Puget Sound, ainsi que plusieurs projets de recherche ciblés.

A. Introduction

In this paper we provide an assessment of the fish habitat significance of a particular ecotone of the marine and estuarine shoreline in British Columbia- locations where aquatic habitat at higher tides merges into terrestrial habitat. An ecotone is defined as a zone of transition between adjacent ecological systems, having a set of characteristic uniquely defined by time and space scales, and by the strength of the interactions between adjacent ecological systems (DiCastri *et al* in Ray and Hayden, 1992). Ecotones at the edges of lakes, streams, and rivers are well described by ecologists (see Naiman and Decamps (1997) for a recent review) and are called riparian zones. The word "riparian" is derived from the Latin word for river and is strongly imbedded in the ecological, legal, and environmental planning literature. The following is a working definition of riparian habitat, adopted by Department of Fisheries and Oceans (DFO) and Ministry of Environment, Lands and Parks (MELP) in a recent document (2000) dealing with fish habitat protection:

"an area adjacent to a stream that may be subject to temporary, frequent, or seasonal inundation, and supports plant species that are typical of an area inundated or saturated soil conditions, and that are distinct from plant species on freely drained adjacent upland sites because of the presence of water".

(See http://www.env.gov.bc.ca/fsh/protection_act/sppd/documents/pdf/sppd-reg.pdf)

Riparian habitats have been studied for several decades (Naiman and Decamps, 1997) and their importance for fish is well recognized. In Pacific region, they are managed as fish habitat using a variety of prescriptions, which restrict removal of riparian vegetation at varying distances from the stream shoreline (Millar *et al*, 1997). The primary rationale for these management practices is protection of juvenile salmon and trout habitat. Riparian vegetation in small streams and rivers provides several important physical features important for these fish including shade, temperature control, large organic debris, low velocity refuges during high runoff and as well stabilizes channel banks. Riparian vegetation provides food for juvenile salmonids directly by insect drop and indirectly via detrital food webs (e.g. Richardson, 1992)

Scientific data on the ecotone between the land and the sea are scarce in Pacific region, and habitat managers are dealing with uncertainty when assessing these areas in relation to forestry, urban development, and other industrial activities. This ecotone was called the supralittoral fringe in the classical intertidal ecology studies conducted near Nanaimo, BC by Stephenson (1943) and this term is well established in the ecological literature. However because the vegetated area immediately above the high tide line is commonly called "marine riparian" by habitat managers, we will use the latter term for the purposes of this paper. It should be noted that when we use the term "marine riparian" we are not restricting this term to include only vegetated area because, as explained below, some unvegetated habitat at or near high tide may be very important as fish habitat. The focus of the limited ecological data on marine riparian has however focused on vegetation. Protection of vegetation along marine and estuarine shorelines has clearly been recognized as a priority for fish habitat managers in other coastal jurisdictions (Appendix 1). For example, the State of Washington's recently updated Shoreline Management Act sets a buffer zone of “one-half-site-potential tree height, or 100 ft (30.3 m) (whichever is greater) along lakes and marine shorelines” (Anon, 2001). This buffer zone was chosen to maintain ecological functions important for critical fish habitat (Penttila, 1997; Anon, 2000), as well as erosion prevention to protect property. In the Tongass National Forest in southeast Alaska, the US Forest Service, maintenance of a 1000-ft (330 m) beach fringe buffer zone has been identified as a management objective (US Forest Service, 1997). Other jurisdictions, especially on the east coast of the US, have also introduced scientifically defensible buffer zones and guidelines to help protect fish and wildlife using the marine riparian (e.g. DesBonnet *et al*, 1994; Palone and Todd, 1997. http://www.chesapeakebay.net/pubs/subcommittee/nsc/forest/handbook.htm).

As explained below, marine riparian is different in several key aspects compared to riparian vegetation. To conform somewhat to the freshwater literature, we will restrict our consideration of vegetation in the marine riparian to vascular plants and will not include algae, lichen or mosses. However it should be noted that the black seaside lichen (*Verrucaria maura*) is a dominant plant in the marine riparian of the BC coast, and may have a characteristic fauna associated with it (Kronberg, 1988).

We provide a focused review of the scientific literature on marine riparian habitat and answer three specific questions posed by fish habitat managers on this component of coastal ecosystems. The role of marine riparian as an element of marine and estuarine ecosystems needs to be documented in order to apply the habitat provisions of the Fisheries Act and develop scientifically defensible guidelines for integrated management on the coast. There are approximately 27,000 km of marine and estuarine shorelines in coastal British Columbia and, clearly, management of these habitats is a major scientific and management issue. Current approaches taken by habitat staff in Pacific Region for management of marine riparian range from no requirement of a buffer zone to 50 m vegetation retention zones adjacent to sensitive habitat types such as eelgrass beds and herring spawning areas (M. Kotyk, Habitat and Enhancement Branch, personal communication). However these guidelines were apparently developed in the absence of any scientific documentation other than a literature review (Robinson and Cuthbert, 1996) and a contracted discussion paper (Williams *et al*, 1996) so it is not obvious how the buffers were established. Guidelines proposed by Provincial agencies provide more extensive buffer widths (e.g. Ministry of Forests (1996), Clayoquot Sound: up to 150 m; Ministry of Environment, Lands and Parks

(1996), Saanich Inlet (100 m)), but the data supporting them are not given in the source documents.

First of all, we comment on some of the major differences on how to identify the marine riparian. The three specific questions posed by habitat managers are then addressed, conclusions and recommendations are given in the final part of the paper.

B. Recognizing marine riparian zones

As pointed out by Richardson *et al* (1997), transitional habitats between the sea and land are often ignored because of the different backgrounds of marine and terrestrial biologists, but are important for species and processes, which span the boundary. For this reason data to define marine riparian are poorly developed. Identification of the marine riparian zone by hydrologic and botanical criteria which are used in freshwater is not possible. We could not find a practical and functional definition of marine riparian in the literature. For this reason we propose possible criteria, which helps to set the context of the knowledge base on marine riparian, and also offer a definition.

The presence of an adjacent body of water that is subject to tidal action is the most important criteria to identify the marine riparian. For a given elevation above chart datum (O.D.), the average frequency of immersion can be estimated for a particular site on a beach using the standard tidal prediction equations that the Canadian Hydrographic Service (CHS) uses. The equations are internationally accepted and based on astronomical events, namely distance of the earth to the sun and moon. For example, Figure 1 shows that at the elevation of the marine riparian (includes salt marsh plants and shrubs) at Tsawwassen (3.8 to 4.0 m O.D.), tidal computations predicted about 10-20% of the high tides in 1995 reached or exceeded the particular elevation.

According to the definitions used by CHS hydrographers, the marine riparian is at the land-water interface at the higher high water, mean tide mark (HHWLT)- the average of all the higher high waters from 19 years of predictions (Forrester, 1983). Therefore the shoreline on Canadian Hydrographic Service (CHS) charts is shown as HHWLT but in practice, it is usually best determined in the field from the vegetation and driftwood. Included in the CHS definition of HHWLT is a predictable effect of wind, air pressure, river runoff and surface heating on the annual and semi-annual sea level oscillations. In most BC ports, the range of the predicted annual tide is of order 10 cm or more. However, the influence of storms (period shorter than a year) or El Nino (return period longer than a year) are not included. Storms can raise measured sea levels by 30 to 50 cm above predictions for a day or so. Two El Ninos in the past 20 years (1982/83, and 1997/98) have raised the sea level 30 cm above prediction for the entire winter (pers comm Bill Crawford, CHS, December 1999). River discharge in tidal freshwater habitats, such as the lower Fraser River, is another confounding variable. However, discharge can be incorporated with tides into hydrological models which in turn can be used to predict submergence (Stronach, 1995).

