A Component of British Columbia's
Land Use Strategy

North Coast LRMP

Background Report

Hydroriparian Ecosystems of the North Coast

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Summary

This report provides background information on riparian ecosystems for the North Coast LRMP. The report

- describes North Coast riparian ecosystems,
- reviews riparian ecological functions,
- presents riparian management policies for BC and neighbouring jurisdictions,
- lists potential strategic planning issues for consideration.

Literature is taken from the North Coast where possible. Where research is cited from areas outside the North Coast, the report describes the potential relevance of studies to North Coast ecosystems. This summary is written without reference to the literature for ease of reading. Please refer to the full text for citations.

What are Riparian Ecosystems?

Riparian ecosystems occur where water and land meet. In the North Coast, because of the cool, wet climate, the distinction between wetland and upland is not always clear—riparian ecosystems can extend over entire landscapes. To acknowledge the tight coupling between land and water, this report discusses “hydroriparian ecosystems”, that include both water and adjacent land in one integrated ecosystem. Hydroriparian ecosystems extend to the edge of the influence of water on land or land on water, and include both underground and above ground effects. They are dynamic systems, and may be modified by flooding, erosion and sedimentation.

Hydroriparian Ecosystems of the North Coast

The North Coast divides into two physiographic units. The Hecate Lowland area features low relief, cool wet weather with little snow and generally nutrient-poor bedrock. Consequently, the area is dominated by extensive blanket bogs and scrub forest interspersed with patches of productive forest in better drained areas and on richer bedrock. Watersheds tend to be small. Narrow, low gradient streams drain slopes. There are many small, but few large, floodplains and estuaries. Exposed marine shores are common. At its eastern boundary the Hecate Lowland changes into the Outer Coast Mountain unit and physiography is steeper.

The Outer Coast Mountains, directly inland from the Hecate Lowland, feature steep, rugged mountains and cool, wet weather with abundant snow at higher elevations. Watersheds may be very large. Steep headwater streams and gullies drain the mountainsides, carrying water, sediment and organic materials to the fans and floodplains that line valley bottoms. Lakes head some valleys. Small wetlands are common on floodplains, but extensive wetlands are uncommon. Large, productive estuaries are common, linking freshwater and marine ecosystems.

The report outlines an example of a possible hydroriparian classification system designed for the North Coast. To illustrate how the system could be applied, the report outlines the most common hydroriparian ecosystems found in the Hecate Lowland and Outer Coast Mountains.

How do Hydroriparian Ecosystems Function?

Four types of function characterise hydroriparian ecosystems:

- land influences adjacent water;
- water influences adjacent land;
- hydroriparian ecosystems link landscapes; and
- are hotspots of biodiversity.

Land influences adjacent water by:

- **providing downed wood** that influences stream shape and provides food and shelter for a variety of organisms. The rate of input depends on the type, frequency and intensity of disturbance in riparian forests. This influence is most important in small streams, fans and floodplains across the North Coast.
- **providing organic material** in the upper watershed that supports hydroriparian food webs throughout the drainage. This influence is most important in small streams across the North Coast.
- **providing shade** that moderates light and temperature, and influences aquatic invertebrate communities and other organisms. This influence is most important in small streams. Temperature moderation is likely less important in the North Coast than in warmer climates.
- **filtering sediment and dissolved materials**. Sediment filtration is important in the steep terrain and fans of the Outer Coast Mountains.
- **stabilising banks** and reducing erosion caused by flooding. This influence is important on small steep streams, floodplains and fans across the North Coast.

Water influences adjacent land by

- **increasing ecosystem productivity** by providing moisture and nutrients in well-drained soil. This influence is obvious in the large floodplains and fans of the Outer Coast Mountains.
- **decreasing ecosystem productivity** by promoting organic matter accumulation (increased moss growth, slower or incomplete decomposition) in poorly-drained soil. This influence is most noticeable in the extensive bogs of the Hecate Lowland.

- **modifying the microclimate** of adjacent land, influencing plant growth, soil microbes, amphibians and other organisms. This influence is most obvious in the shoreline forests of the Hecate Lowland; in other ecosystems, it is likely less important in the North Coast than in warmer, drier climates.

Hydroriparian ecosystems link landscapes by

- **transporting water** downstream above and below the ground. Water drains quickly from the Outer Coast Mountains and slowly from the Hecate Lowland. Forest canopies intercept a portion of precipitation, moderating water flows to hydroriparian ecosystems.

- **transporting sediment** downstream, modifying ecosystems as it moves. Sediment can increase productivity (e.g. by creating fans and floodplains in valley bottoms) or reduce productivity (e.g. by covering stream beds and reducing habitat). Debris flows are more common on steep slopes.

- **transporting small organic material** from small headwater streams to other hydroriparian ecosystems. This movement is particularly important in nutrient-poor systems like those of the North Coast. Salmon carry organic material upstream.

- **transporting downed wood** that accumulates on fans and floodplains and influences flow dynamics and flood dynamics on larger rivers.

- **serving as corridors** for plant and animal movement. A variety of invertebrates and vertebrates feed and travel along hydroriparian ecosystems.

Hydroriparian ecosystems are important to biodiversity because they

- **contain the most diverse structure and vegetation** of the coastal temperate rainforest due to flooding, debris flows, downed wood, animal activity, productivity, landform and elevation. Most terrestrial vertebrates of the North Coast use hydroriparian ecosystems; invertebrate diversity is also high. Estuaries, fans, floodplains and wetlands are the most diverse ecosystems in the North Coast.

- **contain rare ecosystems**. Several shoreline, fan and floodplain ecosystems across the North Coast are listed as rare in BC.

- **are home to rare and important species**, including plants, fish, amphibians, birds and mammals listed by the Conservation Data Centre as threatened or at risk. In the North Coast, estuaries are used by most listed birds, tailed frogs live in small steep streams in the Outer Coast Mountains, and grizzly bears rely heavily on floodplains, fans and estuaries.

The structure and functions of hydroriparian ecosystems reflect local and upstream disturbances. If resource development alters the frequency, type and/or intensity of disturbance, it may alter any of the functions listed above. Data, particularly for the

North Coast, are sparse. The report describes potential impacts of resource development under each function.

Management Policies

In BC, forest management practices in hydroriparian ecosystems have changed over the past 30 years from days of no regulations, through the Fisheries/Forestry Guidelines to the Forest Practices Code. Guidelines have been refined over the years, in response to increased understanding of riparian ecosystems, with the aim of improving practices to maintain riparian function and aquatic ecosystem integrity.

Policies vary considerably among coastal jurisdictions (Alaska, BC, Clayoquot Sound, State and Federal regulations in Western Washington), although these various coastal riparian systems are relatively similar ecologically and in their response to forest management. Most jurisdictions set fixed-width management zones or reserves along streams, lakes and wetlands to protect the local influences of land on water and water on land. These policies are currently under review as the focus moves towards a landscape-level approach to riparian management. Currently, riparian policies in Washington and Clayoquot Sound recognise the importance of landscape links in management, while those in Alaska and the rest of BC do not. Ecological emphasis varies among jurisdictions: slope stability and fish are the only stated concerns in Alaska; the Forest Practices Code and Washington regulations list a variety of riparian functions, but base classification and management primarily on the presence of selected fish; only the Clayoquot Sound recommendations base classification on land-water ecosystem units.

Issues

The report lists four general principles for consideration by the LRMP in relationship to hydroriparian ecosystems:

- Should resource management use natural disturbance as a guide?
- What spatial and temporal scales are appropriate for planning?
- How should hydroriparian ecosystems be classified?
- Should management consider local site information and a watershed context, or should management have fixed prescriptions everywhere?

The report highlights eight hydroriparian ecosystems that may benefit from special consideration:

- headwater streams,
- fans and floodplains,
- estuaries,

- shoreline forest,
- karst landscapes,
- wetlands,
- ecosystems in organic terrain,
- hotsprings.

The report notes two final issues with implications for those listed above:

- global warming,
- windthrow.

Information Gaps

Currently, very few studies have examined hydroriparian ecosystems in the North Coast. Results from studies in other areas give guidance, but need to be interpreted in light of similarities and differences between the ecosystems studied and the North Coast. The extent of hydroriparian ecosystems makes many studies difficult to interpret. Principle information gaps include

- North Coast hydroriparian disturbance and recovery regimes,
- the cumulative effects over space and time of exceeding the natural range of variability in disturbance regimes,
- the relative effectiveness of alternative management regimes in protecting entire hydroriparian ecosystems (e.g., fixed-width buffers, landscape-level management, etc.; landscape-level planning exercises are underway in BC and the US),
- the importance of small streams to downstream ecosystems (active research in this field is currently all outside the North Coast),
- the influence of shoreline vegetation on nearshore ecosystems,
- the ecology and potential impacts of management on low productivity forests in organic terrain (there is currently a project underway in the North Coast to investigate this issue).

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1.0 Introduction

1.1 Background

This report provides background information and presents issues to the North Coast LRMP Table concerning the ecology and management of riparian ecosystems in the North Coast Forest District. The report reviews North Coast riparian ecosystems, riparian ecological functions, riparian policy history and policies in other jurisdictions, and presents a list of strategic planning issues for consideration by the LRMP Table.

The report relies on the most recent literature available, interviews with specialists, and the experience of the authors. We have used data from the North Coast where possible. Most riparian research, however, originates from south-eastern Alaska, south-western British Columbia (Carnation Creek) and the Queen Charlotte Islands/Haida Gwaii, and the US Pacific Northwest. Where several papers illustrate a similar point, we cite those most relevant to North Coast riparian ecosystems (priority for citation: 1. North Coast; 2. Pacific Coastal Ecoregion (south-eastern Alaska, Central Coast and Southern BC Coast, western Washington); 3. inland BC, Alaska, Washington or Oregon; 4. elsewhere). When information for the North Coast is unavailable, we note how the North Coast may differ from information taken from other geographic areas.

Where we discuss the impacts of human disturbance on ecological functions, we focus on the types of disturbance potentially resulting from forest management—typically, episodic removal of vegetation and reduction in forest structure (downed wood, big trees, gaps, snags). Chronic disturbance from urban, agricultural or industrial development potentially impacts riparian ecology more than forest management (e.g. pollution, dams, long-term removal of riparian vegetation, channel confinement), but these developments are unlikely to be extensive in the North Coast.

1.2 Riparian Ecosystems

Riparian ecosystems occur where water and land meet. Traditionally, water and the adjacent land have been considered separately as aquatic and terrestrial systems. Because the two are tightly coupled, however, in this report we use the term "hydroriparian ecosystems" (Clayoquot Sound Scientific Panel "CSSP" 1995) to refer both to water (= "*hydro*") and the adjacent land ("*ripa*" = bank) that influences, and is influenced by, water. We reserve the term "riparian" for describing vegetation growing adjacent to freshwater and marine aquatic ecosystems.

Hydroriparian ecosystems are much more than river banks. They include streams, rivers, lakes, wetlands and marine shores. They extend horizontally to the edge of the influence of water on land or of land on water. They extend vertically, below ground to a watery world of microbes, and above ground to the canopy where precipitation first drips (Gregory *et al*. 1991, Naiman *et al*. 2000). They flow and change, continually modified by disturbance effects of flooding, erosion and sedimentation. In the wet North Coast, the distinction between upland and wetland is often unclear, and hydroriparian ecosystems can extend over entire landscapes.

As the interface between water and land, hydroriparian ecosystems are ecologically important in four ways. First, the land influences adjacent water. Vegetation moderates temperature and water input, provides structure and nutrients and stabilises banks. Bedrock and soil determine water chemistry and channel form. Second, water influences adjacent land. Flow erodes banks and deposits sediments creating soil. Flooding, in well-drained soils, creates mosaics of diverse and productive communities. Third, hydroriparian ecosystems link landscapes by transporting water and solutes, sediment, food and organisms. In essence, they form the "circulatory system of the ecological landscape" (CSSP 1995). Fourth, because of their diverse forms, frequent disturbance and productivity, hydroriparian ecosystems are home to diverse plants and animals, including rare communities and species—they are hotspots of biodiversity. Throughout this report, we will use these four classes to describe and interpret ecological functions and management issues of hydroriparian ecosystems.

1.3 North Coast Ecological Context

The forms and functions of riparian ecosystems result from interactions among the physical processes produced by an area's unique climate and physiography and the organisms that populate them. The North Coast lies nestled within the Pacific Coastal Ecoregion that stretches from California to Alaska (Naiman and Bilby 1998). In general, moving north within the ecoregion, temperature decreases, rainfall increases, watershed size decreases and seasonality of discharge decreases (Naiman and Bilby 1998). Table 1 compares mean annual temperatures and precipitation at coastal weather stations in south-eastern Alaska, Prince Rupert, south-western BC and south-western Washington. Temperature correlates well with latitude; precipitation varies with local topography.

Table 1. Mean annual temperature and precipitation at selected coastal weather stations.

Location	mean annual temperature (°C)	annual rain (mm)
Haines, Alaska	4.5	1,540
Prince Rupert	6.9	2,411
Carnation Creek, sw BC	8.6	6,480
Long Beach, sw Washington	10.1	2,108

The North Coast contains two of the four Pacific Coastal subregions—the Northern Lowlands and Islands, and the Northern Mainland Mountains (Naiman and Bilby 1998), corresponding respectively with the Hecate Lowland Ecosection and the Outer Coast Mountains (including portions of the Kitimat Ranges and Alaska Panhandle Ecosections; see map in Appendix 1; Holland 1976). This classification provides ecologically uniform units for discussing riparian issues.