Marine riparian vegetation includes numerous species of grasses, sedges, shrubs, and trees found at or near HHWLT. Since many plants along the shoreline, except for halophytes (those tolerant of salt), are limited by the presence of salt water, their seaward growth into the middle intertidal zone is restricted. However this generalization also needs a caveat because of specific conditions in Pacific region. Coastal vegetation is sometimes defined as a halophyte community but this definition is not very useful in coastal British Columbia (characterised by thousands of kilometres of shorelines with brackish water in fjords) and estuarine embayments, as well as higher salinity areas on the west coasts of Vancouver Island and Haida Gwaii. There are also several hundred kilometres of freshwater tidal habitat in lower reaches of the Fraser River, the Skeena River, and other major coastal rivers. For some marine riparian vegetation, inundation or soil saturation by salt water (salt marsh species such as pickleweed, *Salicornia virginica*) or brackish water (sedges such as Lynbyei's sedge (*Carex lyngbyei*) or cottonwood (*Populus balsamifera*) is important. Salt marsh communities in BC are found between 3.8 and 4.5 m O.D. (Levings, 2001). For others such as cedar (*Thuja plicata*) or hemlock (*Tsuga heterophylla*), found well above HHWLT, wetting of the soil by salt water may be deleterious to the plant but the presence of the vegetation may still be important for stability of the upper beach habitat. These species extend into the backshore zone, here operationally defined as part of the terrestrial habitat inshore of the marine riparian. On sandy beaches, dune grass (*Elymus mollis*) and shore pine (*Pinus contorta*) are known as species, which stabilize shifting sand. These species are not usually recognized as halophytes but do fit into an operational definition of marine riparian plants. In areas where surf and wave action is a major force, the seaward limit of salt spray has been proposed as an indicator of the landward extent of marine processes (Barbour and Robichaux, 1976; Howes and Harper, 1984). However this is primarily a physical indicator. Salt marsh plants usually do not extend into the marine riparian above HHWLT, because soils there are not saturated with saline water.

Based on the above, and a more extensive review document in preparation (Levings, 2001), we offer the following. Marine riparian habitat is found:

a. seaward of the HHWLT to the limit of salt marsh or brackish marsh vegetation or to the tidal elevation which is submerged < 10 % annually
b. landward of the HHWLT to the limit of salt spray, dune vegetation, and/or one half potential tree height or 30 m linear distance, whichever is greater

C. Are riparian areas along the foreshore of marine and estuarine areas considered to be fish habitat as defined under the *Fisheries Act*?

1. Spawning habitat

There are no research projects in Pacific region that have specifically investigated or surveyed habitats near high tide for fish spawning activity. However, there is substantial evidence from Puget Sound which shows that unvegetated beach substrate in the marine riparian, is used as spawning and incubation habitat. Penttila (1997) showed that sand and gravel substrate near high tide is spawning and/or incubation habitat for two marine forage fish species surf smelt (*Hypomesus pretious*) and sand lance (*Ammodytes hexapterus*) in Puget Sound. About 20% of the shoreline in Puget Sound may be used by surf smelt and/or sand lance as spawning habitat (Penttila, 1997). Both of these species are widespread in Pacific region estuarine or marine areas. Surf smelt spawning habitats have been documented in the Fraser River estuary (Levy, 1985) and the incubating eggs of this species are known to be sensitive to suspended sediments >0.5 mg l^{-1} (Morgan and Levings, 1989). Sand lance and surf smelt spawning areas are poorly known in Pacific region. Herring (*Clupea harengus pallasi*) deposit their eggs on algae and eelgrass at lower tide levels (Humphreys and Hourston, 1978), but as noted below, still may benefit from the presence of marine riparian vegetation.

Vegetation at or above high tide can filter sediment from upland erosion areas and is relevant to incubation habitat at all tidal levels, since unconfined fine sediment could spill over the entire intertidal zone. In certain areas of the coast where chum and pink salmon spawn in the intertidal zone, albeit at lower elevations than the marine riparian, such spillage would directly affect spawning habitat. An example would be beach spawning of pink and chum near the Dean River estuary on the Central Coast (http://www.luco.gov.bc.ca/slupinbc/cencoast/reports/ccpasrpt/ccpasa5.htm).

Numerous additional fish and invertebrates species living lower on beaches relative to the marine riparian use various elevations as spawning habitat because they are sedentary or have a very small home range. Habitats in the middle to low intertidal zone are used as nesting and incubation habitats for littoral fish showing these life history traits especially gunnels (e.g. coxscomb prickleback (*Anoplarchus purpurescens*); Peppar, 1965) and cottids (e.g. sharpnose sculpin (*Clinocottus acuticeps*); Marliave, 1981). All invertebrates are susceptible to smothering or burial by sedimentation rates in excess of natural conditions. Filter and detrital feeders such as clams, barnacles, and polychaete worms are abundant at various levels on the intertidal zone. A variety of harvested and ecologically significant filter feeding bivalves live in the intertidal zone of Pacific region (Coan *et al* , 2000). Algae and vascular plants at the base of the food web are also negatively affected by excess sediment, as documented by Levings and Moody (1976) for sedges at the Squamish River estuary.

2. Rearing and migration habitat

Higher elevation beach habitats submerged at high tide, at or immediately below the elevations where marine riparian vegetation is found, are clearly recognized as rearing and migratory habitat for juvenile salmonids in Pacific region. Young salmon move in shallow coastal water on their migration from the river mouth to the open ocean and there is evidence use of this habitat confers survival value to the species by virtue of food provided and refuge functions (Levings, 1994). Depending on beach topography, these areas may only be a few centimetres deep on high spring tides and hence are suitable habitats for relatively small life history stages such as fry (< 50 mm). Healey (1979) was one of the first investigators to document the landward migration of chinook fry (*Oncorhynchus tshawytscha*) at high tide, in the Nanaimo River estuary. " At high tide, the young chinook were scattered along the edges of the marshes at the highest points reached by the tide" (Healey, 1991). In this particular estuary, marine riparian vegetation is characterized by brackish marsh (e.g. *Carex lyngbyei)*. In fjords such as Howe Sound, chum (*O. keta)* and chinook salmon fry have been found at high tide in other riparian vegetation such as shrubs (e.g. willow, *Salix* spp) and coniferous trees (e.g. Grout *et al* , 1998). In constricted coastal seaways such as Discovery Passage, all species of juvenile salmon were found in significant abundance at high tide on sand and gravel beaches with overhanging coniferous vegetation (Brown *et al*, 1987). Chum and chinook salmon fry also have been caught at very high intertidal elevations in salt marshes characterized by halophytes such as pickleweed and saltgrass (*Distichlis spicata*) (e.g. Tsawwassen salt marsh) (Table 1). In tidal freshwater regions, such as the North Arm of the Fraser River estuary, chinook fry were found in a mixture of riparian vegetation including willow, alder (*Alnus rubra*), blackberry (*Rubus procerus*), cattails (*Typha latifolia*), and rushes (*Scirpus* spp) (Levings *et al*, 1991) (Fig 2a,b).

Some fish food invertebrates, which live specifically in or near the marine riparian, include certain amphipods (e.g. *Paramoera mohri*; Volk *et al*, 1984), aphids (e.g. Whitehouse *et al*, 1993) and springtails (Collembola) (Levings *et al,* 1995). As far as we are aware there have been very few studies that have specifically documented the types and amounts of fish food such as the above produced in marine riparian areas and the ecological processes involved. In freshwater riparian systems the connections between insects and riparian vegetation have been researched for many years (e.g. Erman,1984; Nakano *et al,* 1999) and showed nearly all aquatic insects spend some portion of their lives in riparian zones for feeding, pupation, emergence and mating, and egg laying. Numerous studies have documented the importance of dipteran insects, especially chironomids, in the diet of juvenile salmon caught in the coastal zone (see Higgs *et al,* 1995 for summary). Some of the chironomids found in fish stomachs may have been true marine insects that complete their life cycle in the intertidal zone (e.g. Morley and Ring, 1972). Unfortunately the insects are not identified to the taxonomic level which would permit this discrimination. Taxonomic detail is also needed to determine if the Collembola occurring in juvenile salmon stomachs (e.g. Levings *et al*, 1995) and in marine riparian sampling (see below) originated in the marine riparian or were species adapted to lower intertidal zones. According to Thorp and Covich (2001), the vast majority of the approximately 700 species of Collembola in North America live in moist terrestrial habitats. However there are also well known intertidal species and some have been found in both the intertidal zone and forest habitats (Christiansen and Bellinger, 1988).

Most of the research on vegetation-invertebrate relationships in the marine riparian has focused on estuarine and salt marsh plants. As expected there is a positive relationship between plant and invertebrate abundance (Figure 3) reflecting the role of the plants in providing structure. For some insects such as springtails, features of the riparian soil such as moisture content may be important (Lek-Ang *et al*, 1999).