1.3.1 Hecate Lowland

The Hecate Lowland is a narrow, low-lying area of the coast and adjacent islands that ranges between 15 km and 45 km wide, ending to the east at a generalised elevation of about 600m (Holland 1976). The Hecate Lowland is never more than 25 km from salt water (Banner *et al*. 1993). Relief is not large but topography can be rugged as the area grades into the Outer Coast Mountains. Much of the area lies in a low, flat plain (Holland 1976).

Although the Hecate Lowland was once glaciated, glacial deposits are rare, occurring mostly on larger valley bottoms. Most of the area is covered with a veneer of organic material over granitic bedrock scoured by glacial ice. Steeper slopes have colluvial and morainal parent material. Although largely dominated by granitic bedrock, metamorphic and sedimentary rocks (including limestone) also occur.

The Hecate Lowland is dominated by the Central Very Wet Hypermaritime Coastal Western Hemlock Subzone Variant (CWHvh2) at low elevation (Banner *et al*. 1993; Green and Klinka 1994). This subzone experiences a strongly maritime-influenced climate, with high annual rainfall (1,500 – 3,000 mm/year), very little snow, and cool temperatures in all seasons. Fog is common in summer (7 days/month from July to September). Because of the extreme precipitation and bedrock low in nutrients, the majority of the area supports extensive slope/blanket bogs (on slopes up to 60%) with interspersed patches of slow-growing, scrubby forest. Where drainage and nutrient availability improve (on colluvial or morainal slopes, floodplains, fans and over metamorphic rocks and limestone), forest productivity increases. The predominant tree species are western redcedar and western hemlock, with Sitka spruce largely confined to shoreline forests, well-drained sites on steep sidehills or on fans and floodplains. Amabilis fir, yellow cedar and shore pine are also common.

Above about 500m, snowfall increases, temperatures get cooler, and the Wet Hypermaritime Mountain Hemlock Subzone (MHwh) replaces the CWHvh2. In the MHwh, tree dominance changes to yellow-cedar, mountain hemlock, and amabilis fir. The MHwh is restricted to a few elevated peaks within the Hecate Lowland.

Hydroriparian ecosystems essentially cover the entire Hecate Lowland. Wetlands (bogs, ponds and small lakes) cover 51-75% of the landscape (Banner et al. 1986, 1988). Small, low-gradient streams are very common, draining the extensive slope/blanket bogs. Steep streams and torrented gully systems that are often associated with steep, unstable slopes are common in higher relief terrain along the boundary with the Outer Coast Mountains. There are many small, but few large, estuaries and floodplains, because watersheds are small and primarily rain fed (MacKenzie *et al*. 2000). Exposed marine shores, some supporting unique plant communities, are common.

1.3.2 Outer Coast Mountains

To the east of the Hecate Lowland, and directly adjacent to the ocean in the north, the Outer Coast Mountains rise to a general elevation of about 2,200 to 2,600m, with highest elevations of about 3,000m (Holland 1976). The Outer Coast Mountains are cut by major river valleys and ocean fjords, resulting in areas of dramatic relief.

Glacial landforms dominate the Outer Coast Mountains landscape. Colluvial and morainal landforms dominate the valley slopes, and occasionally glaciofluvial terraces occur along major valley sides. Most medium and large valleys feature productive valley floor complexes of fans (created by alluvial and colluvial processes) and floodplains, with scattered organic veneers in poorly-drained depressions. Fans and floodplain systems are common in association with estuaries where small- and medium-sized watersheds enter the sea. Floodplains commonly grade into large estuaries where valleys meet the sea.

Several subzones of the Coastal Western Hemlock Zone occur in the Outer Coast Mountains below about 900m. The most common are the Submontane and Montane Very Wet Maritime CWH Variants (CWHvm1, CWHvm2). Others include the Wet Maritime CWH Subzone (CWHwm), and the Submontane and Montane CWH Variants (CWHws1, CWHws2). The Outer Coast Mountains are strongly influenced by the ocean; the maritime influence decreases eastward. Temperatures are mild and rainfall is heavy. More precipitation falls as snow than in the Hecate Lowland, although low elevation coastal areas receive very little snow.

These CWH subzones form the heart of the temperate rainforests of British Columbia. The most common tree species are western hemlock, western redcedar, Sitka spruce and amabilis fir, and very large stands occur on fans and floodplains along the valley floors and lower slopes. Most forests in the Outer Coast Mountains contain trees older than 280 years; the forests themselves may be thousands of years old. Deciduous ecosystems of black cottonwood and red alder are common on floodplains and landslide areas. Avalanche tracks dominated by slide alder dissect the old forests on the valley walls. Wetlands are uncommon and restricted mostly to depressions.

Above 900m, the CWH zone is replaced by the Moist Maritime Mountain Hemlock, Windward Variant (MHmm1), and tree dominance changes to mountain hemlock, amabilis fir, and yellow-cedar. Temperatures decrease and snow accumulation increases dramatically, with very heavy snow accumulations throughout the zone. Above 1,100m, continuous forest gives way to tree islands of western hemlock and amabilis fir in the Moist Maritime Mountain Hemlock Parkland, Windward Variant (MHmmp1), an area of very short summers and very high snowpack. In much of the Outer Coast Mountains, the vegetated MHmmp1 is of limited occurrence because of steep terrain dominated by rock and permanent ice. Very little true Alpine Tundra (AT) occurs in the Outer Coast

Mountains, although edaphically controlled alpine-like ecosystems dominate much of the MHmmp1.

The Outer Coast Mountains contain a variety of hydroriparian ecosystems, from small steep headwater streams and gullies, running down into fans and wide floodplains. Moderately-sized linear lakes head some valleys and a variety of small wetlands dot floodplains. Large estuaries fed by rivers, rain, glaciers and permanent snow are well represented (MacKenzie *et al*. 2000)

1.4 Natural Disturbance Regimes

The entire North Coast is wet and cool. In such climates, fire ignitions rarely grow into large forest fires. For example, on the west coast of Vancouver Island, Gavin (2000) found a 3,500-year mean return interval for significant forest fire. Almost all of the biogeoclimatic subzones within the North Coast (CWHvh2; CWHvm1,2; CWHwm; MHwh1, MHmm1) are classed as Natural Disturbance Type 1: ecosystems with rare stand-initiating events (Biodiversity Guidebook; BC Ministry of Forests 1995). The CWHws subzone, occurring in a very small portion of the Outer Coast Mountains, is classed as Natural Disturbance Type 2: ecosystems with infrequent stand-initiating events.

Landslides, flooding, and wind are the predominant disturbance agents in both the Hecate Lowland and Outer Coast Mountains. Long, intense rainfalls initiate both landslides and flooding. In the Outer Coast Mountains, spring rain-on-snow events lead to high run-off. Landslides and avalanche chutes are clearly marked on the landscape by vertical patterns of red alder, slide alder and relatively young conifer communities. Landslides are common on steeper slopes in the Outer Coast Mountains, and in a transitional area in the Hecate Lowland. Flooding is localised, occurring along streams, rivers, fans and floodplains.

Wind disturbance may be frequent in some areas of the North Coast. In southwestern Alaska, large- and small-scale windthrow is the most important disturbance agent of forest composition, structure and productivity (Harris and Farr 1974, Bormann et al. 1995). Impacts vary from virtually complete blowdown over large areas, leading to even-aged regeneration, to partial removal of stand dominants, resulting in patchy, multistory stands (Nowacki and Kramer 1998). For a given wind, impact varies with stand structure, composition and vigour, as well as slope position, soil structure and moisture content, and the velocity and persistence of the wind (Nowacki and Kramer 1998, Harris and Farr 1974). Topographic position of a stand in relation to episodic storm winds is the most important factor in assessing potential wind effects (Nowacki and Kramer 1998). Windthrow is an important disturbance agent in maintaining the productive capacity of soil (Bormann et al. 1995).

A recent study completed on the operable timber harvesting land base of the North Coast Forest District estimated annual windfall at 13,417m^3/yr (Mitchell 1998). Of this total, 1,818 m^3/yr, or about 14%, was related to harvesting at cutblock boundaries. This represents an estimated area of less that 30 ha/yr that was windfelled over the 37 year period between 1960 and 1997.

2.0 Hydroriparian Classes

Headwater streams, floodplain rivers, bogs and estuaries serve different ecological functions. Section 2 introduces some important hydroriparian classes for the North Coast, and provides ecological rationales for each class. Section 3 uses this classification to discuss the ecology of North Coast hydroriparian ecosystems.

Hydroriparian ecosystems, traditionally divided into “riparian zones” and their associated aquatic ecosystems, have been studied from many perspectives over several decades. A diversity of approaches has led to a vast and confusing array of definitions and classifications, and there is still no ideal classification system (Naiman 1998). In 1991, a landmark paper (Gregory *et al*. 1991) summarised information to date, proposing an ecosystem perspective of riparian zones focussing on links between land and water within a landscape context. Although research continues to investigate individual components of hydroriparian ecosystems, there is general agreement in the literature of the past decade that an ecosystem approach and landscape context are necessary to maintain hydroriparian function.

The concept of treating water and the adjacent land as one integrated ecosystem was used by the Clayoquot Sound Scientific Panel (CSSP 1995) in forest ecosystems very similar to those that occur in the North Coast. The concept is valuable because it emphasises the inter-relatedness of land and water. At the watershed level, the hydroriparian ecosystem extends from the smallest high-elevation seeps, through valley-bottom fans and floodplains, to the valley-mouth estuary. Individual components of the watershed hydroriparian ecosystem (floodplains, fans, wetlands, headwater streams) can be thought of as hydroriparian subsystems. This approach emphasises the connectedness of hydroriparian elements within a watershed.

Tables 2a, b, and c describe selected stream, lake and wetland, and marine hydroriparian sub-systems that occur in typical watersheds of the Hecate Lowland and the Outer Coast Mountains as an example of a possible classification system. The classification is not intended to be exhaustive but to demonstrate the application of the hydroriparian concept, and to describe the ecological characteristics of the most abundant and important hydroriparian subsystems.

Streams are divided into classes by gradient, width and flow based on the following ecological rationales:

Stream Gradient Classes:

- <8% streams are usually zones of sediment deposition, have riffle-pool morphology and are used by anadromous fish
- 8 – 20% streams are zones of sediment transportation and deposition, have step-pool morphology and are used by resident fish
- >20% streams are zones of sediment input and transportation, have cascade or step-pool morphology and are rarely inhabited by fish

Stream Width:

- <3 m streams are completely shaded by riparian vegetation
- 3 – 30 m streams are not completely shaded, but can be completely spanned by downed wood
- >30 m rivers are generally not completely spanned by downed wood

Stream Flow:

- perennial streams flow year round and have rich communities of aquatic invertebrates
- seasonal streams are dry for a season, but have a stable source of water and have rich communities of aquatic invertebrates
- ephemeral streams flow for as short period after storms

Table 2 a: Stream Hydroriparian Ecosystems

		Stream Characteristics				*Classification*[1]	
Hydroriparian Ecosystem	***Ecosystem Characteristics and Notes***	***Gradient (%)***	***Width (m)***	***Flow***	***Biogeoclimatic Site Series***	***FPC***	***CSSP***
Small steep streams	• may travel down slope as a single channel, or join with others to form a larger stream at the valley bottom; may end upslope in gullies; stream network expands with precipitation and shrinks as slopes drain, forming a network of perennial, seasonal and ephemeral streams; narrow floodplain or seepage ecosystems often occur along the stream; vegetation may be devil's club, salmonberry, or red alder • ***Hecate Lowland:*** common only in transition area to the Outer Coast Mountains; high soil saturation and steep relief mean areas often highly unstable; red alder stands are common in areas of recent soil failures • ***Outer Coast Mountains:*** common from the valley floor to upper slope areas; flow through western hemlock, Sitka spruce, red cedar and amabilis fir forests with a range of site conditions and understory vegetation	> 20	< 3	perennial seasonal ephemeral	CWHvh2/04,06 CWHvm/01,05,08 CWHws/01,04,06 CWHwm/01,03,04	S6	B3a (i, ii)
Torrented gullies	• steep streams, often cut into deep glacial till or bedrock; periodically transport large debris flows that originate at higher elevations; deposit mineral soil and vegetation from the gully to fans at the base of the valley walls • ***Hecate Lowland:*** common only in the transition area to the Outer Coast Mountains; steep, unstable linear gullies; often evidence of recent landsliding and dominated by seral red alder stands; commonly deposit debris materials directly into the ocean • ***Outer Coast Mountains:*** common along the larger valleys throughout the area; gully walls may be unstable glacial deposits, bedrock, or productive seepage ecosystems dominated by western hemlock and Sitka spruce with Devil's club and a rich herb community; lower gradient gully bottoms often have small floodplain areas with abundant shrubs and herbs, red cedar and amabilis fir	>20	<3	perennial seasonal	CWHvh2/04,06 CWHvm/01,05,08 CWHws/01,04,06 CWHwm/01,03,04	S5,S6	B3b
Small, low gradient streams	• streams in low gradient areas with low sediment and debris transport potential; often form important fish habitat; adjacent vegetation varies from dry to wet sites • ***Hecate Lowland:*** very common draining organic terrain in forested and non-forested ecosystems; unique because streambanks are largely organic with streams cut to bedrock; hydrology that supports flows in streams that drain organic terrain is complex and poorly understood; often connected to a range of small and medium sized lakes and pools • ***Outer Coast Mountains:*** uncommon due to high relief; often associated with small floodplains in areas of low gradient in the mid elevations; also found as seasonal streams in backchannel areas on major floodplains or fans	8-20	< 3, 3-10	perennial seasonal	CWHvh2/01,11,12,13 CWHvm/variable CWHws/variable CWHwm/variable	S2-S6	A2 (i-iii)