In the North Arm of the Fraser River, dipteran insects from the marine riparian eaten by chinook salmon fry (Levings *et al*, 1991) were sampled in pit traps with liquid soap. Traps set out under shrubs and trees (alders, willows, blackberries) caught between 150 and 450 dipterans m^{-2} d^{-1} (Table 2). To contribute new data on potential fish food provided from marine riparian, we conducted preliminary studies at two locations in February and March 2001. While the data were obtained a few weeks before juvenile salmon were in the sea, they do provide useful information on potential available invertebrates from contrasting marine riparian habitats. Using the same arthropod trapping methodology, we sampled in Howe Sound and on the east side of the Strait of Georgia, near Parksville. Details on methods and locations are given in Appendix 2.

The abundance data on insects, especially dipterans, was within the same order of magnitude at Parksville, Howe Sound, and North Arm of the Fraser River estuary (Tables 2, 3, and 4).

At Parksville, abundance of coleopterans, dipterans, and talitrid amphipods was significantly different (anova, $p < 0.05$, df=48) at five stations characterized by differing vegetation (grass, woodlands, urban, dune, estuarine marsh, Table 5). The lowest abundance of invertebrates was observed at the dune stations.

The sampling at Howe Sound showed that traps set out on a beach where riparian vegetation had been removed for townhouse development and replaced with riprap (Furry Creek North) caught fewer arthropods compared to forested beaches at Furry Creek South and Porteau (Table 3; Precision ID, 2001). Collembola chironomid adults, and talitirid amphipods were the dominant arthropods at the vegetated sites in Howe Sound, with one superfamily and two families represented (Entomobryoidea, Hypogastruridae, and Sminthuridae). Differences in abundance of these three taxa between the three locations were statistically significant ($p<0.05$). The Superfamily Entomobryoidea was the most abundant insect taxa in the survey (7117 m^{-2} d^{-1} at Porteau). In a small subsample of Collembola identified by a specialist, the species present were all from semi-terrestrial as opposed to intertidal habitats (Appendix 3). There were more arthropod taxa observed in the two forested Howe Sound locations (20-21) compared to the unvegetated location (13) (Table 3). The abundance of chironomid adults at Furry Creek South and Porteau was within the same range at the North Arm and Parksville locations. Further statistical analyses of the Howe Sound data are required. The data suggest that although Porteau and Furry Creek differed in the composition of their understory vegetation types and backshore substrates (Table 6), the abundance of insect taxa was about the same in the two locations. Taltrid amphipods were likely more abundant at Porteau.

D. What are the relative values of the differing riparian categories along the marine and estuarine foreshore to fish and fish habitat? Or, are some riparian areas more valuable than others?

The concept of relative values of the differing riparian categories for fish and fish habitat is a paradigm which may not be useful for modern ecosystem management as specified by the Oceans Act. Initially, the ecological objectives of the particular ecosystem should be decided upon (O'Boyle *et al*, 2001); the management of separate habitat types as entities isolated from one another should be avoided. As described elsewhere (Levings 1998; Simenstad and Cordell, 2000), it would be preferable to move to a landscape approach for habitat management so that interrelationships between various habitat types can be maintained. As an example, the development of willow shrub in an estuary may be dependent on vegetation such as sedges because the latter traps sediment, increasing the elevation of sand and mud flats to a level that willows are adapted to. All marine riparian has an intrinsic value of providing stability and ecosystem integrity through direct or indirect means. The interrelationship between sedges and willows mentioned above is an example of a direct linkage. An example of an indirect linkage would be the role of wave energy in maintaining beach slope. The natural slope of gravel and sand beaches and mud flats is usually < 5% and this slope is maintained by seasonal changes in accretion and erosion (Clark, 1996) that in turn are generated by wave action. Sand beaches are also dependent on longshore currents and dynamic processes, which bring sediment from adjacent sources. In the Strait of Georgia, these sources are often escarpments or "feeder bluffs" - a classical example is the cliff at Cape Lazo near Comox, which supplies sand to maintain Goose Spit on the northern part of Baynes Sound. It is important to clearly differentiate these natural processes from engineering procedures such as "shoreline stabilization" which can result in undesirable ecological effects (Clark, 1996).

Riparian vegetation established on stable beaches maintains a soft shoreline by absorbing and reflecting wave energy in root systems and exposed woody structures. If the shoreline is hardened, more wave energy is reflected which results in steepening of the shore and winnowing of finer sediment. A changed ecosystem results. Some effects on ecosystem integrity can be complex and indirect. For example the scarring of estuarine mud and sand flats by large organic debris originating from riparian trees may be important as colonization pits for fragments of marsh plants (Maser and Sedell, 1994).

For the interim, until DFO moves to an ecosystem objective based system, we suggest that a practical system for valuing marine riparian should consider its ability to: 1. provide shade; 2. supply and/or filter shore derived sediment; 3. stabilize shorelines, in association with the values of the habitat found seaward (Table 7); 4. filter and mineralize non point organic pollutants such as nitrate from septic fields. The intrinsic value of the habitat for food production, temperature regulation, and wave energy absorption and structure provision should also be considered. The former abilities might be particularly valuable for situations where the impact from stressors, such as sediment from erosion on the landward side, might be reduced by the filtration action of riparian vegetation. The types of habitat found on the intertidal zone, seaward of the marine riparian, is also a factor. For example, at some sheltered areas (e.g. west side of Baynes Sound), the shore is characterized by salt marsh in the high intertidal and eelgrass in the low intertidal (Tamasi *et al*, 1997). There are no data on effects of sediment on eelgrass from BC studies. However, seagrass in Philippine estuaries showed reduced biomass when silt and clay in sediment exceeded about 12% (Terrados *et al*, 1998). The role of marine riparian in treating organic pollutants has been poorly explored in our region compared to other parts of the world; for example, Chesapeake Bay (Palone and Todd 1997). However, in some parts of BC where sewage systems for coastal communities are not in place (e.g. Baynes Sound), this may be an unappreciated impact of removing marine riparian.

In addition to the above general comments on ecosystem functioning, the following are some overview statements on the function of marine riparian that may be of specific importance to fish.

Food production: Although there have been few specific studies in our region, based on general ecological knowledge of feeding types and food webs, it is clear that detritus from trees and shrubs is a key energy supply for invertebrates in the marine riparian (e.g. Collembola, Cameron, 1972). In addition, carbon from terrestrial vegetation along the marine shorelines can enter pools of dissolved and particulate organic carbon as shown by Simenstad and Wissmar (1985) for Hood Canal (Puget Sound). In a freshwater example, LeSage *et al* (2001) found many of the same general types of organisms we obtained in our beach trapping studies in leaf litter and wood fragments in the riparian zone of Alaska streams. These included Coleoptera, Collembola, and Diptera (Ceratopogonidae, Tipulidae, and Chironomidae). France (1998) used $\delta^{13}C$ analyses to suggest that dipterans in Ontario lakes may be relying more substantially upon allochthonous detritivory than upon autochthonous algivory for energy. Wrack algae is involved in food webs supporting talitrid amphipods and their beetle predators (Richards, 1984) in the marine riparian. There is little *in situ* production of algae other than in localized freshwater seeps in the latter habitat.

Temperature regulation: In summer, warming of surface water would be expected in the very shallow water column (< one m) adjacent to the marine riparian, especially for the hours near high water slack tide when there is little water movement. Temperatures near shore of 20 - 22º C have often been observed in outer Howe Sound in spring and summer (Levings, unpublished data). Temperature in overlying and interstitial water in the marine riparian may be mediated by shading effects and by percolation of groundwater, although local data for both factors are scarce. Penttila (2001) investigated shading effects on survival of surf smelt eggs in Puget Sound at sites with overhanging big leaf maple (*Acer macrophyllum*), red alder, and willow relative to unshaded sites. He found significantly fewer dead surf smelt eggs at the shaded locations (35.6% vs 59.7%, $p<0.05$). Some species of fish food organisms (e.g. the fish food amphipod *Paramoera bousfieldi*, Staude, 1984) have localized populations in freshwater seeps, perhaps because they are adapted to the cooling flows from this source as well as the brackish conditions. Freshwater aquifers can release water into the intertidal zone beneath an intact marine riparian zone (Figure 4) and their hydrology (flow, temperature) is dependent on its integrity.

Wave energy absorption: A natural shoreline "softened" with terrestrial vegetation, including drift logs, at the high tide line is a component that helps maintain the beach at a natural slope. A soft shoreline provides proper damping and reflection of wave energy, which is responsible for longshore transport of sediment and maintenance of the beach ecosystem. Artificial fill and riprap can disrupt the processes involved in beach maintenance (Figure 5). Given the prevailing up inlet wind in summer in BC fjords and embayments, it is likely that longshore drift carries sediment to the north and the down inlet winds moves sediments south in the winter. There is a well known equilibrium state for natural beaches with undisrupted backshores, so usually there is no net accretion or erosion – this is the stable state for beach ecosystems (Clark, 1996).

Structure: Trees and woody debris originating from the marine riparian may be of direct importance as shelter for fish and invertebrates at all levels of the intertidal zone, as found by Everett and Ruiz (1993). Some structural aspects of marine riparian habitats are linked in complex sediment supply processes such as the delivery of sand from feeder bluffs as a foundation for development of vegetation communities (see above). For riparian vegetation on sand dunes (e.g. dune grass *Elymus mollis* (Barbour and Robichaux, 1976)), this is obviously a key factor. Dune grass has been recognized as an important element of fish habitat in the Fraser River estuary by the FREMP Habitat Classification Review Committee (memo from the latter committee to the FREMP Land and Water Use Committee dated Nov 8, 1999 and Levings, unpublished field observations).

E. Are there sufficient data in the scientific literature to recommend an appropriate setback for these differing riparian areas to ensure a HADD (harmful alteration, disruption or destruction) does not occur as constituted under Section 35 (2) of the *Fisheries Act*? If not, what research programs are required?

There are insufficient data in the scientific literature to recommend generic or region-wide setback distances to ensure a HADD does not occur in marine riparian habitats. Further research is needed to determine buffer widths for various vegetation units that compose the marine riparian. In addition to research on biological functions such as fish food supply (e.g. for juvenile salmon rearing) and spawning (e.g. surf smelt and sandlance), studies need to be conducted on physical factors such as soil integrity. Given the varying susceptibility of trees to wind damage, the setback distances need to be wide enough so that they do not blow down and uproot in storms, causing erosion and introducing excess sediment to the intertidal zone.

Salt marshes, mudflats, and brackish marshes found seaward of HHWLT currently seem to be well recognized as fish habitat subject to HADD regulations. It should be noted they are included in the marine riparian according to our definition and while the marshes are currently managed as separate entities, setbacks above HHWLT will help in their management.

This conclusion is partially based on the need to avoid damage from sediment sloughing from terrestrial habitats onto rearing or spawning habitat. In addition to effects on food webs (see above) or those from high levels of suspended sediment (see Birtwell, 1999), excess deposition of eroded material results in loss of living space by filling shallow water habitat. Because of the variation in potential damage, the dimensions of the setback may have to be modified by site specific conditions such as slope stability. As shown in Table 7, not all types of backshore habitat have the potential to act as sediment corridors through the marine riparian. In addition, not all industrial developments have the potential to create disruptive sediment supplies through the marine riparian. For example, reforestation, which is a routine practice in many managed forests, may reduce sloughing and may be a useful mitigation technique. On the other hand, placement of riprap permanently "hardens" the shoreline, and revegetation of the marine riparian might not prevent sloughing from the backshore.

We also recommend that consideration be given to the setbacks proposed by the Clayoqout Sound Scientific Panel (MoF, 1996) and in Puget Sound (Anon, 2001) if a precautionary approach is being taken for fish habitat management in the Region. We recognize that both the Clayoquot and the Puget Sound setbacks were developed without extensive research, as far we know, on the ecology of the marine riparian. However, the setback distances are likely based on the extensive data bases from streamside management of streams and rivers as well as direct observations of shoreline damage, especially in the case of Puget Sound (e.g. Broadhurst, 1999).

An immediate comprehensive scientific review of these guidelines should be undertaken before DFO adopts these setbacks for general fish habitat management. Focus should be on how the experts derived them, their efficacy to date, the degree to which biological and geophysical conditions in Clayoquot Sound are representative of those elsewhere in the Region, and the applicability of their forestry-oriented derivation to urbanized shorelines.

Whether the Clayoquot guidelines are "appropriate" is perhaps not a scientific question but an operational one. However, their width matches or exceeds those suggested by DFO and MELP habitat managers in other parts of the Region, which range from that represented by narrow fringe of trees and shrubs (often < 10 m) on the Fraser River estuary to 100 m on Saanich Inlet (MELP, 1996). There have also likely been site specific decisions made by DFO habitat managers on marine riparian setbacks elsewhere in the Region but documentation is difficult to obtain.

F. Required Research

Research papers on the importance of marine riparian habitat, as fish habitat in Pacific region, are virtually absent from the peer reviewed literature. This is in sharp contrast to the numerous completed and ongoing projects on freshwater riparian. Thus, it is clear there is a need for focused research on this key feature of coastal ecosystems. The following is a short list, not necessarily in priority, of suggested research topics:

1. Factorial experiments to investigate impact of removing and enabling buffer zones of various widths of marine riparian vegetation, taking into account shoreline treatments differ with various industrial activity e.g. forestry vs urbanization vs armouring, as well as substrate differences.

2. Process investigations dealing with the interaction of sediment supply, patterns of longshore movement, wave energy and vegetation and how these factors induce dynamic stability in the marine riparian.

3. Detailed investigations of juvenile salmon and other fishes feeding habitats and microhabitat usage of the marine riparian, focusing on conditions at high tide and availability of fish food organisms, including their detailed identification. Fieldwork should cover the range of marine riparian found in the Pacific region. A first priority might be gravel, cobble, and rocky beaches, given that these features account for the majority of the shorelines in BC, yet are least documented in terms of ecosystem functioning.

4. Surveys to determine the importance of marine riparian for surf smelt and sand lance spawning and incubation and compare to findings in Puget Sound.

5. Investigations on the role of marine riparian for filtering and treating organic pollutants from upland septic fields.

6. Research on the role of natural and modified marine riparian zones in the recycling of detritus including algal wrack and leaves and woody material from trees and shrubs.

Acknowledgements

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Table 2. Number of adult dipterans (number $\bullet$ m ^{2} $\bullet$ day^{-1}) caught in insect drop traps (trays filled with soapy water) at the marine riparian on the North Arm of the Fraser River, May 21-22, 1986 (see Levings *et al*, 1991 for location).

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Species list from a subsample of Collembola from insect trap sampling at Furry Creek (FC) and Porteau Cove (PC) in February and March 2001.

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Species	Set Number 1	Set number 2	Set number 3	Set number 4
Chum salmon fry	178	25	3	133
Chinook salmon fry	0	3	4	30
Shiner perch	8	12	0	0
Staghorn sculpins	2	2	0	1
Stickleback	0	1	0	0

Table 1. Fish caught in four beach seines (15 m x 1.5 m) at the seaward edge of the salt marsh, southwestern flank, at Tsawwassen, adjacent to ferry terminal causeway. Samples were obtained between 0530 and 0650 PDT, at tide levels of 4.3 -3.9.m OD on May 6, 1997 (Levings, unpublished).

Dipteran taxa	Number • m ^{2} • day^{-1}
Dolichopodidae	152
Canaceidae	76
Scatophogidae	<0.1
Ceratopogonidae	76
Ephydridae	<0.1
Chironomidae	457
Empididae	76

Table 2. Number of adult dipterans (number • m^{-2} • day^{-1}) caught in insect drop traps (trays filled with soapy water) at the marine riparian on the North Arm of the Fraser River, May 21-22, 1986 (see Levings *et al*, 1991 for location).

	FURRY CREEK South-Forested		FURRY CREEK North-Riprap		PORTEAU Forested	
	MEAN	**%**	**MEAN**	**%**	**MEAN**	**%**
Entomobryoidea	732.94	24.97	54.44	16.20	7117.95	55.84
Hypogastruridae	1334.12	45.44	3.94	1.17	126.23	0.99
Sminthuridae	39.45	1.34	1.58	0.47	22.09	0.17
Canaceidae adult	8.68	0.30	9.47	2.82	3.16	0.02
Ceratopogonidae adult	8.68	0.30	0.79	0.23	6.31	0.05
Chironomidae adult	414.99	14.14	228.80	68.08	522.29	4.10
Chironomidae larvae	0.00	0.00	0.00	0.00	6.31	0.05
Empididae adult	1.58	0.05	0.00	0.00	4.73	0.04
Muscidae adult	0.00	0.00	0.79	0.23	0.00	0.00
Sciomyzidae adult	0.79	0.03	0.00	0.00	1.58	0.01
Diplopoda	0.79	0.03	0.00	0.00	6.31	0.05
Tipulidae adult	0.00	0.00	0.00	0.00	4.73	0.04
Acari adult	29.98	1.02	1.58	0.47	74.16	0.58
Araneae adult	18.15	0.62	3.94	1.17	1.58	0.01
Opiliones adult	0.79	0.03	0.00	0.00	1.58	0.01
Ligiidae adult	3.16	0.11	0.00	0.00	388.17	3.04
Talitridae adult	320.32	10.91	26.82	7.98	4449.70	34.91
Aphididae adult	11.83	0.40	0.79	0.23	0.00	0.00
Cicadellidae adult	4.73	0.16	0.00	0.00	3.16	0.02
Hebridae adult	0.79	0.03	0.00	0.00	0.00	0.00
Tingidae adult	0.79	0.03	0.00	0.00	0.00	0.00
Staphylinidae larvae	1.58	0.05	0.00	0.00	0.00	0.00
Staphylinidae adult	0.79	0.03	0.00	0.00	1.58	0.01
Ichneumonidae adult	0.00	0.00	0.79	0.23	0.00	0.00
Thysanoptera adult	0.00	0.00	0.00	0.00	3.16	0.02
Mymaridae adult	0.79	0.03	2.37	0.70	3.16	0.02
MEAN NO. PER M^2	**2935.70**	**100.00**	**336.09**	**100.00**	**12747.93**	**100.00**
NO. TRAPS	**20**		**20**		**10**	