Table 2 a (con't): Stream Hydroriparian Ecosystems

		Stream Characteristics				***Classification***	
Hydroriparian Ecosystem	***Ecosystem Characteristics and Notes***	***Gradient (%)***	***Width (m)***	***Flow***	***Biogeoclimatic Site series***	***FPC***	***CSSP***
Fans	• develop at the base of torrented gullies and steep streams where the stream reaches the valley floor and deposits debris; highly dynamic ecosystems where young soils develop from gravel and sand deposited by periodic debris flows • support coniferous or deciduous forests of various ages depending on disturbance history; very large Sitka spruce and western hemlock common in less active areas of the fan; conifer stands often feature wide spacing and large tree crowns, red alder and slide alder the most common deciduous species; fans feature abundant berries and forbs and are important wildlife habitat • ***Hecate Lowland:*** fairly rare; occur mostly in the transition area to the Outer Coast Mountains; where they occur, fans represent areas of high productivity ecosystems within a landscape of predominately low productivity ecosystems • ***Outer Coast Mountains:*** common at lower elevations where they form a valley floor complex with floodplains; such floodplain-fan valley bottom systems characterise many watersheds	8-20	< 3, 3-10	perennial seasonal	CWHvh2/06,07 CWHvm/05,08 CWHws/04,06 CWHwm/03,04	streams S2-S6; fans not classified	A2 (I-iii)
Floodplains	• built from the deposition of sediment in low gradient reaches; constantly created and eroded, resulting in a changing mosaic of ecosystems, creating high productivity and biodiversity • ***Hecate Lowland:*** infrequent; mostly small; where they occur, floodplains represent areas of high productivity forests and non-forested ecosystems within a landscape of predominately low productivity bog ecosystems; forests are a mosaic of large stands of widely-spaced Sitka spruce and western hemlock, and red alder stands on lower surfaces • ***Outer Coast Mountains:*** common; range from very narrow along small streams to 1 km wide or more; forests range from impressive stands of widely-spaced Sitka spruce and western hemlock, to red alder or black cottonwood stands, and willow, black cottonwood/red alder stands on the lowest benches; areas of poor drainage or beaver- and debris-dammed areas may support shrub and sedge wetlands; forested swamps occur in depressions, often along the base of the valley walls; floodplains often grade into estuaries on medium and large rivers	< 8	<3, 3-30, >30	perennial seasonal	CWHvh2/08,09,10 CWHvm/09,10,11 CWHws/07,08,09 CWHwm/05,06,07	streams S1-S4; active floodplain delineated	A1 (i-iii); contem-porary floodplain delineated
Karst landscapes	• described only for the Hecate Lowland • nutrient rich soil and well-developed drainage supports very productive forests relative to neighbouring stands underlain by granitic bedrock • pH buffered, even temperature, streams support diverse and abundant invertebrate communities and rapidly growing fish • water travels underground through channels and caves	variable	some entirely under-ground	perennial seasonal ephemeral	CWHvh2/05	classed by size of above ground streams	not applicable

1. FPC = Forest Practices Code Classification, Biodiversity Guidebook (FPC 1995); CSSP = Clayoquot Sound Classification (CSSP 1995)

Table 2 b: Wetland and Lake Hydroriparian Ecosystems

Hydroriparian System	***Ecosystem Characteristics and Notes***	***Biogeoclimatic Site Series***	***FPC Classification***	***CSSP Classification***
Forested swamps	• forested wetland ecosystems with mineral seepage that increases productivity compared to other wetlands; often occurs in small stands on floodplains and around wetlands • ***Hecate Lowland:*** **uncommon**; occur on lower slopes and depressional areas; soils mostly peaty although gleyed mineral soils do occur; trees root on mounds; open canopies with dense herb and shrub communities • ***Outer Coast Mountains:*** common in depressions on larger floodplains adjacent to valley walls or at the base of fans; soils often a veneer of fine peat over fine-textured mineral soil that impedes drainage; seasonally inundated from valley sidewall or river; western hemlock, Sitka spruce, and western redcedar grow on elevated mounds, abundant skunk cabbage fills depressions between the mounds; many other herbs and shrubs	CWHvm/14	not classified as wetlands if plant indicators not present	swamps
Sedge fens	• sedge-dominated wetlands occurring in landscape depressions with variable amounts of mineral seepage; often fringed by low and tall shrub communities; soils mostly fibric and mesic peat over fluvial deposits • ***Hecate Lowland:*** relatively uncommon; occur near river channels and small lakes where lateral seepage occurs • ***Outer Coast Mountains:*** common; occur mostly in depressions on floodplains; often at base of fans or in back channel areas	CWHvh,vm,ws,wm /31	W1, W3	fens
Slope/blanket bogs	• level to sloping, large bogs; mostly organic veneers and blankets over bedrock; vegetation sphagnum and sedges, with scattered small western and mountain hemlock, and yellow cedar (at higher elevation) • ***Hecate Lowland:*** very important landscape feature covering >50% of the landscape; forms a mosaic with forested ecosystems on organic soils • ***Outer Coast Mountains:*** rare; small areas occur in the CWHvm2 and the MHmm1 in the area transitional to the Hecate Lowland	CWHvh2/31	W1, W5	bog
Wetland ponds	• small, shallow freshwater ecosystems, often with organic banks and abundant algal and macrophytic vegetation • ***Hecate Lowland:*** common; in non-forested and forested landscapes; hydrology determined by flows in organic soils adjacent to ponds; part of a complex of ponds and streams leading from wetlands to stream networks • ***Outer Coast Mountains:*** rare; associated with slope wetlands in CWHvm2 and MHmm1in areas transitional to the Hecate Lowland.	not classified	<1ha unclassified	shallow open water
Lakes	• freshwater ecosystems providing an important component of regional biodiversity • ***Hecate Lowland:*** very abundant small lakes; often connected with ponds and small, low gradient streams to form a network of diverse freshwater habitats • ***Outer Coast Mountains:*** several deep, medium-sized lakes occur in faulted bedrock structures; small lakes rare and associated with slope wetlands in CWHvm2 and MHmm1in areas transitional to the Hecate Lowland.	not classified	L1, L3	lakes

Table 2 c: Marine Hydroriparian Ecosystems

Hydroriparian Ecosystem	*Ecosystem Characteristics and Notes*	*Biogeoclimatic Site Series*	*FPC Classification*	*CSSP Classification*
Shoreline saltspray forests	• differ from other upland forests because of the effects of salt spray and strong winds, tidal flooding and marine-related landforms such as beaches, estuaries and glaciomarine sediments • ***Hecate Lowland:*** common; salt spray sites occur on windy, unprotected shores; Sitka spruce dominates; understory varies with landform and marine effects; unique and productive epiphytic lichen communities because of wind and salt spray • ***Outer Coast Mountains:*** rare; marine-freshwater forest communities occur in the transition between floodplain and estuaries; unique flora and important habitat values	CWHvh2/14,15,16, 17	n/a	open water shoreline
Estuaries	• marine water and sediment mixes with freshwater and river sediment to create a productive mosaic of unique forest wetlands, shrub thickets, sedge and grassland ecosystems, salt, brackish, and freshwater marshes, and mudflats; • ***Hecate Lowland:*** uncommon; estuaries are small because of small contributing areas and low sediment transport • ***Outer Coast Mountains:*** common; very small to very large; large estuaries occur in conjunction with floodplain-fan valley systems; small occur where fans empty directly into the ocean	CWHvh2/18,19 similar site series in CWHvm[1]	n/a	protected water shoreline; estuaries and lagoons

[1] Similar ecosystems to the CWHvh2/18,19 exist in the CWHvm, although these are not listed in Banner *et al*. (1993)

3.0 Ecological Functions of Hydroriparian Ecosystems

Section 3 describes the ecological functions of hydroriparian ecosystems. For each ecological function, we present the current status of knowledge, its relative importance in different North Coast hydroriparian classes, the effects of disturbance (where known), and interactions with other functions. Tables 3a and 3b summarise important local and landscape ecological functions of each of the hydroriparian classes defined in Tables 2a, 2b, and 2c. The tables reflect the typical importance of each function; exceptions are common due to site-specific factors.

After reviewing the important functions of a particular hydroriparian class, the reader can use the text below the tables to better understand each function. Note that most functions interact with other functions.

Table 3 a. Principle local functions of hydroriparian subsystems in the North Coast

	Influence of land on water					Influence of water on land	
Class	Downed Wood	Shade	Fine Organic Material	Filtering	Bank Stability	Ecosystem Productivity	Microclimate
Small steep streams	***[1]	**	***	**	***	*	*
Gullies	***	*	*	**	**	0	*
Small, low gradient streams	***	**	***	**	***	*	*
Fans	***	*	*	***	***	***	*
Small floodplains	***	***	***	**	***	***	*
Large floodplains	*	*	*	*	**	***	*
Karst landscapes	*	*	*	**	**	**	*
Forested swamps	***	*	*	0	0	*	0
Fens	**	0	*	***	0	*	?
Bogs	?	0	?	?	0	***	*
Ponds	**	*	*	**	**	**	*
Small-medium lakes	*	0	*	**	**	**	**
Shoreline forests	0	0	0	*	*	**	***
Estuaries	*	0	*	*	*	***	**

1. Importance of ecological influence in a particular hydroriparian ecosystem class: *** very important, ** important, * somewhat important, 0 not important, ? unknown importance. For example, the land adjacent to small steep streams influences streams strongly by adding downed wood, but the water in small steep streams serves a minor role in moderating the microclimate of adjacent land. Some influences may be “positive” while others may be “negative” (e.g. decreased productivity in bogs caused by soil saturation).

Table 3 b. Principle landscape functions of hydroriparian subsystems in the North Coast.

	Landscape links					Biodiversity		
Class	Water Transport/ Storage	Sediment Transport/ Storage	Organic Material Transport/ Storage	Downed Wood Transport/ Storage	Plant and Animal Movement	Coarse Filter	Rare Ecosystems (CDC-listed)	Fine Filter
Small steep streams	input/transport[1]	input/transport	input/transport	input/transport	*[2]	*	0	?
Gullies	transport	input/transport	transport	input/transport	*	?	0	?
Small, low gradient streams	transport	transport	transport	input/storage	*	*	0	?
Fans	transport	storage	storage/ transport	input/storage/ transport	**	***	***	*
Small floodplains	transport	storage	storage	input/transport/ storage	**	*	*	?
Large floodplains	transport	transport/ storage	input/transport /storage	input/transport/ storage	***	***	***	*
Karst landscapes	transport	transport	transport	input/transport	**	***	*	*
Forested swamps	transport/ storage	storage	input? /storage	input/storage	?	**	0	*
Fens	transport/ storage	storage	input/storage	storage	0	*	0	*
Blanket bogs	storage	storage	storage	storage	0	*	**[3]	?
Ponds	storage	storage	storage	storage	0	**	0	?
Small/medium lakes	storage	storage	storage	storage	*	**	0	*
Shoreline forests	na	na	na	na	**	***	***	*
Estuaries	transport	storage	transport/ storage	transport/ storage	***	***	**	***

1. Principal ecological role as input, transport or storage of material.
2. Importance of ecological influence in a particular hydroriparian ecosystem class: *** very important, ** important, * somewhat important, 0 not important, ? unknown importance. For example, estuaries have several listed species of interest in fine filter examinations of biodiversity, whereas the status of many organisms living in small steep streams is unknown (no tailed frogs in Hecate Lowland); most rare ecosystems in the Hecate Lowland are shoreline forests and estuaries.
3. Abundant within North Coast, but globally rare

3.1 Influences of land on water

On a local level, the land immediately adjacent to water, and its associated riparian vegetation, influences hydroriparian ecosystems in several ways. This section discusses the roles of riparian vegetation in providing small and large organic material, shading water, stabilising banks and filtering chemicals. The downstream effects of these influences are discussed in the Section 3.2.3, Landscape Links.

3.1.1 Downed Wood

Large downed wood influences stream morphology by creating pools and regular patterns of sediment and nutrient deposition (Bilby and Bisson 1998). Woody debris increases channel diversity and provides habitat, food, and shelter from the current for invertebrates and fish, and habitat for amphibians, birds and small mammals (Bilby and Bisson 1998, Steel *et al*. 1999).

Large pieces of wood enter hydroriparian ecosystems in two ways. First, trees fall from stream banks due to windthrow, erosive undercutting or disease (Andrus 1998, Murphy and Koski 1989). Most fallen trees originate less than one tree height from the bank (see Figure 1; McDade *et al*. 1990). Second, trees are transported from upstream by highwater flows, or from uphill by avalanches and landslides. Prevalent disturbance type determines the principle means of input across the North Coast. Avalanches (in the Outer Coast Mountains), landslides (throughout the North Coast, particularly on steep or unstable slopes) and windthrow (in susceptible areas) provide structure to North Coast hydroriparian ecosystems at different rates in different areas. Models of woody debris input exist, but do not include transport from upstream, and are not designed for North Coast disturbance patterns (Kennard *et al*. 1999).