Table 3. Abundance (mean number • m^{-2} • day^{-1}) and percentage of various arthropods trapped at three marine riparian sites in Howe Sound in February and March 2001.

Taxa/Site	1 (grass)	2 (woodlands)	3 (urban)	4 (dune)	5 estuary-marsh)
Amphipods	370	81712	7562	1384	4740
Dipterans	55	699	479	68	123
Coleopterans	699	41	411	27	14

Table 4. Abundance (number • day^{-1}) of amphipods, coleopterans, and dipterans trapped at five marine riparian sites near Parksville, March 20, 2001.

Vegetation/Location/Site	Overstory Species	Understory Dominants	Comments
Grassland /Rathtrevor Provincial Park/1	None	Miner's lettuce, Purple dead nettle, Beach pea, Bentgrass, Barley, Vetch	
Woodland /slightly North of Rathtrevor Park/2	Douglas fir, Hemlock	Miner's lettuce, Beach pea, Lichen, Oregon grape, Moch orange, Bracken fern, Baldhip rose, Nootka rose, Rubus sp., Variable willow, Canadian sand-spurry, Salal, False Lily of the Valley	
Urban /slightly North of woodlands site, San Pariel Subdivision, Parksville/3	Douglas fir, Arbutus	Scotch broom, Daffodils, Junipers	No samples collected as all vegetation was on private property. Vegetation noted was visible within the 20 m of the driftline.
Sand Dune /Brant Point/4		Silver burweed, Aster, Miner's lettuce, Seabeach sandwort, Purple dead nettle, Beach Pea, Black knotweed, Scotch broom (visible)	
Estuary/mouth of Englishman River/5	Douglas fir	Aster, Miner's lettuce, Moss, Barley, tall Grass sp., Silverweed, Scotch broom, Thistle	

Table 5. Dominant marine riparian vegetation near the arthropod traps on March 20, 2001 at five locations near Parksville, BC. (Appendix 2). All species of overstory trees and understory species are shown.

Vegetation/ Location	**Overstory Species**	**Understory dominants**	**Comments**
Furry Creek South	Sitka spruce, western red cedar, Douglas Fir, red alder, western hemlock.	Dune grass, beach pea, salal, western red cedar, hemlock, red alder, red huckleberry, salmon berry, rose, false lily of the valley.	12 additional understory species. Native soils in the backshore. Dominant beach substrates sand and gravel. LOD.
Furry Creek North	unvegetated	unvegetated	Dominant beach substrate riprap, with LOD. Asphalt in the backshore
Porteau	Sitka willow, western red cedar, red alder, big leaf maple, Douglas fir, cherry.	Rose, snowberry, salal, oceanspray.	11 additional understory species. Campsite sand and gravel in the backshore. Dominant beach substrates sand and gravel with LOD.

Table 6. Dominant vegetation near the arthropod traps in February and March 2001 at three locations in Howe Sound (Appendix 2.). All species of overstory trees are shown. Understory species are listed only if they occurred in at least 3 of the 5 assessment plots at the particular locations.

Intertidal/ Backshore	**rock**	**sand**	**soil**	**meadow**	**deciduous**	**coniferous**	**mixed**	**shrubs**	**marsh**
Sed supply	N	H	H	M	L	L	L	L	M
rock	1	1	1	1	1	1	1	1	1
Cobble/shell	1	5	5	4	2	2	2	4	4
sand	1	1	1	4	2	2	2	4	4
mud	1	10	10	4	2	2	2	4	4
rockweed	1	10	10	10	10	10	10	10	10
Sea lettuce	1	10	10	10	10	10	10	10	10
kelp	1	10	10	10	10	10	10	10	10
eelgrass	1	10	10	10	10	10	10	10	10
Tidal marsh	1	10	10	8	8	8	8	8	9

Table 7. Proposed scheme linking backshore and intertidal habitats. Sediment supply from the backshore in the absence of buffer zone is rated as N- none, H - High, M - medium, L -low. The sensitivity of the various intertidal habitats to particular sediment supply regimes is rated from 1 (low) to 10 (high). Habitat nomenclature from Jamieson *et al* 2000.

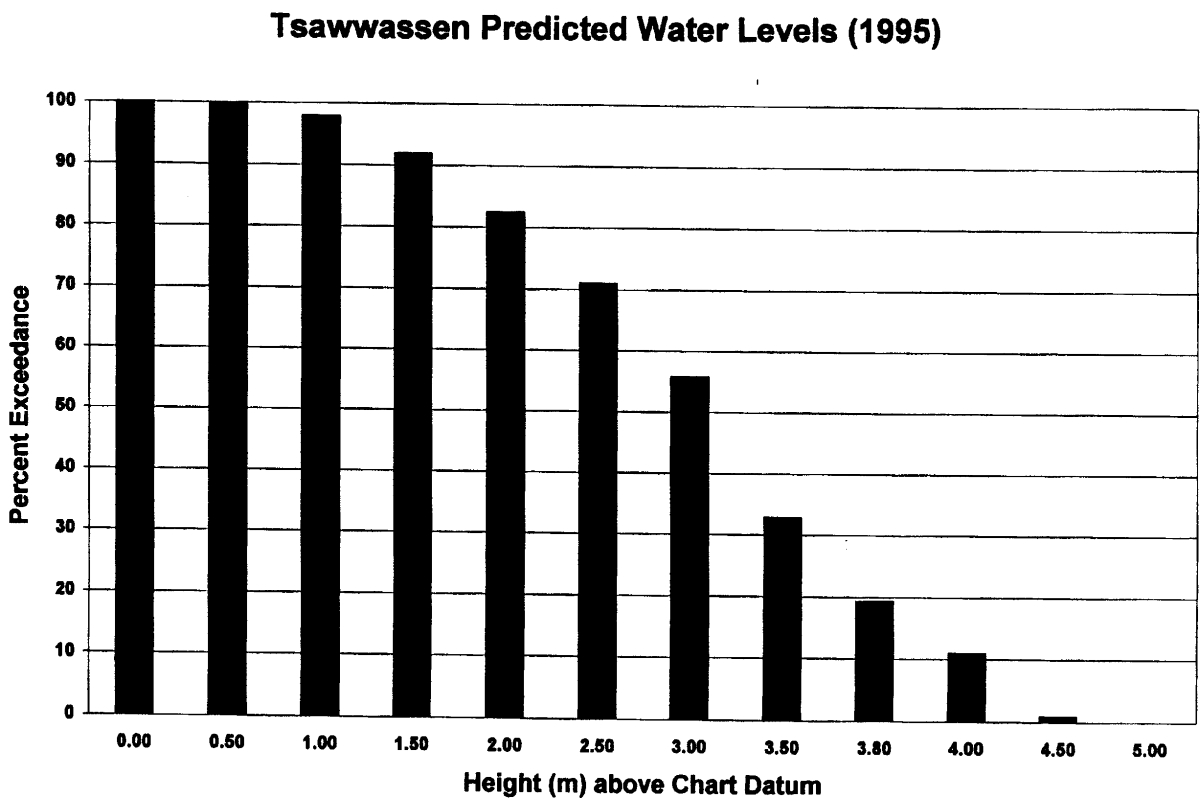
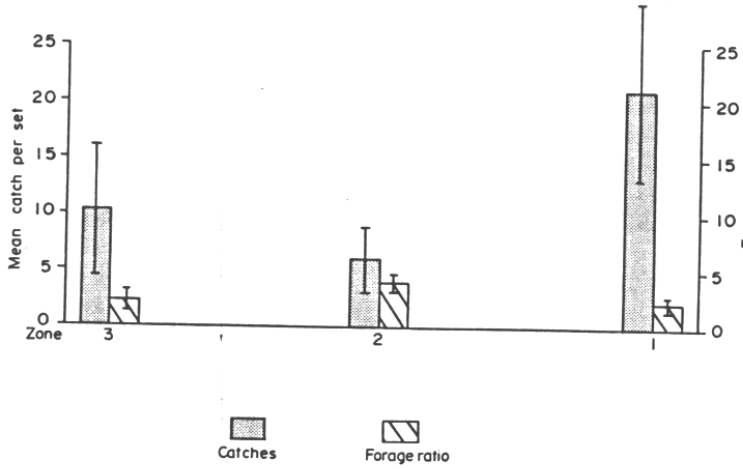


Figure 1. Percentage of tides in 1995 (n=8760) that exceeded a particular elevation (m over chart datum) at Tsawwassen, Roberts Bank, in 1995. Data courtesy of Bodo de Lange Boom, CHS.



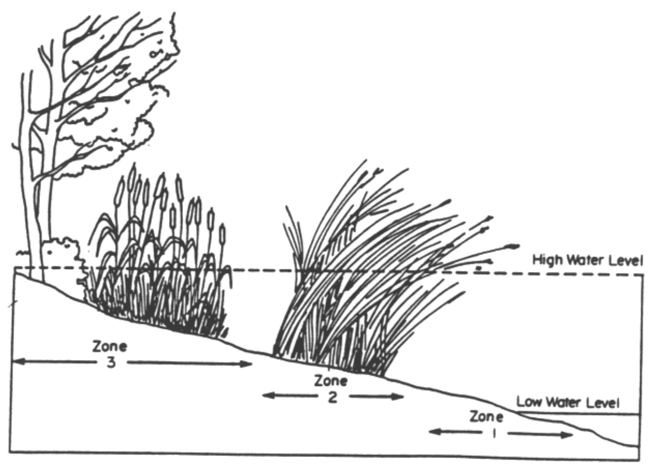


Figure 2a (upper panel). Mean catch per set of juvenile chinook salmon and forage ratio (%) of three habitat zones on the North Arm of the Fraser River estuary. Zone 3 is marine riparian (see Fig 2b) (from Levings *et al*, 1991).

Figure 2b (lower panel). Habitat zones on the North Arm of the Fraser River estuary. Zone 1: lower intertidal, uvegetated; zone 2: mid to upper intertidal, sedge zone; zone 3: marine riparian: rushes and willows.

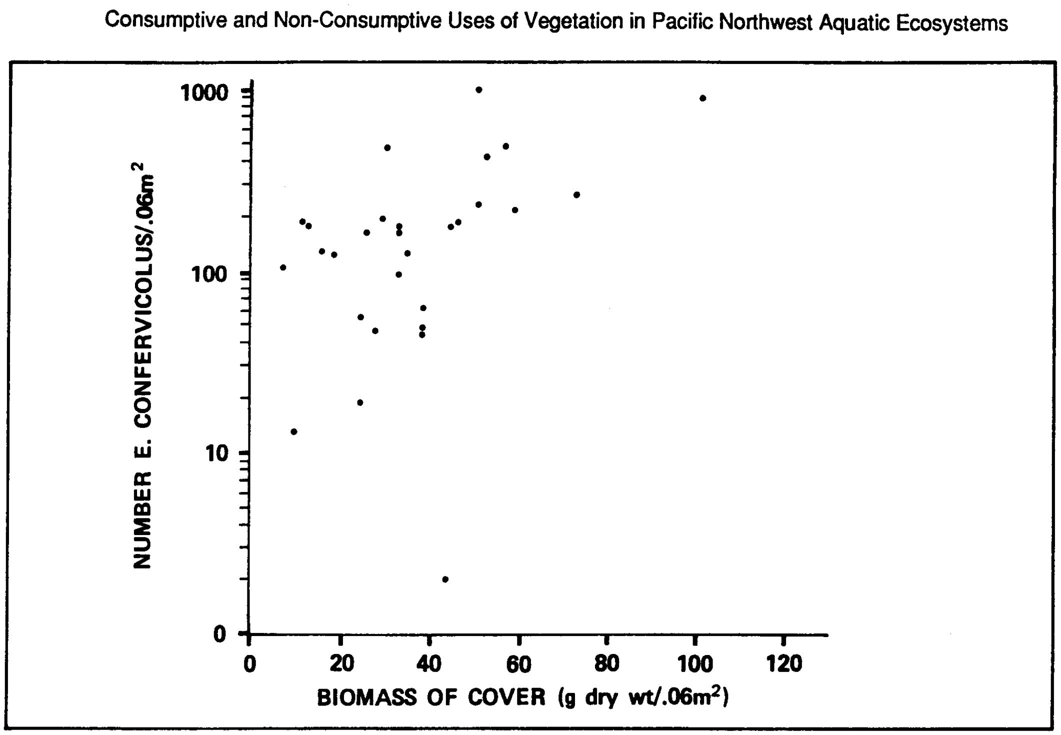


Figure 3. Relationship between amphipod abundance (*Eogammarus confervicolus*) and sedge rhizome biomass at the Squamish River estuary (from Levings, 1986).

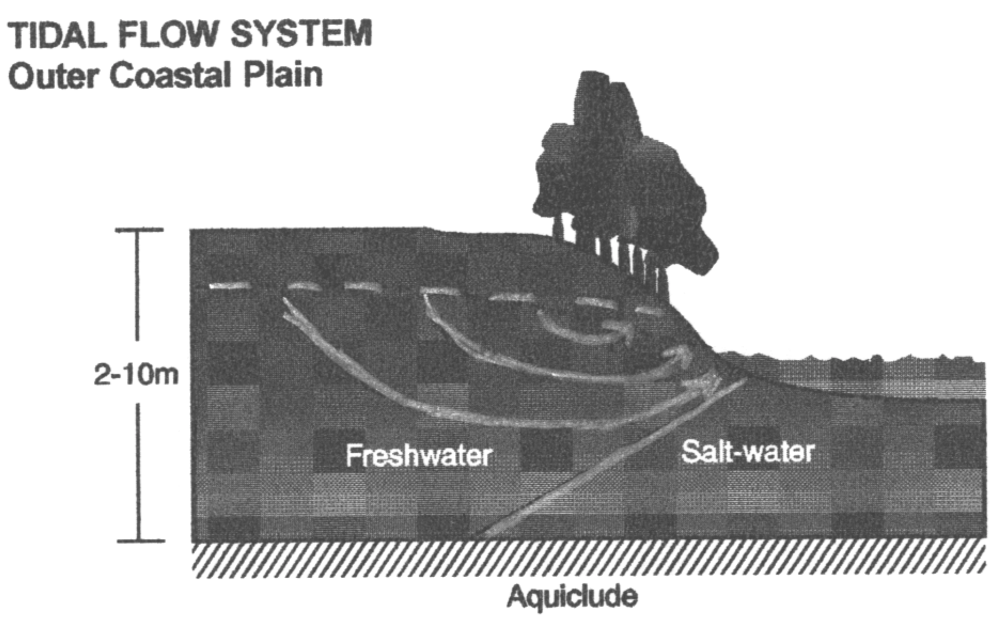


Figure 4. Schematic diagram showing the connection between groundwater aquifers and the coastal zone (from Palone and Todd, 1997)