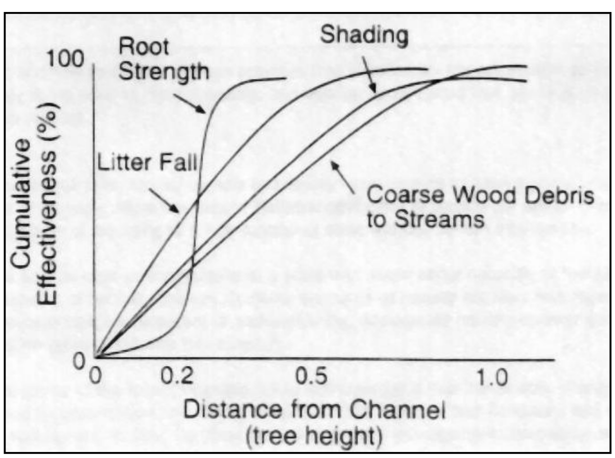

Figure 1: Distance required to maintain selected riparian functions. From FEMAT (1993).

The type of riparian vegetation determines the age and species of wood entering the water, factors with implications for persistence in the channel (Naiman *et al*. 2000). Deciduous wood and smaller pieces deplete faster (Hyatt and Naiman 2001). Hence, red alder, common in North Coast riparian vegetation, is less valuable as a source of downed wood (Bisson *et al*. 1987). Once in the water, wood decays exponentially—half the pieces last only 10 years, 80% disappears within 50 years, and a few pieces become buried and are then exhumed by erosion centuries later (Hyatt and Naiman 2001).

Large pieces of downed wood often form complex log jams that considerably alter stream morphology and habitat features. When jams first form, the disruption to stream morphology essentially destroys fish habitat (Hogan *et al*. 1998a). Over decades, as flow and sediment deposition patterns become established, log jams create diverse, complex channels that are valuable habitat; 50-year-old jams provide highly productive fish habitat (Hogan *et al*. 1998a). On the coast, log jams occur episodically following periods of extreme weather. In the Queen Charlotte Islands/Haida Gwaii, for example, over 85% of the woody debris jams originated from four disturbance events over the last 110 years (Hogan and Schwab 1991). Forest harvesting shifts the frequency distribution of log-jam age from an even distribution of young, moderate and old jams to a distribution dominated by young jams (Hogan *et al*. 1998a).

Downed wood is important throughout most hydroriparian classes. In narrow to moderately wide streams, trees can span the entire stream and create a step-pool structure (Montgomery and Buffington 1998). In wide streams, very large trees with intact root wads create jams that can be stable for centuries and create floodplain forest mosaics (Abbe and Montgomery 1996). Low gradient rivers can have abundant woody structures, e.g., one debris pile (3 – 500m^2) per 15 m from on a river in western Washington (Steel *et al*. 1999). Wood carried downstream by flooding is deposited in larger rivers, lakes, estuaries, marine shores and oceans where it again provides food and habitat. Far offshore, it can provide food and cover for more than 100 invertebrate species and more than 130 fish species (Sedell and Maser 1994).

Downed wood enters hydroriparian ecosystems following natural or management disturbances. Any change in the natural range of variation in disturbance type, intensity, size or frequency will change the pattern of input. For example, harvesting of riparian vegetation can be followed by a single, large input of wood, followed by decades, or centuries, of reduced input (Sedell and Maser 1994, Scrivener *et al*. 1998). As existing instream structures decompose and no new wood falls, sediment movement can accelerate and stream morphology can simplify (review in Montgomery and Buffington 1998). Recovery from loss of coniferous downed wood may take centuries as large trees need to grow, fall and become incorporated into the stream ecosystem (Gregory *et al*. 1987).

Downed wood interacts with transport and storage of water, sediment and organic matter, and with biodiversity (see discussions in sections below).

3.1.2 Shade

Riparian vegetation shades water, moderating light levels and temperature. Conifers provide shade year-round, while deciduous trees and shrubs provide seasonal shade. Narrow forest streams are entirely shaded by trees, although canopy gaps are common in old forests. As channels widen, the canopy opening above the water increases and shading decreases. As a result, wider streams usually have more algal growth, and support an aquatic invertebrate community dominated by algal "grazers", in comparison with narrow, shaded streams with an invertebrate community dominated by leaf "shredders" (Vannote *et al*. 1980, Cummins and Merritt 1996, Hawkins and Sedell 1981; see Section on Transportation of Organic Material).

With removal of riparian vegetation, more sunlight reaches the water, potentially increasing algal growth and providing more food for algal grazers. Because of the importance of aquatic invertebrates as fish food, many people have studied the impacts of riparian vegetation on invertebrate communities. Unfortunately, impacts are difficult to predict. Removing riparian vegetation sometimes leads to an increase in algal production (e.g., Kiffney *et al* unpublished manuscript, Tait *et al*. 1994, Ulrich *et al*. 1993), but sometimes does not, perhaps due to nutrient limitations or interactions with grazer populations (e.g., Shortreed and Stockner 1983, Feminella *et al*. 1989, Wellnitz *et al*. 1996). Open streams with high algal production sometimes have more grazing invertebrates (e.g., Hawkins *et al*. 1982, Tait *et al*. 1994), and sometimes do not, perhaps due to increased sediment (e.g., Kiffney *et al*. unpublished manuscript), or to changes in the algal community from non-filamentous diatoms to filamentous green algae, that is less available as food for invertebrates (e.g., Shortreed and Stockner 1983). Higher numbers of grazers are sometimes correlated with an increase in fish abundance (e.g., Murphy *et al*. 1981, Bilby and Bisson 1992), and sometimes not (e.g., Tait *et al*. 1994). As riparian vegetation regrows, shade increases, until young and mature forest, without canopy gaps, shades the water completely. In these seral stages, shading discourages algal growth, with associated effects on stream fauna. In Oregon, streams in dense young forest have fewer insects and fewer trout than adjacent streams in oldgrowth (Murphy and Hall 1981).

Retaining strips of riparian vegetation can buffer disturbance effects on stream invertebrates. Studies have found no difference in the invertebrate communities of undisturbed streams and streams with 30 m buffers, but differences with smaller buffers (primarily decreases in populations of shredders and increases in populations of algal grazers; e.g., Newbold *et al*. 1980, Culp and Davies 1983), reflecting the shading effect of riparian vegetation (Figure 1). Aquatic invertebrate communities can recover from episodic disturbances fairly rapidly, recolonising by drift, flight, swimming or movement from underground water refuges (review in Hershey and Lamberti 1998). In a Washington stream, the community had almost fully recovered 2 years after removal of all invertebrates, entirely due to ovipositing adults from nearby streams (Whiles and Wallace 1995).

In narrow streams, when riparian vegetation is removed, summer water temperature increases, daily temperature fluctuation increases, and winter temperature can increase or decrease (Holtby 1988, Shrimpton *et al*. 1999). Cool water contains higher levels of dissolved oxygen and allows easier breakdown of organic wastes (Banner and MacKenzie 1998). Increased water temperature can decrease survival rates of sensitive fish and amphibians, increase growth rates, change patterns of migration, increase susceptibility to disease and/or increase competition with warm water species (Hartman and Scrivener 1990, Voller 1998). Again, effects are not easily predictable. For example, in Carnation Creek on Vancouver Island, although young salmon grew faster after riparian vegetation was removed, the number of adults returning to spawn decreased, possibly because quick-growing smolts migrated to sea early and suffered a lower survival rate (Hartman and Scrivener 1990).

Temperature increases are transmitted downstream (Shrimpton *et al*. 1999), and effects can accumulate when vegetation is removed from several streams simultaneously (Ringler and Hall 1975). Although no studies have investigated the impacts of canopy removal on temperature in the North Coast, temperature changes are likely between those found in Alaska (0.7°C/100m of opening; Meehan 1970) and those recorded in Carnation Creek (mean increase of 0.7 – 2°C between December and April; Holtby 1988). In the interior of BC, near Prince George, where the climate is warmer and drier than the North Coast, 10 m riparian buffers moderate, but do not prevent, rises in temperature (Shrimpton *et al*. 1999).

As riparian vegetation regrows, stream temperature declines and moderates. This change takes between four and 20 years, depending on stream size (Beschta et al. 1987). Biological recovery from changes in temperature depends on the magnitude of the increase relative to the sensitivity of organisms using the streams. In the North Coast, temperatures may remain below the threshold of sensitive organisms (e.g. tailed frogs) due to the cool climate (e.g. Dupuis and Steventon 1999).

Shade interacts with fine organic material, microclimate, and biodiversity (see discussion in sections below).

3.1.3 Fine Organic Material

Organic matter entering hydroriparian ecosystems from riparian vegetation supports the productive capacity of streams (Vannote *et al*. 1980, Wallace *et al*. 1997, Richardson 1991). Narrow streams often make up more than half of total stream length in a watershed (Richardson 1999), and are completely shaded by vegetation. Organic matter (dead leaves, needles and twigs, invertebrates, droppings) falling from this vegetation can provide more than 95% of the energy entering a stream (Fisher and Likens 1973).

Leaf input from deciduous trees and shrubs is highly seasonal, whereas input from conifers is spread throughout the year at lower levels. Herbs enter the water primarily during floods (Gregory *et al* 1991). Leaf particles must be retained within a stream to serve as food for most aquatic organisms. Large and small downed wood obstructs flow and saves organic matter from being transported downstream before it can be processed (Bilby 1981, Speaker *et al*. 1985, 1988). Retention is higher in smaller streams and in streams with rougher beds (Minshall *et al*. 1983). Many shrub and herb leaves are processed within 1 – 2 months, whereas conifer needles and deciduous leaves with waxy cuticles, e.g., aspen, willows, may last for 1 – 2 years (Gregory *et al*. 1991).

Organic input is most important in small streams. These streams support communities of aquatic invertebrates dominated by "shredders", that specialise in breaking down organic detritus (Vannote *et al*. 1980, Cummins and Merritt 1996). Removal of riparian vegetation may decrease and change the composition of organic input, leading to changes in invertebrate communities (e.g., Hachmöller *et al*. 1991). In Carnation Creek, removal of vegetation decreased litter input by 75%, and decreased litter retention (Hartman and Scrivener 1990).

Organic input interacts with downed wood, shade, biodiversity and transportation of organic material (see discussion in sections above and below).

3.1.4 Filtering

Riparian vegetation intercepts underground water and above ground sediment and debris (review in Naiman and Décamps 1997). Tree trunks, shrub stems, downed wood and site microtopography reduce the impact of sediment and debris moving down slopes into water. See Section 3.3.2, Transport and storage of sediment for impacts of sediment on organisms.

The roots of riparian vegetation and associated micro-organisms absorb and break down dissolved organic and chemical materials, reducing nutrient loads entering streams and lakes (Addiscott 1997, Bencala *et al*. 1993, Schmitt *et al*. 1999). Such filtering is an important function of riparian vegetation in agricultural areas, where fertilisers and pesticides applied to fields travel through underground water into hydroriparian ecosystems (Lowrance *et al*. 1984, Peterjohn and Correll 1984), and in watersheds managed for drinking water quality. In northern Vancouver Island, when nitrogen fertiliser was added to replanted forests, streams with 50-m buffers had 20 times less nitrogen than those without buffers; concentrations in control streams were even lower (Perrin *et al*. 1984).

The ability to filter sediment is an important function in the steep, unstable terrain of the North Coast, along streams, lakes and some marine shores (depending on shore type). Solute filtration (e.g. of chemicals and fertilisers) will likely be less important in the North Coast, because agriculture is almost non-existent and widespread use of fertilisers or herbicides on forests is unlikely (Allen Banner personal communication).

Filtering interacts with bank stability, transportation of sediment and organic material (see discussion in sections below).

3.1.5 Bank Stability

By binding soil, rock and organic material, riparian roots stabilise banks, reduce erosion and reduce sedimentation. Because trees withstand floods better than shrubs, they provide stability over longer periods. In the North Coast, this function is especially important on floodplains on smaller streams, and on steep slopes, where roots reduce the rate of lateral erosion or landsliding. On large valley-bottom floodplains, bank erosion is often below the main rooting depth; bankside trees are undermined and fall into the river. On fans, the trunks and roots of large trees play a particularly important role in intercepting and storing deposited sediments, in stabilising the fan, and in directing stream flow.

3.2 Influences of water on land

3.2.1 Ecosystem Productivity

Ready availability of water can increase or decrease ecosystem productivity. Water is in excess on most sites in the North Coast. In well-drained areas, water encourages a productive and diverse plant community, particularly in floodplains and fans. Conversely, in poorly-drained areas, water accumulates and promotes organic soil development with reduced nutrient availability, resulting in development of low productivity bogs and bog forests.

Water influences adjacent land through flooding over the surface, or flowing underground. Both flows carry nutrients important to the productivity of terrestrial ecosystems. The effect varies strongly among hydroriparian classes.

Floodplains are built from sediments carried from the upper parts of the watershed and deposited on the flat valley floor as a series of bench and bar landforms that are constantly eroded and rebuilt. Differences in elevation and location within the floodplain result in a variety of flooding and sedimentation effects, which in turn result in a range of plant communities and high species diversity over very short distances (Pollock *et al.* 1998). In the North Coast, the lowest benches and bars along channels are colonised by deciduous shrubs and trees, while those in backchannel areas support willow-sedge communities, and wetland types. The highest floodplain benches support forests dominated by very large Sitka spruce, western redcedar, western hemlock, and amabilis fir, with highly productive subcanopy shrub and herb communities that are important foraging areas for bears, birds, and ungulates. Deer and bears modify microtopography by browsing and trampling vegetation, and hence impact ecosystem productivity (Naiman and Rogers 1997). The high productivity on floodplains is a function of the nutrient-rich sediments deposited, abundant underground water and free drainage. Recently, fertilisation from decomposing salmon carcasses in floodplains has been implicated as an important factor in productivity (Ben-David *et al*. 1998; see section on transportation of organic material). Productive communities also develop on small floodplains in upper areas of the watershed, where gradients decrease and sediments can be deposited.

The composition and productivity of floodplain ecosystems is strongly impacted by the nature of flooding. Flooding leads to sedimentation, scouring, and bank erosion. Effects vary with the frequency, seasonality, and duration of floodwaters. The lowest floodplain benches along channels are inundated several times a year during any season, and also experience considerable erosion and sedimentation. Vegetation on low benches and bars traps sediment, causing the floodplain to expand horizontally and vertically. Backchannel and interlevee areas are often poorly drained, so that floodwaters are trapped and soils stay saturated for prolonged periods during the growing season. In these areas, wetlands and swamp forests are common. On the highest benches, overbank flooding is rare, and sediment is only deposited for a short distance into the forests along the banks. Sediment deposition away from the main channel is usually limited to a thin skin of silt and clay deposited in still water.

Fans are built from the deposition of materials moving off steep slopes on to the flat valley floor. Although these soil materials are usually quite coarse, providing few nutrients, underground water is abundant and provides a continuous supply of plant nutrients leached from watershed soils above. On richer, softer metamorphic rock, fan soils are very rich. As a result, fan ecosystems in the North Coast often support productive forests that are very similar in composition and structure to floodplain forests. In the Hecate Lowland, fans represent the most productive ecosystems because of deep, freely-drained soils and relatively recent disturbance history.

Although riparian vegetation strongly influences the structure and productivity of small steep streams, these streams may have limited impact on soil moisture and nutrient status of the adjacent riparian forest ecosystems, especially when flows are constrained within channel banks. Where channels are unconstrained, the highly variable flow periodically enriches adjacent land and leads to narrow bands of diverse vegetation and larger trees.

Wetlands develop where water accumulates on the landscape. The composition and structure of wetland ecosystems is affected by the duration of flooding and the chemical composition of the water (MacKenzie and Banner 2000, unpublished manuscript). The high rainfall and low rates of evapotranspiration in the North Coast mean that soils on all but steep slopes tend to be saturated year round. Because much of the North Coast bedrock is poor in mineral nutrients, organic soils accumulate as plants slowly decompose in the oxygen-poor environment, and bogs develop over thousands of years. Bogs and bog forests are abundant in the gentle terrain of the Hecate Lowland, covering more than 50% of the landscape. In some areas, due to the wet climate and underlying bedrock, bogs occur on slopes up to 60% (though more commonly, up to 30%; Kayahara and Klinka 1996). On steeper slopes, soils are well drained, hence organic materials do not accumulate and ecosystems are more productive. There is a tension between succession to forest or to bog that is sensitive to climate and disturbance. Fossil records suggest that bogs expand during cool, wet periods, and contract during drier periods (Mitsh and Gosseling 1993). Hydrological fluctuations likely also impact the direction of succession (Banner *et al*. 1983).

In the low productivity bog and forest mosaic of the Hecate Lowland, forest harvesting and road building may change ecosystem productivity: disturbance and mixing of organic and mineral horizons may increase tree productivity, while canopy removal and increase in soil water may decrease productivity. Removal of the forest canopy increases water reaching the ground by 22 – 30% (Maloney and Rysavy 2000), with many potential hydrological impacts (Maloney *et al*. 1999). Studies are currently underway examining the impacts of changing hydrology and disturbance from forest harvesting on ecosystem productivity (Banner *et al*. 1999)[1].

3.2.2 Microclimate

Water, and associated riparian vegetation, can affect the microclimate of the surrounding forest. Soil and air temperature increase with distance from water, while soil moisture and humidity decrease. These effects can extend for up to three tree heights (Figure 2). Plant growth, soil microbe activity and insect movement all depend on specific microclimatic conditions (Brosofke *et al*. 1997). Amphibians rely on moist, cool areas to breathe and avoid dehydration (Dupuis *et al*. 1995). A study in western Washington found microclimatic gradients around small (2 – 4 m wide) streams extending from 31 – 62 m from the stream (Brosofke *et al*. 1997). The authors found that harvesting interrupted or eliminated microclimatic gradients and concluded that undisturbed gradients would be maintained by buffers extending beyond riparian vegetation (more than 45 m wide in their study area). They also found that stream temperature was related more strongly to upland than to riparian soil temperature, perhaps because groundwater remains longer in the upland area.

With the exception of shoreline forests, microclimatic effects are likely less pronounced in the cool forests of the North Coast. For example, although rain levels were similar between the western Washington study (~1700 – 2800 mm/year[2]) and the North Coast (~1500 – 3000 mm/year), mean temperature in Washington was about 3°C warmer.

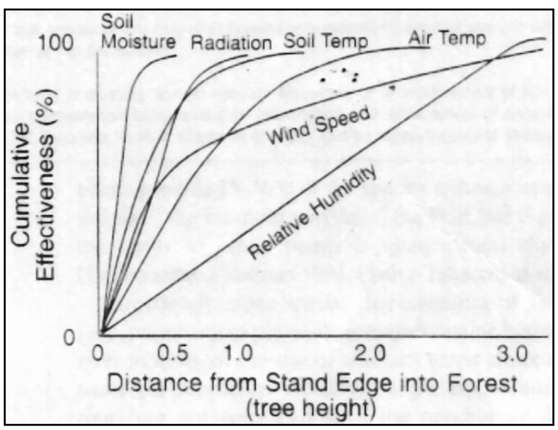

Figure 2: Distances over which water may affect terrestrial processes. From FEMAT (1993).

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[1] The HyP3 research project has been investigating the hydrology, ecology and productivity of low productivity bog forests over the past 4 years. Many of the results to date will be summarised in 2001 (Allen Banner, personal communication).

[2] Not reported by Brosofke *et al*. 1997. Calculated from the nearest weather stations providing Washington climate normals.

3.3 Landscape links

The characteristics of hydroriparian ecosystems are determined by movement and storage of water, sediment and organic matter (large downed wood and small particles), and by the landscape through which water flows (Church 1992). The upstream – downstream connection is much stronger for hydroriparian ecosystems than for upland ecosystems. The sections below discuss the movement of water, sediment, organic matter and organisms through the landscape.

3.3.1 Transportation and Storage of Water

Water enters hydroriparian ecosystems from precipitation, from ground water and from upstream. Input, and hence flow, varies seasonally. During spring snowmelt and fall storm season, flow increases, adding energy to the system and moving sediment and small and large organic matter downstream. High flows function to keep gravel free of sediment, providing habitat for invertebrates and vertebrates (CSSP 1995). Periodically, very high flows erode banks, move log jams and transport large amounts of sediment. These flows can change the nature of channels. In steep, fast-flowing streams, water cuts into the surface, forming gullies. In lower gradient streams, sediment carried by water is deposited in floodplains and fans. Cool water travels downstream from shaded headwater streams.

Water also links surface and underground ecosystems. The area of saturated sediment beneath the surface of hydroriparian ecosystems is an area of blending: land and water mix, and ground and surface water mix. Large populations of microbes living in this watery habitat with its cocktail of waters mean that streams with large underground water zones retain and process dissolved nutrients, and decompose waste, better than streams without (Naiman *et al*. 2000). The habitat volume underground may be many times the surface habitat volume (Stanford and Ward 1988).

In the North Coast, underground ecosystems below riparian red alder trees may retain pools of nitrogen fixed by bacteria growing in the alder roots (Cole *et al*. 1990, Triska *et al*. 1989). Because of the patchy nature of alder stands, available nitrogen may also be patchy (Fevold 1998). In south-eastern Alaska, streams with alder canopies provide more detritus and invertebrates to downstream communities (Wipfli 1997 and personal communication).

Underground water flow depends on surface roughness (riparian plants, large downed wood) and on buried wood. Changes in underground flow paths and water residence times can change oxygen concentration, water chemistry and food supplies (Naiman *et al*. 2000). Research into the importance of underground water is recent, and we could find no information directly pertaining to the North Coast.

Water transportation and storage within a watershed determines in large part the nature of hydroriparian ecosystems. Differences in relief and climate between the Outer Coast Mountains and the Hecate Lowland result in the very different hydroriparian ecosystems that dominate the two landscapes (see Tables 2a, 2b, 2c).

In the steep landscapes of the Outer Coast Mountains area, abundant rain either evaporates from the surface of trees or falls to the forest floor. Once on the forest floor, rainwater seeps into the upper soil organic layer and through lower mineral soil layers, where it may leach organic and inorganic chemicals from the soil. Soil water then moves downslope either along bedrock or compact surficial material, or along underground conduits, such as those formed by large roots. The underground flow breaks out of the soil as streamflow and forms the characteristic pattern of streams in a watershed.

The surface stream network expands in response to precipitation events and snowmelt in the watershed, and decreases as soils drain and baseflow is achieved. These groundflow-streamflow processes determine the distribution and flow characteristics of ephemeral, seasonal and perennial flows in a watershed (Figure 3). As water moves through watersheds, it may be stored for variable periods in soils, lakes and wetlands.

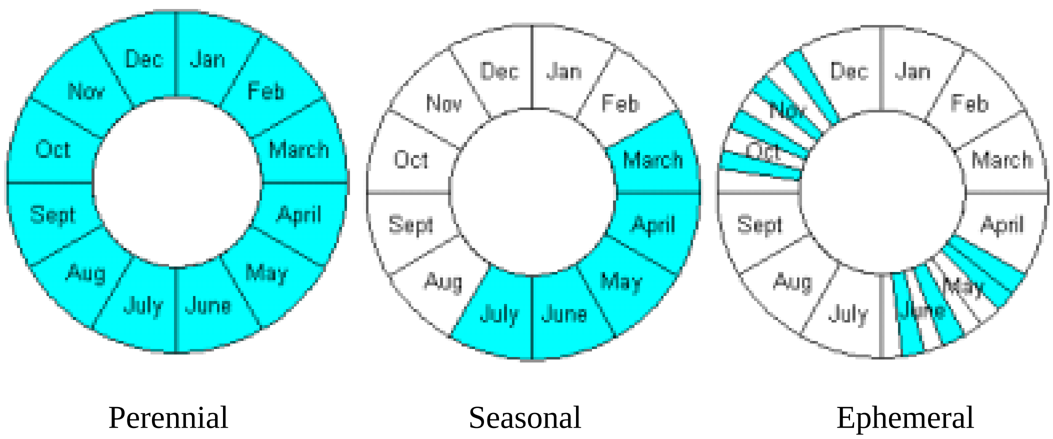

Figure 3: Schematic showing typical flow regimes for perennial, seasonal and ephemeral streams.

In the Hecate Lowland, the combination of very high precipitation, high humidity, cool temperatures, and low topographic relief means that water drains very slowly off the land. As a result, bogs have developed over extensive areas, retaining rainwater in the organic soils. Most soil remains saturated, accepting or releasing very little water after rainfall. Water can be stored for decades in bogs. Numerous lakes also store water.

Beavers change water flow and can flood areas, modifying productivity and habitats over time (Butler 1995, Pollock *et al*.1998).

Removal of the forest canopy decreases water interception and evapotranspiration and increases snow accumulation and snow melt, leading to increased soil water (22 – 30% more in the low productivity forests of the Hecate Lowland; Maloney and Rysavy 2000), overland flow and increased storm flow volume (Ziemer and Lisle 1998). Roads compact surfaces, intercept underground flow and increase overland flow, delivering water more rapidly to channels during storms and leading to earlier and higher peak flows (Ziemer and Lisle 1998). Increased water flow often leads to increased sediment transport (see Section 3.3.2. Transportation and Storage of Sediment). Although these effects are usually visible on hillslopes, evaluation of downstream effects becomes difficult in large watersheds due to statistical and physical reasons (Ziemer and Lisle 1998). Hydrological recovery time varies with effect. For example, evapotranspiration rates recover rapidly as vegetation grows over 5 – 10 years, natural levels of snow accumulation and melt take decades and the impacts or roads are nearly permanent (Ziemer and Lisle 1998). The combination of heavy precipitation and snow cover on the ground ("rain-on-snow events") is common in the Outer Coast Mountains, and results in very large pulses of water entering the drainage system.

3.3.2 Transportation and Storage of Sediment

Hydroriparian ecosystems are dynamic, continually shaped by hydrogeomorphic processes such as sediment and water flow regimes (Benda *et al*. 1998, Montgomery and Buffington 1998). Most sediment in the North Coast moves in debris flows, occurring when underground water saturates deep soil levels and reduces soil strength so that soil and vegetation slide downhill to hydroriparian ecosystems (Buchanan and Savigny 1989). Debris flows can also start in stream channels when high water levels break debris dams and allow collected sediment and organic material to rush downstream. The torrent of water, large wood and sediment scours stream channels (Naiman *et al*. 2000). Eventually, the debris is deposited in fans or lake bottoms.

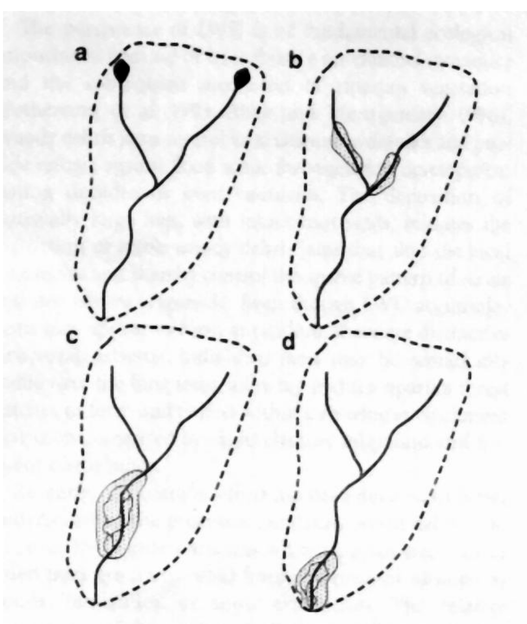

Figure 4: Movement of a sediment wedge through a stream network. From Montgomery and Buffington (1998).