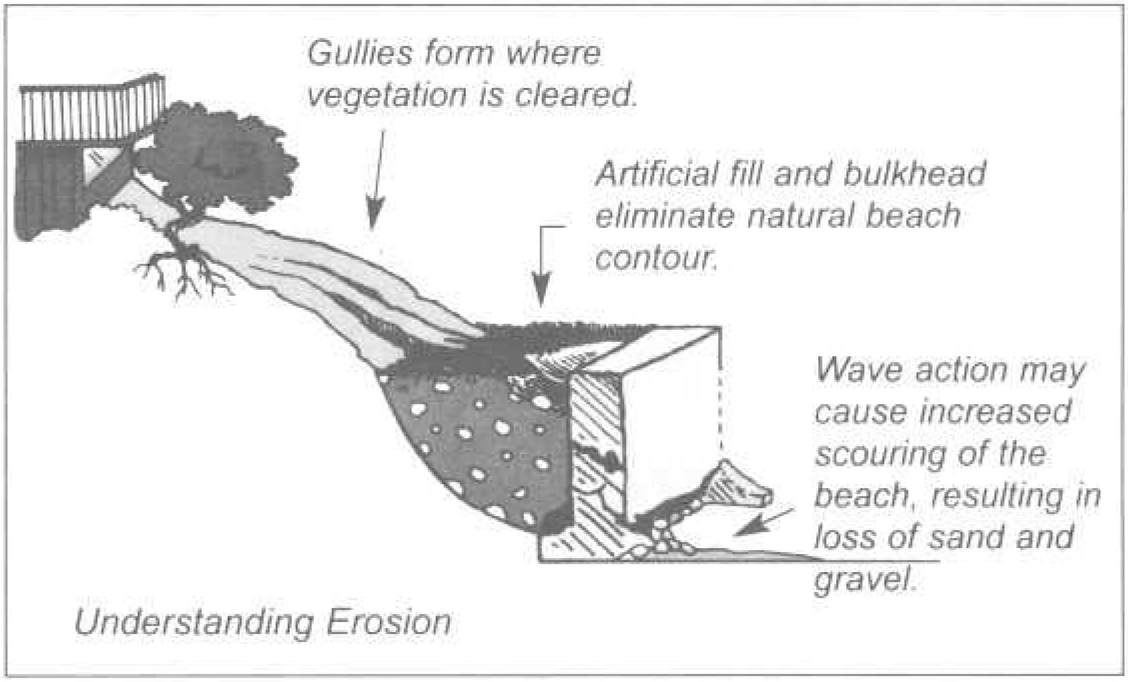


Figure 5. Erosion of marine riparian when armoured (from Broadhurst, 1999)

Appendix I

Selected examples of recommended buffer zones for marine riparian in British Columbia, Washington, coastal northeast USA, and Alaska.

A. Ministry of Forests, 1996.

R7.35. On Class A (1) and A (2)(i) shores (low shores adjacent to open waters), extend a riparian reserve inland 150 m from the seaward edge of forest vegetation, or to the inland limit of shore-associated features (e.g.overgrown sand dunes), whichever is greater. The distance is determined by wind forces and the distance for wind attenuation inside the forest. Measurements on the lower Alaskan coast indicate that 150 m is sufficient to achieve this.

R7.36. On the remaining Class A (2) shores (cliffs, bluffs, and steep shores adjacent to open waters), extend a riparian reserve 100 m inland from the top of the coastal slope or bluff. On eroding shores, a larger distance may be specified if required by slope stability criteria.

R7.37. On Class B marine shores, extend a riparian reserve 100 m inland from the seaward edge of forest vegetation, or to the inland limit of shore-associated features (e.g. sand dunes and lagoons, now within the forest), whichever is greater. For lagoons within the forest, establish a reserve on the inland shore (R7.30).

R7.38. In estuaries proper, make a smooth transition from the marine shore reserve to the streamside special management zone.

B. Saanich Inlet Study, 1996. Synthesis report: Technical Version. BC MELP.

"The sensitivity of nearshore habitats should be recognized by the establishment of a sensitive habitat buffer zone extending a minimum of 100 m (wider if necessary) from the high tide mark and covering areas of the inlet watershed with steep upland slopes. " Saanich Inlet report p. 10-12

C. Washington

The Washington Shoreline Management Act sets a buffer zone of “one-half-site-potential tree height, or 100 ft (30.3 m) (whichever is greater) along lakes and marine shorelines” (Anon, 2001).

D. Chesapeake Bay (Palone and Todd, 1997)

The ability of the buffer to filter chemical contaminants is highly variable; however, forest buffers 35 to 125 feet wide are generally recommended to remove nutrients and other chemical contaminants, depending on pollutant loading and site conditions (Palone and Todd 1977). Buffers 50 to 100 feet wide are usually recommended to trap sediments, with the buffer expanding where there are steep slopes or where sediment loading is high (Palone and Todd 1977).

E. Alaska, Tongass National Forest (US Forest Service, 1997)

Management objectives of the beach and estuary fringe habitat (summarized)

- to maintain the ecological integrity of beach and estuary fringe forested habitat to provide sustained natural habitat conditions and requirements for wildlife, fish, recreation, heritage, scenery and other resources
- to maintain an approximate 1000 foot wide beach fringe of mostly unmodified forest to provide important habitats, corridors, and connectivity of habitat for eagles, goshawks, deer, marten, otter, bear, and other wildlife species associated with the maritime-influenced habitat
- the beach fringe is an area of approximately 1000 ft slope distance inland from mean high tide around all marine coastline

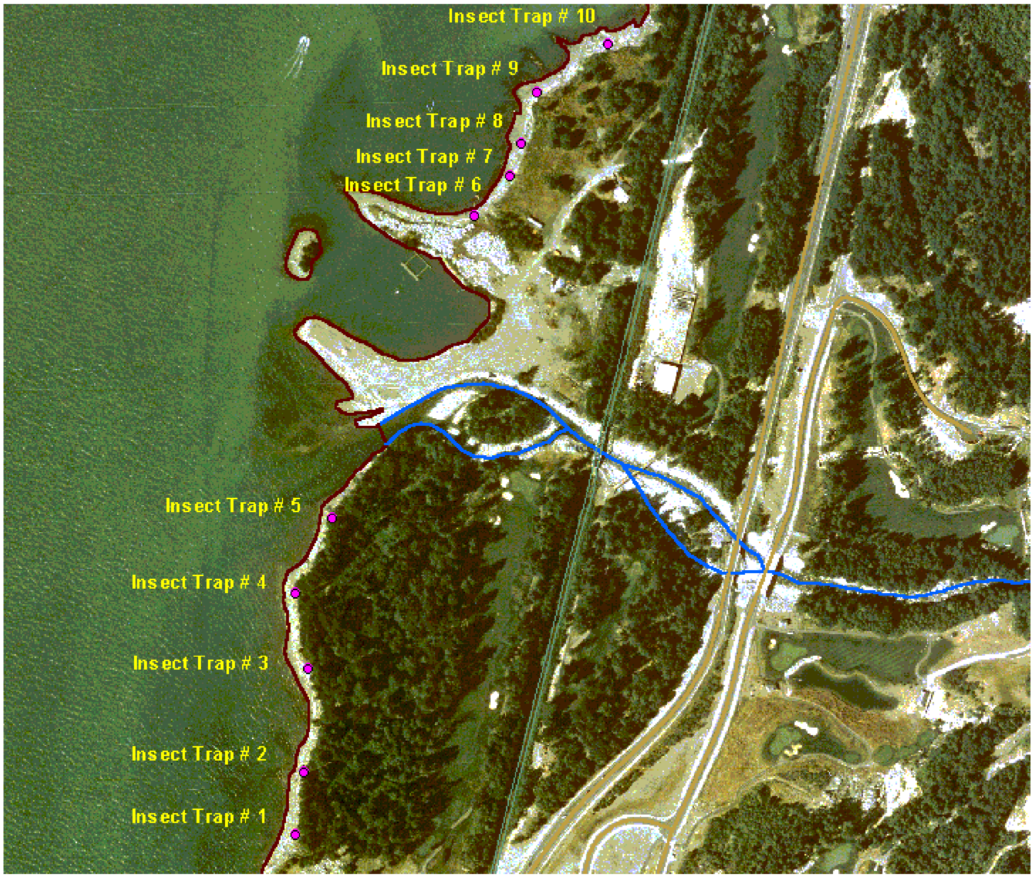
Appendix 2. Methods for arthropod trapping and vegetation mapping used in February and March 2001 surveys.

A. Howe Sound (Appendix Figure 1 a, b)

Three locations in Howe Sound were sampled, one south of the mouth of Furry Creek (forested), a second north of the mouth of Furry Creek (urban, riprap shoreline) and a third at Porteau Provincial Park (forested). A transect about 500 m long was arrayed along the drift line, parallel to the shoreline, at each location. On each transect 5 sample trays (21.5 cm x 33.5cm x 9 cm) were dug into the substrates approximately 100 m apart. Except for the riprap shore, where the trays could not be sunk into gravel or sand, the top rim of the trays were level with the substrate surface. Traps were set out for 24 h on five dates at Furry Creek (February 14, 27 and March 2, 14, and 27 2001). Porteau Provincial Park was sampled on March 2, 14, and 27 2001. Once the trays were placed in the substrate, non-scented liquid soap, sufficient to cover the bottom, was added to the tray to a depth of about one mm and each tray site was marked with a public warning sign indicating the purpose of the study and the contents of the trays. The horizontal distance from the vegetation, if present, to the trap location, and weather conditions were recorded and photographs of each tray were taken (Levings, unpublished).