Different areas within a watershed experience different types and frequencies of disturbance, and different recovery rates. Steep channels recover quickly because of their ability to transport materials. Lower gradient channels, where sediment accumulates, usually take longer to recover (Naiman *et al*. 2000). If sufficient sediment is introduced (perhaps from several simultaneous landslides), channel type may be modified. For example, riffle-pool channels can become braided reaches as sediment is deposited along lower gradient reaches (Naiman *et al*. 2000). Sediment deposits gradually move downstream like a wave (a 'sediment plug'), modifying the ecosystems as they move (Figure 4; Montgomery and Buffington 1998).

Recent models of geomorphologic processes (Montgomery 1999, Benda *et al* 1998) provide conceptual approaches to examining the effects of, and recovery from, disturbance. Such models could be applied to the North Coast, but would take considerable work. Generally, in the mountainous regions of the North Coast, steep slopes, in combination with the wet climate, create potential instabilities in soils. In many watersheds, the annual total amount of sediment moved occurs over a few significant events in the fall and winter when large storms deposit very high levels of precipitation (Rood 1984, Sidle *et al*. 1985). Avalanches also supply sediment to hydroriparian ecosystems in susceptible areas of the Outer Coast Mountains; blowdown supplies lesser amounts in susceptible areas throughout the North Coast. Major movement of sediment is limited by low relief in the Hecate Lowland. Individual landslides are common on steeper ground in the transition to the Outer Coast Mountains. Natural sediment rates in the North Coast, as determined from lake core samples of deep lakes in the Outer Coast Mountains and adjacent Kalum Forest District, are three times higher per unit area of catchment than further inland, reflecting the steep slopes and lack of flat basins (Beak-Aquafor 2000). Sediment input is highly variable and episodic, but shows an increasing trend over the last half century, independent of land use, matching a climatic trend of increasing precipitation over the same period (Beak-Aquafor 2000).

Increased levels of fine sediment deposition can clog stream gravel and impact stream invertebrates and young fish stages that depend on well-oxygenated gravel for habitat (Scrivener and Brownlee 1989, Tripp and Poulin 1986). Increased suspended and deposited sediment also impacts nearshore marine organisms, including herring, shellfish, other invertebrates, macroalgae and eelgrass (Johnson and Wildish 1982, Sushko and Freeman 1991, Newcombe 1994, Thayer *et al*. 1975, Morgan and Levings 1989, Austin 1996). Increased sediment input can result from natural disturbances as well as road construction and deactivation, forest harvesting and landing development in steep coastal watersheds (Rood 1984, Sidle *et al*. 1985, Howes 1987) as well as from fish farming (Naylor *et al*. 1998). Sediment input is episodic, generally following periods of intense rain. For example, in the Queen Charlotte Islands/Haida Gwaii, six storms transported 77% of the mass moved over the past 150 years (Schwab 1998).

Forest harvesting and road building increase the rate of land movement (reviews in Sidle 1985, Beak-Aquafor 2000). Across the Pacific Coastal Ecoregion (see Section 1.3), studies found landslide volume increased above undisturbed areas by 3 – 31 times in harvested areas and 10 – 87 times in roaded areas (Beak-Aquafor 2000). In the Queen Charlotte Islands/Haida Gwaii, following a 1978 storm resulting in 264 slides, slides occurred 15 times more per ha in clearcuts and on roads than in forests, disturbing 43 times more area (Schwab 1983). Debris torrents originating in clearcuts scoured seven times more stream bed than those originating in unmanaged forest (Schwab 1983). Similarly, in Clayoquot Sound, a 1996 storm led to 260 slides, with 86% starting in harvested areas (South Coast Ministry of Forests data, 1996). Data for the North Coast are not available to calculate impacts of development on slide frequency or extent (Jim Schwab, Bob Cuthbert, personal communication). Mean slide area is comparable between the Queen Charlotte Islands/Haida Gwaii (0.6 ha; Schwab 1988) and the North Coast (1.2 ha over the last 4 years, Bob Cuthbert, unpublished data). In general, the Hecate Lowland is less susceptible to landslides than Clayoquot Sound or west Queen Charlotte Islands/Haida Gwaii due to the gentler terrain, but the Outer Coast Mountains may be more comparable.

Slides occur more often after forest harvesting due to several reasons: as roots decay, soil strength declines (Buchanan and Savigny 1989); without canopy interception, more water reaches the soil; roads channel and redirect flow (Montgomery 1994). Debris flows can occur decades after harvesting (in Clayoquot Sound, the 1996 slides occurred in areas clearcut up to 40 years previously). Experience in coastal BC and SE Alaska shows that forest harvesting and road building on steeper slopes is more likely to cause landslides and increase sediment to streams (Kayahara and Klinka 1996). The chance of debris flows depends on several factors, including the area of the watershed harvested, proximity to hydroriparian ecosystems, soil type and terrain form.

Fans are particularly susceptible to movement of sediment when harvesting and road-building practices do not recognise hydrogeomorphic processes. In areas adjacent to the North Coast, recent research is finding that risks depend upon the natural frequency of disturbance (Dave Wilford, personal communication).

Increased sediment levels in coastal streams resulting from soil disturbance and road building last 6 – 10 years after forest harvesting (review in Scrivener et al. 1998). The impacts of debris torrents and bank erosion last longer as hillsides slide over time (review in Scrivener et al. 1998). Streams take from 5 – 60 years to recover from individual debris torrents (Sullivan *et al*. 1987, Hogan *et al*. 1998a).

3.3.3 Transport and Storage of Fine Organic Material

Fine organic material entering narrow streams from riparian vegetation forms the energetic base of hydroriparian food webs (Fisher and Likens 1973, Triska *et al*. 1982). Along with dissolved organic material in underground water (Neal *et al*. 1990), litterfall also provides important nutrients (Triska *et al*. 1984).

Organic particles are either decomposed by micro-organisms, fragmented by aquatic macroinvertebrates, physically broken down or leached and released as dissolved organic matter (Gregory *et al*. 1991). One group of aquatic invertebrates, “shredders”, breaks down coarse organic particles so that they become available to invertebrates further downstream that feed by filtering and gathering the fine particles. These organisms, in turn, become food for fish. Most organic particles once fragmented or dissolved (70 –

94% of input) travel downstream to enrich plant and animal communities in streams, lakes, wetlands and estuaries (Dieterrich *et al*. 1987, Richardson 1992). Experimental removal of aquatic invertebrates reduced leaf processing rates by 50 – 74% and reduced annual production of fine particulate matter to one third of pre-treatment levels (Cuffney *et al*. 1990), illustrating the importance of invertebrates to the hydroriparian food web. In nutrient-poor systems of south-eastern Alaska, headwater streams provide most of the aquatic and terrestrial invertebrates and detritus for downstream habitats—nutrients particularly important as fish food (Wipfli and Gregovich 2001). These streams are comparable to many systems in the North Coast.

Even tiny seasonally-flowing channels play a role. Seasonal channels (dry for a period, but with a stable source) in coastal BC support an equally diverse invertebrate community, and larger population of some species (Price *et al*. unpublished manuscript, Muchow and Richardson 1999), as continuous channels (flowing year-round). Ephemeral channels (flowing for a short period after precipitation), conversely, seem to support a less diverse community that is a subset of the community found in continuous streams (Price *et al*. unpublished manuscript).

Organic material does not just travel downstream; it is also deposited laterally during flooding (see Section 3.2.1, Ecosystem Productivity), leached underground (see Section 3.3.1, Transportation and Storage of Water) and carried upstream by fish, particularly spawning salmon. Salmon grow at sea and transport and deposit these nutrients in the streams where they spawn and die. High water flows deposit carcasses next to streams where they decompose and become available to plants. Dissolved nutrients may enter the underground flow and become available to plant roots. Scavenger and predators may carry salmon from the stream, and subsequent faecal matter may transport nutrients even further (Ben-David *et al*. 1998). In coastal temperate rainforests of Western Washington and Southeast Alaska, 18 – 25% of the nitrogen in riparian vegetation comes from the seas via salmon (Bilby *et al*. 1996, Ben-David *et al*. 1998). Plants up to 200 m from a channel can contain nitrogen originating from salmon. The role of salmon as food for a diversity of vertebrates in riparian areas is well-known: 40 species of birds and mammals in south-eastern Alaska and 22 species in Washington have been documented eating salmon (Cederholm *et al*. 1989, Willson and Halupka 1995). These vertebrates transport organic matter even further from “riparian zones”, adding to the link between land and water and to the extent of hydroriparian ecosystems.

In the North Coast, as elsewhere, narrow streams provide organic material to be fragmented by invertebrates and travel downstream. In the North Coast, where salmon populations are relatively healthy, return of organic material upstream is likely a bigger factor than in regions with reduced salmon populations.

3.3.4 Transport and Storage of Downed Wood

Downed wood modifies channel structure, flow and sediment deposition throughout river systems (see section on Downed Wood Input). It also provides habitat and food in all types of hydroriparian ecosystems from streams, through lakes and wetlands to estuaries and intertidal zones (Sedell and Maser 1994). Transport of structural pieces of wood downstream during times of high water flow links headwaters with downstream ecosystems. Wide channels contain fewer and bigger pieces of wood because small pieces move through wide streams more easily (Bilby and Bisson 1998).

In the North Coast, large logs move through the steep landscapes of the Outer Coast Mountains more readily than they move through the gentler slopes of the Hecate Lowland.

3.3.5 Plant and Animal Movement

Hydroriparian ecosystems serve as corridors for plant and animal movement (Gregory *et al*. 1991). Because of frequent natural disturbances, floodplain mosaics are particularly sensitive to invasion by opportunistic pioneer (i.e. weedy) species. These plants move along riparian zones rather than along upland routes (DeFerrari and Naiman 1994). In some coastal streams in Washington and Oregon, one quarter of species are exotic, covering three quarters of the ground (DeFerrari and Naiman 1994, Planty-Tabacchi *et al*. 1996). After disturbance, the number and cover of non-native plants decreases upon canopy closure. Development, particularly roads, near floodplains has the potential to introduce weeds that could travel along the floodplain. Due to isolation of much of the area (excepting the Skeena River corridor), there are likely fewer weedy, invasive species present on North Coast floodplains.

Some flying insects use riparian openings as travel corridors (John Richardson, personal communication). Many aquatic insects are weak fliers, emerging from one stream system and laying eggs nearby (although this research is outside the temperate rainforest; e.g. Griffith *et al*. 1998). These species travel up sections of streams, but usually do not travel across watershed boundaries, leading to high levels of endemism (John Richardson, personal communication).

Vertebrates travel up and downstream. Resident fish migrate along relatively short stretches of streams while anadromous fish can travel from headwater streams to the ocean and back (see Sections on Organic Movement; Fish). Some amphibian species stay near water their entire lives except during wet weather (e.g. tailed frogs; Sutherland unpublished manuscript), while others live in upland ecosystems, returning to water to breed. Insectivorous birds and bats forage over water and a variety of specialist and generalist birds and mammals use hydroriparian ecosystems for foraging, breeding and travelling (see Section 3.4, Biodiversity). Some organisms (particularly grizzly bears) travel large distances between hydroriparian ecosystems and other areas seasonally. Evidence for movement of terrestrial vertebrates along strips of riparian vegetation left after forest harvesting is sparse, limited to birds (Machtans *et al*. 1996).

3.4 Biodiversity

Hydroriparian ecosystems are rich and diverse, home to a variety of organisms, some generalists, some specialists. We discuss the importance of hydroriparian ecosystems to biodiversity in three sections: the Coarse Filter section describes the ecosystems and organisms in general, the Rare Communities section looks at special hydroriparian ecosystems, and the Listed and Special Species section describes individual species that may need to be considered at a fine filter level.

3.4.1 `Coarse Filter

Riparian forests contain the most diverse vegetation (floristically and structurally) of the coastal temperate rainforest (Pollock 1998). Spatial and structural heterogeneity created by flooding, debris flows, lateral river migration, downed wood, animal activity, productivity, landform and elevation create a mosaic of non-equilibrium ecosystems of various physical conditions and allow a large number of species to coexist (Pollack *et al*. 1998, Naiman *et al*. 2000). The diversity of forest ages, plant species, structural attributes, and proximity to water provides shelter and food for a diversity of animals (Bunnell *et al*. 1999, Kelsey and West 1998). Estimates of the proportion of terrestrial vertebrate species using hydroriparian ecosystems run from 50 – 75% (Bunnell *et al*. 1999, CSSP 1995, Morgan and Lashmar 1993).

Bryophyte (moss and liverwort) diversity is very high in coastal temperate rainforests. In the coastal forests of the US Pacific Northwest, bryophyte diversity was particularly high in riparian habitats, and five of eight rare species were limited to riparian areas (FEMAT 1993). In these same forests, many bryophytes did not become established until stands were >100 years old, and reached their greatest development in 400-year-old stands. A third of known rare bryophyte occurrences in BC are in the CWH zone (Ryan 1996). A small proportion of these reported occurrences are in the North Coast, but, until recently, there has been very little sampling done in the region (Ryan 1996). Current studies in the North Coast include an inventory of lichens, bryophytes and vascular plants in bogs and poor fens and a study of lichens and bryophytes living on western red cedar leaf scales[3]. Foliicolous (living on leaves) lichens and bryophytes are relatively rare in temperate latitudes, and, in Canada, are limited to the outer coast and waterfalls of western BC (Patrick Williston, unpublished manuscript).