At the West Vancouver Laboratory, tray contents were washed onto a 250 micron sieve and thoroughly rinsed to remove the soap. Materials retained on the sieve were backwashed into a vial and preserved in 5% formalin. Vial contents were then sorted and identified using an illuminated lens and a dissecting microscope stored in 50% isopropanol solution.

Visual observations of vegetation type were made on each sampling trip. On April 3 2001the percent cover of vegetation was assessed 5 m to the south and north and 10 m into the backshore from the location of the traps (total plot size 100 m^2). Aerial photos obtained in 1999 were also used to help vegetation mapping. For presentation of station locations in GIS, orthophotos from 1994 were used.



Appendix Figure 1a. Aerial photo obtained in 1994 of the Furry Creek area foreshore showing locations of the arthropod traps deployed in February and March 2001. Furry Creek is the centre of the photo, north is to the top. Highway 99 is in the centre right of the photo. In 2000, the beach to the north of the creek mouth was armoured with riprap to protect a major townhouse development. In 2001, over 60 % of the vegetation inshore of the forested area south of the creek mouth was removed in preparation for further development. At the time the arthropod traps were deployed, a buffer strip of at least 15 m was present.

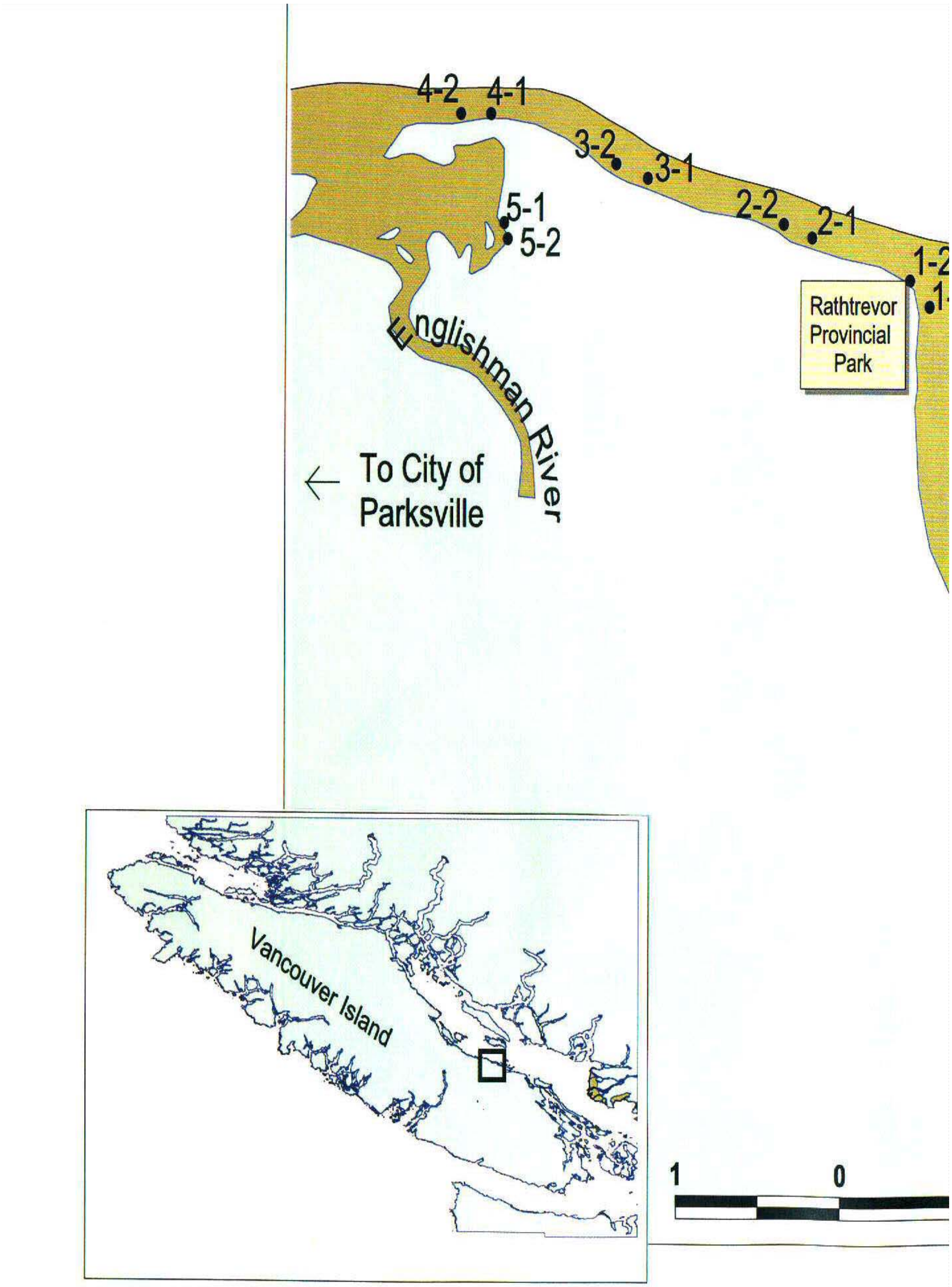
Appendix Figure 1b. Aerial photo obtained in 1994, of the Porteau Provincial Park foreshore, showing locations of the arthropod traps deployed in February and March 2001. Highway 99 is on the right hand side of the photo, north is to the top.

B. Parksville (Rathtrevor Beach) (Appendix Figure 2)

At each of five sample sites, two transects 28 -45 m length were arrayed end to end along the drift line. The marine riparian at each site was as follows: 1 - open grassland; 2 - forested woodland; 3 - urban housing; 4 - sand dune; 5 - estuary (mouth of the Englishman River). On each transect 5 sample trays (21.5cm x 33.5cm x 9 cm) were dug into the substrates approximately 8 m apart. The top rim of the trays were level with the substrate surface. The horizontal distance from the vegetation, if present, to the trap location, temperature and weather conditions were recorded and photographs of each tray were taken. Once the trays were placed in the substrate, non-scented liquid soap, sufficient to cover the bottom, was added to the tray to a depth of about one mm and each tray site was marked with a public warning sign indicating the purpose of the study and the contents of the trays. The trays were left for 24 hours (March 20-21, 2001) at which time they were retrieved and taken to the Pacific Biological Station at Nanaimo for sorting.

The tray contents were washed onto a 710 micron sieve and thoroughly rinsed to remove the soap. Materials retained on the sieve were backwashed into a vial and preserved in 5% formalin. Vial contents were then sorted using an illuminated lens and a dissecting microscope and samples of each species type were stored in 50% isopropanol solution. Samples were initially sorted to categories of Order Amphipoda, Order Isopoda, Order Collembola, Order Coleoptera, Order Hemiptera, Order Diptera, Class Arachnida and Other (ants, fleas and millipedes).

To assess vegetation, visual observations during sampling were recorded for overstory and understory species. Random representative understory species were also collected for identification. On May 2, 2001, vegetation biomass was assessed in three random locations along the transect and within 15 m backshore from the driftline. Plants were clipped to the substrate and dry weights were obtained (Jamieson, unpublished).



Appendix Figure 2. Map of the shoreline near Parksville (Rathtrevor Provincial Park) showing locations of the arthropod traps deployed in March 2001.

Appendix 3. Species list of Collembola from insect trap sampling at Furry Creek (FC) and Porteau Cove (PC) in February and March 2001. Identifications completed by M. Fernand Therrien, Laval, Quebec, based on a random subsample of 24 specimens.

F. Hypogastruridae
Hypogastrura (Hypogastrura) cf viatica (Tullberg, 1872) (FC)
Hypogastrura (Ceratophysella) pseudarmata (Folsom, 1916) (FC)

F. Isotomidae
Anurophorus (Anurophorus) pacificus Potapov, 1997 (FC)
Archisotoma besselsi (Packard, 1877) (FC,PC)
Isotoma (Halisotoma) marisca Christiansen and Bellinger, 1988 (PC)

F. Tomoceridae
Tomocerus (Pogonognathellus) flavescens Tullberg, 1871 (FC)

F. Sminthuridae
Sminthurinus (Sminthurinus) maculosus Snider 1978 (PC)
Ptenothrix (Ptenothrix) maculosa (Schott, 1891) (PC)