Coastal temperate rainforests also have very high invertebrate diversity (Lattin 1990), although hydroriparian invertebrate communities are largely undescribed. Studies of canopy invertebrates in floodplain forests of Vancouver Island have identified new, and apparently rare or endemic species (Winchester and Ring 1999). The hydroriparian invertebrate communities living in hot springs and caves (ecosystems present in the North Coast) include uniquely adapted organisms (review in Scudder 1996). Communities of aquatic invertebrates change with stream persistence (seasonal and continuously flowing

[3] Three draft papers in progress. Contact Patrick Williston.

streams house different communities of insects; Delucchi and Peckarsky 1989, Price *et al*. unpublished manuscript) and with stream width (see Section 3.3.3, Transportation of Organic Matter).

A recent analysis of terrestrial vertebrates associated with coastal hydroriparian ecosystems summarises information for the North Coast and Central Coast area (Bunnell and Wahbe unpublished manuscript). About 90 species of terrestrial vertebrates (~53%) show strong affinities for riparian areas during the breeding season. Another 10 – 20 upland and inland species migrate to coastal riparian habitat in winter. Of the breeding species, most (53% CWH, 40% MH) show no preference for a particular stand age, but many show affinities for particular habitat elements including deciduous trees or shrubs (37%), edge (37%), conifers (21%) and cavities (24%). Only one of the cavity nesters is able to excavate its own hole; others rely on natural cavities. Of species showing a preference for a particular stand age, 16% prefer old forest (>140 years), 29% prefer mature and old forest (>100 years) and 16% prefer young forest (< 20 years); 2% prefer mid-seral stages (60 – 100 years) provided that they are primarily deciduous. Bunnell and Wahbe note that many habitat associations are based on anecdotal evidence.

Wildlife communities vary with hydroriparian class and ecological attributes. Although some vertebrate specialists (e.g. amphibians, some birds) use small headwater streams, species richness tends to be higher downstream (Kelsey and West 1998). Bird community diversity increases with river size and with the percentage of deciduous trees at a site (i.e. with extent of floodplain; Lock and Naiman 1998). In a river in western Washington, bird and small mammal diversity increased with availability of woody debris piles (Steel *et al*. 1999). A few species prefer wetlands and bogs; others are associated with forests near the sea (Bunnell and Wahbe unpublished manuscript). A variety of vertebrates use lakeshores and marine shores. Nearshore subtidal and intertidal hydroriparian ecosystems are disproportionately important for marine organisms. Estuaries, at the interface of land, fresh water and sea water, are particularly productive ecosystems, and are used by 80% of all coastal wildlife species (MacKenzie et al. 2000), including several rare and endangered species (see Section 3.4.3, Listed Species).

A recent reconnaissance of 18 selected estuaries in the North Coast classifies each estuary by its form and vegetation, and lists the importance of each to waterfowl, grizzly bears, salmonids, herring, eulachon and shellfish (MacKenzie *et al*. 2000). Juvenile salmon, particularly chum and chinook, use estuaries to forage (abundant food leads to high growth rates; Healey 1982), to undergo the transition from fresh to salt water, and to hide from predators. Herring and eulachon spawn in some north coast estuaries (MacKenzie et al. 2000). Waterbirds congregate in estuaries during herring spawning to eat roe; millions of birds migrating along the BC coast depend on estuaries for food and subsequent breeding success (Savard and Kaiser 1982). Waterbirds also use estuaries in winter. The Skeena complex of wetlands has been identified as having provincial and national significance for breeding, migrating and wintering waterfowl (Hayes *et al*. 1993). A variety of large and small mammals inhabit estuaries, including grizzly bears.

Although many vertebrates use hydroriparian ecosystems, little is known about the use of strips of riparian vegetation left after forest harvesting. Some studies have examined the use of buffer strips by songbirds in eastern BC and the US. These studies conclude that reserve zones from 25 – 175 m (depending on the study) are necessary to maintain songbird diversity near pre-disturbance levels (e.g. Spackman and Hughes 1995, Croonquist and Brooks 1993, Kinley and Newhouse 1997). As expected, forest interior species are lost first (Thurmond *et al* 1995). Studies are beginning in Washington and Oregon observing wildlife in buffer strips (Kelsey and West 1998).

3.4.2 Rare ecosystems

The Conservation Data Centre (CDC) lists 13 rare plant communities that occur in the North Coast Forest District (Appendix 2). All are oldgrowth forests, and all are components of the hydroriparian ecosystems described in Tables 2a, b, and c. CDC-listed ecosystems are considered rare for two reasons: they are naturally rare on the landscape, or they have been disturbed preferentially, so that they are now rare. In the North Coast, shoreline forest ecosystems are naturally rare, while floodplain and fan ecosystems have been preferred targets of forest harvesting throughout BC because of their accessibility and productivity. Thus, as a result of being specifically targeted for harvesting, most of those oldgrowth fan and floodplain ecosystems that remain are considered rare.

Shoreline forests are an important group of rare ecosystems in the Hecate Lowland . Some occur in a narrow band on windward shores, where salt spray and related climate effects result in unique plant communities dominated by Sitka spruce. Others are related to soil conditions unique to estuaries. Shoreline forests are important components of the shoreline hydroriparian ecosystem in the Hecate Lowland. Two of the remaining three listed rare ecosystems in the Hecate Lowland are floodplain and fan ecosystems. The remaining listed ecosystems occur on base-rich bedrock, including metamorphic rock and limestone (and hence include karst ecosystems).

Although not rare in the North Coast, the extensive blanket bog mosaic is unique globally (Banner and MacKenzie 2000).

3.4.3 Listed Species and Species of Interest

A complete description of the biology and behaviour of listed species using North Coast hydroriparian ecosystems falls outside the scope of this project—other projects will be providing details. Here, we provide a short summary of information about the hydroriparian habitat requirements for each species where known.

<u>Listed Plant Species</u>

Twenty-two plant species are identified as red- or blue-listed by the CDC for the North Coast Forest District (Appendix 3). Of the 22 species listed, 16 use hydroriparian ecosystems as habitat. This emphasises the important role hydroriparian ecosystems play as repositories of watershed biodiversity.

Fish

All five species of Pacific salmon (sockeye, coho, pink, chum, chinook), as well as trout (anadromous and resident), char, eulachon, sturgeon, burbot, whitefish, herring, sculpins, minnows and sticklebacks use the ocean, estuaries, rivers and/or streams within the North Coast. Various fish species move from freshwater to estuary to marine ecosystems at different times, demonstrating the functional linkage between these ecosystems. Salmon depend on a freshwater environment for reproduction and on a marine environment for growth. Because of their unusual life history, salmon play an important ecological role in hydroriparian ecosystems, returning nutrients upstream (see Section 3.3.3, Transportation and Storage of Fine Organic Material).

There has been considerable research on the habitat requirements of fish on southern Vancouver Island and the Queen Charlotte Islands/Haida Gwaii (e.g. Hogan et al. 1998b). Principle requirements are for stable, diverse channels with downed wood (see Section 3.1.1, Downed Wood) and for clean gravel for spawning (see Section 3.3.2, Transportation and Storage of Sediment).

Escapement data (representing the number of adult salmon returning to spawn) provide a picture of salmon abundance by watershed over time. The Skeena River, a huge watershed extending for hundreds of km inland, supports millions of salmon (0.5 – 3 million from 1994-1999[4]; Ministry of Environment, Lands and Parks 2000). The Nass River (estuary within North Coast) and some smaller coastal watersheds (Kwinamass River, Kitkiata River) also support hundreds of thousands of salmon (MacKenzie *et al*. 2000). Pink salmon are most abundant. Sockeye salmon are abundant in the Skeena and Nass systems, but uncommon elsewhere. Populations of coho, chum and chinook are relatively low (thousands to tens of thousands; MacKenzie *et al*. 2000).

Juvenile coho and chinook salmon live in streams for several months after emergence; some coho use very small even ephemeral streams and ponds during winter to escape from storms (Hartman and Brown 1987, Scrivener and Tripp 1998). Juvenile sockeye live in lakes; chum spawn close to the ocean. Kokanee spawn near lake shores.

Cutthroat trout (*Oncorhynchus clarki*; blue-listed) have varied life-histories (papers listed in Haas 1998); some are resident in small high-gradient streams, others migrate to the ocean. Genetic variability among populations is high (Haas 1998). Cutthroat trout are sensitive to disturbances that alter habitat, pollute water, add sediment, increase angling access or increase risks of hybridisation (Haas 1998).

Bull Trout (*Salvelinus confluentus*; blue-listed)[5] can live in small, high gradient headwater streams, large rivers and/or lakes (Cannings and Ptolemy 1998). They live in cold water and eat aquatic insects and fish. They are very selective about spawning sites,

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[4] Analyses of escapements within the North Coast until 2000 are currently being analysed and will be provided to the LRMP table elsewhere.
[5] Bull trout will be included in a "Managing Identified Wildlife Guidebook" (in preparation).

requiring clean gravel and cobble substrates and deep pools or overhead cover (McPhail and Baxter 1996). They often use high gradient small streams for spawning. Genetic variability among populations is high, suggesting the existence of distinct stocks (McPhail and Baxter 1996). Bull trout populations are sensitive to disturbances that change temperature, substrate, habitat complexity, channel stability, that create migration barriers or that increase risks of extirpation (Rieman and McIntyre 1993). Although bull trout are listed in the North Coast by the Conservation Data Centre, their existence within the planning area is currently unconfirmed.

Dolly Varden Char (*Salvelinus malma*; blue-listed) live in cold streams and have varied life histories, some are resident in small streams, others migrate to the ocean (Haas 1998). Separation of Dolly Varden and bull trout is difficult. Dolly Varden are sensitive to disturbances that alter habitat, pollute water, increase angling access, increase risks of hybridisation.

Eulachon (*Thaleichthys pacificus*; blue-listed) share an anadromous life history with salmon, migrating from the sea to gravel beds for spawning. Like salmon, eulachon transport marine nutrients to terrestrial ecosystems and have fed First Nations populations for centuries. Little is known about eulachon biology[6]. Populations appear to be declining (Lewis 2001).

Tailed Frog (*Ascaphus truei*)

Tailed frog (blue-listed) tadpoles spend 3 – 4 years in small streams (0.5 – 15 m wide; review in Sutherland unpublished manuscript[7]) before metamorphosing. They live in steep (30 – 70%; Dupuis and Bunnell 1997), fast-flowing headwater streams, holding on to rocks with suckers and feeding on diatoms (non-filamentous brown algae). They live in streams with cool (5 – 18.5C), clear water and step-pool habitat (Brown 1975, Dupuis and Steventon 1999). Fish eat tadpoles; hence tadpoles are usually found above barriers to fish movement (Grant Hazelwood, personal communication). Little is known about the lives of adult frogs. They require moist, cool habitat, and only move away from riparian vegetation during wet weather (Sutherland unpublished manuscript).

Portland Canal and the Nass River form the northern limit of tailed frog range (Dupuis *et al*. 2000). Tailed frog distribution is influenced by geology: sedimentary rock breaks into finer fragments than granitic rock, increasing sedimentation and decreasing habitat suitability (Sutherland and Bunnell 1999). The fine sedimentary rock underlying the Nass Basin may prevent migration northward (Dupuis *et al*. 2000). Populations are smaller and more scattered in the North Coast than in neighbouring Kalum District, perhaps because of the high rainfall in the North Coast. Tailed frog tadpoles may be washed downstream during storms, likely decreasing survival. In addition, because summers are cooler in the North Coast, tadpoles may take longer to metamorphose. This added time in streams increases the probability that a tadpole might experience a debris slide or be washed

[6] A variety of research is starting, stimulated by the decline in eulachon runs. The Eulachon Conservation Society has a list of potential threats and research needs (Lewis 2001).

[7] A review of all tailed frog literature is currently in draft form. Contact Glenn Sutherland, Centre for Applied Conservation Biology, UBC.

downstream (Dupuis and Bunnell 1997). Within the North Coast, populations decrease towards the coast. No tailed frogs have been found on the outer edge of the Hecate Lowland, perhaps because streams are slow and vulnerable to high temperatures and algal blooms in summer (Dupuis and Bunnell 1997).

Tailed frog tadpoles are sensitive to disturbances that increase sedimentation (fine sediment decreases available food, hampers respiration, fills substrate interstices), change cover, aeration and flow patterns associated with downed wood, and change exposure to sun (Murphy and Hall 1981). In northern populations in the Hazelton Mountains, streams logged to the bank less than 15 years ago had more sediment, more organic matter and more downed wood than streams with buffers and than unlogged streams. The logged streams contained significantly fewer tailed frogs (Dupuis and Steventon 1999). A Washington study found that tadpoles declined even when buffer strips were left (Kelsey 1995 thesis cited in Kelsey and West 1998). In southern BC, territorial use by adults is more restricted in clearcut than in oldgrowth sites (Wahbe *et al*. 1999). If disturbance extirpates a local population, recovery may be slow as long-distance dispersal is rare (Daugherty and Sheldon 1982); populations show strong genetic differences among streams (review in Sutherland unpublished manuscript).

Birds

Western grebes (*Aechmophorus occidentalis*; red-listed), winter in sheltered waters of lagoons and estuaries, and congregate to feed on spawning herring (Campbell *et al*. 1990, MacKenzie *et al*. 2000).

Pelagic cormorants (*Phalacrocorax pelagicus*; red listed), *pelagicus* subspecies (northern subspecies), breed on cliffs in the inner and outer coast and forage in lagoons and bays (Campbell *et al*. 1990).

Great blue herons, (*Ardea herodias*; blue-listed) *fannini* subspecies (coastal subspecies) use a variety of freshwater and marine ecosystems including sheltered bays, lagoons, inlets, wetlands and rivers (Campbell *et al*. 1990). Some pairs breed near Prince Rupert, the most northerly records in BC.

Most of the world's population of trumpeter swans (*Cygnus buccinator*; blue-listed) breeds in Alaska and winters in BC (Campbell *et al*. 1990). Trumpeter swans use North Coast estuaries in winter (MacKenzie *et al*. 2000).

Brants (*Branta bernicla*; yellow-listed) have drastically declined as a wintering species in BC (Campbell *et al*. 1990). They use estuaries, lagoons and beaches in the North Coast (MacKenzie *et al*. 2000), in spring and summer (likely non-breeding birds).

Harlequin ducks (*Histrionicus histrionicus*; yellow-listed) use freshwater and marine ecosystems (Campbell *et al*. 1990). They are most often found in turbulent waters around rocky islands, but also use estuaries, lagoons and inlets (MacKenzie *et al*. 2000).

Surf scoters (*Melanitta perspicillata*; blue-listed) use freshwater and marine ecosystems. Large numbers of scoters use North Coast estuaries during migration. 300,000 were recorded at Big Bay (south of Lax Kwa'alaams on the Tsimpsean pensinsula) during herring spawning in 1975 (Martin 1978 in Campbell *et al*. 1990), estimated to be about half of the North American population.

Two-thirds of the global population of bald eagles (*Haliaeetus leucocephalus*; blue-listed) live in BC and Alaska (review in Campbell *et al*. 1990). Bald eagles eat fish and hence are associated with hydroriparian ecosystems, including seashores, lakes, rivers and wetlands. They nest in large trees with unobstructed views and nearby food sources. In winter, eagles roost in large conifers, preferring areas near to salmon streams and away from human activity (Campbell *et al*. 1990). Bald eagle nest sites were inventoried in portions of the North Coast in 1998 (Giguere 1998).

The northern goshawk (*Accipiter gentilis ssp. laingi* (red-listed) prefers older forests for nesting and foraging and uses a wide variety of habitats, including rivers, lakeshores, lagoons, coasts, estuaries and islands (review in Campbell *et al*. 1990).

The peregrine falcon (*Falco peregrinus*), Peale's subspecies (blue-listed), is a marine falcon, resident in the North Coast. Peregrines use beaches, tidal flats, islands, estuaries and lagoons—areas that support shorebirds, waterfowl and other birds for prey (Campbell *et al*. 1990). They nest on cliffs and trees on islands.

The gyrfalcon (*Falco rusticus*; blue-listed), although primarily a northern bird of open country, uses areas with congregations of waterbirds (including islands, lakeshores, tidal flats, wetlands) in winter (Campbell *et al*. 1990).

Sandhill cranes (*Grus canadensis*; blue-listed) breed in isolated wetlands and meadows and use shallow wetlands and estuaries for roosting and feeding (review in Campbell *et al*. 1990). They use the coastal islands of the North Coast in spring, summer and fall.

Marbled murrelets (*Brachyrhamphus marmoratus*; red-listed) forage for sand lance, herring and salmon fry in inlets, estuaries and lagoons, as well as in exposed ocean (Campbell *et al*. 1990). They nest in large trees with mossy platforms adjacent to openings (Chatwin *et al*. 1999). Although floodplain forests seem the ideal site for such trees, murrelets also nest in high elevation forests (Hull 1999); high predator populations in floodplain forests decrease habitat value (Burger 1995, Nelson and Hamer 1995).

Three quarters of the world's population of ancient murrelets (*Synthliboramphus antiquus*; blue-listed) nest in colonies on the Queen Charlotte Islands/Haida Gwaii (Campbell *et al*. 1990). There is evidence of birds breeding within the North Coast, on the Moore Islands. Ancient murrelets nest in burrows in forests, usually in moss beneath roots or downed wood. Burrows can be as far as 500 m from shore. Nonbreeding birds usually avoid protected waters.

Cassin's auklets (*Ptychoramphus aleuticus*; blue-listed) are rarely found close to land outside of the breeding season (Campbell *et al*. 1990). They nest in burrows in colonies on islands. Unlike ancient murrelets, breeding colonies rarely extend far into forest.

Rhinoceros auklets (*Cerorhinca monocerata*; yellow-listed) nest colonially in burrows on islands (Campbell *et al*. 1990). Two of the six known clusters of breeding colonies lie within the North Coast (Lucy and Rachael Islands, and Moore Islands). Burrows can be up to 180 m inland, in grassy or forested ecosystems.

Tufted puffins (*Fratercula cirrhata*; blue-listed) nest mostly on treeless islands and prefer outer coastal waters when not breeding (Campbell *et al*. 1990). Tufted puffins are susceptible to disturbance while breeding, vulnerable to oil pollution and depend on sand lance populations.

Very few horned puffins (*Fratercula corniculata*; red-listed) breed in BC (Campbell *et al*. 1990 list only one confirmed breeding location). Nonbreeding birds prefer open marine environments.

Short-eared owls (*Asio flammeus*; blue-listed) hunt in open habitats, including wetlands, estuaries, lakeshores, beaches and lagoons (Campbell *et al*. 1990). They are not recorded as breeding in the North Coast.

Fishers

Fishers (*Martes pennanti*; blue-listed) are suspected, but not confirmed, to live in the North Coast. Fishers breed in large trees in floodplain forests (Don Reid, personal communication).

Grizzly Bears

Grizzly bears (*Ursus horribilis*; blue-listed) in the north coast prefer certain habitats within each season for feeding and sleeping (Hamilton and Bunnell 1986, MacHutchon *et al*. 1993). Bears select valley bottom floodplain and fan ecosystems (generally inland of the CWHvh2; Outer Coast Mountains) for foraging because of the abundance of berries and forbs, and the proximity to fish. Skunk cabbage is an important food and grows in poorly drained depressions on floodplains, commonly adjacent to the valley wall or at the toes of fans. Back-channel sedge fens also provide seasonal foraging on floodplains. Estuaries are important for early spring foraging and again during salmon spawning.

4.0 Management Practices

4.1 History of Riparian Management Practices

Forest management practices in riparian areas in British Columbia have evolved considerably since the onset of harvesting in the North Coast Forest District. Before 1970, no particular consideration was given to riparian areas, and the North Coast bears this legacy in drainages where stream courses were used to yard logs (Dave Wilford, personal communication). In some cases, changes in stream morphology from instream yarding were sufficient to cause a change in salmon species using the drainage (Greg Rawling, personal communication.). Although the impacts of early harvesting on aquatic ecosystems and fish habitat were often severe locally, the regional impact was quite low because of the limited area being harvested at that time (e.g. 202 ha harvested in the 1930s, 457 ha in the 1940s). In the 1970s, the impacts of forest harvesting on stream environments were being studied at Carnation Creek on Vancouver Island (Hartman and Scrivener 1990) and in the Pacific Northwest region of the US (Krygier and Hall 1971). One documented effect was the potential for clearcut harvesting over a considerable portion of the watershed to alter hydrologic flows, load streams with logging debris, and increase lateral erosion on channels (Rothacher 1971, Swanston 1971). This increase in awareness in the 1970s led to the Coastal Forest Management Guidelines where reference was made to opening size and rate-of-cut as it may effect watershed hydrology and aquatic ecosystems (Dave Wilford, personal communication).

The 10 year results of work conducted in Carnation Creek on Vancouver Island (Hartmann 1982) was followed by development of the British Columbia Coastal Fisheries/Forestry Guidelines in 1988. The objective of the guidelines was "to help integrate fisheries and forest resource management in coastal British Columbia." The guidelines reflected an increased awareness of the direct and indirect impacts of forest harvesting on fish habitat. A stream reach classification system (Class I-IV) was developed to identify the most important fish streams, rate-of-cut recommendations that no more than one-third of a whole watershed could be harvested over a 25-year period, and specific recommendations for roads and landings, falling and harvesting and silviculture were presented (Toews and Wilford 1978).

In the Coastal Fisheries/Forestry Guidelines, fall away/yard away recommendations were intended to keep logging debris out of streams, prevent damage to banks, and prevent destabilisation of large organic debris in the stream, i.e., to create a streamside management zone that would retain some riparian function. Streamside management zones were intended to maintain riparian vegetation, streambank stability, and a future source of large woody debris to the stream. Streamside areas were to be equal to the channel width on both sides of the stream, to a minimum of 10m and a maximum of 30m. In the streamside area, selective tree removal could only occur beyond 10m of the streambank; provided the original structural and functional characteristics of the original stand were maintained and site disturbance was minimal. Retention of trees was recommended in the streamside management zone on small, steep streams where tree roots and large organic debris maintained stream bank stability and channel morphology. The guidelines also recognized fisheries sensitive zones, fish windows, torrented gullies, and specific recommendations for silviculture.

An inspection of coastal cutblocks (126 randomly selected cutblocks over eight Forest Districts) between 1988 and 1992 found no evidence that logging practices had changed with the introduction of the Coastal Fisheries/Forestry Guidelines and found that impacts to streams declined considerably with increased compliance (Tripp 1998). Most impacts resulted from poor harvesting (leading to debris torrents) rather than from poor road building (Tripp 1998). In streams with fisheries concerns surveyed in the North Coast, 50% of fish-bearing streams and 100% of the non-fish-bearing streams had moderate or major impacts (Tripp 1998).

An administrative review by Keith Moore identified the need for training (Dave Wilford, personal communication). Subsequently, about 10,000 people received training.

The Coastal Fisheries/Forestry Guidelines were replaced by the Forest Practices Code Act in 1995, and many of the concepts of the Coastal Fisheries/Forestry Guidelines were included in the Timber Harvesting Regulations and Operational Planning Regulations of the Act.

4.2 Overview of Current Riparian Policies

Existing riparian policies vary considerably among jurisdictions. For example, in 1995, a comparison of 15 jurisdictions from North America, Europe and Australia found practices ranging from minimal protection, to lengthy sets of requirements (Westland Resources Group 1995). The policies most relevant to the North Coast LRMP include those from coastal forests in western Washington State and south-eastern Alaska, as well as US federal policies on coastal forest. Washington and Alaska revised their regulations in 1999. The recommendations of the Clayoquot Sound Scientific Panel (CSSP 1995) are also relevant[8]. The following section will summarise current management practices in BC (Forest Practices Code "FPC" and Clayoquot Sound Scientific Panel "CSSP"), Alaska (state and private) and Washington (federal and state).

In south-eastern Alaska, regulations focus on protecting fish habitat and slope stability (Alaska 2000). On state land, water bodies used by anadromous fish, or of high value to resident fish (<8% gradient), have 100 m riparian management areas. No harvest is allowed within 30 m of the water; harvest in the remaining 70 m must be consistent with maintaining important fish and wildlife habitat. Next to tributaries to fish streams,

[8] The Clayoquot Sound recommendations are currently being considered by the Central Coast LRMP and by the Tlell LRUP; Fred Bunnell, personal communication.

harvesting must meet slope stability standardss. No details are provided. On private land, all alluvial streams <8%, wetlands, lakes and estuaries have 20 m reserves. Around all water bodies, harvesting must comply with slope stability standards within 15 – 30 m (depending upon classification).

Regulations for western Washington aim to protect and restore riparian functions and features (Washington State 1999). On forested land (including private land, with some exemptions), regulations define reserves around all streams, wetlands, lakes and marine shores. Marine shores and hydroriparian ecosystems with a slight, moderate or high value to fish, wildlife or people have a riparian management area extending to one site-potential tree (30 – 70 m depending on site). The management area is divided into a 17-m no-harvest "core", and an "inner" and "outer" zone (with variable widths depending on site and management plans). Management direction is to leave a desired density of trees in the inner zone to protect a variety of ecological functions and to leave ~ 40 trees/ha in the outer zone for wind firmness and downed wood input. All other hydroriparian ecosystems (with continuous or seasonal flow) have 10-m reserve zones. Sensitive sites on tributaries to the systems described above have 17-m reserve zones. These sensitive sites must total more than half of the tributary length. No harvest is allowed on fans. Stream initiation points and intersections are protected by 30 x 30 m reserves.

US federal regulations for the Pacific Northwest were based on the FEMAT (1993) recommendations developed following concern over the spotted owl. They require wide reserves around all hydroriparian ecosystems (Westland Resource Group 1995). For example, seasonal streams without fish have 30 m reserves; streams with fish (continuous or seasonal) have reserves of 100 m or more on each side (two site-potential trees). Reserves are widened to incorporate ecological boundaries (e.g. 100 year floodplains, riparian vegetation, more productive sites).

The Clayoquot Sound Scientific Panel designed recommendations to ensure the sustainability of forest harvesting in Clayoquot Sound (CSSP 1995). Their report emphasises the connectivity of entire drainage systems and the necessity of considering the entire hydroriparian zone. They classify streams based on channel type (alluvial or not), gradient (<8%, 8 – 20%, >20%), entrenchment and stream width. Lakes are defined as nutrient rich or poor and further divided by shore features. Wetlands are classed by type and marine shores are classed as adjacent to open or protected waters and then by shore features. Panel recommendations require reserve zones around all but ephemeral channels and channels contained by stable rock banks. Reserves vary from 20 m around small, steep headwater streams to 50 m or more (to the edge of the contemporary floodplain) around low gradient streams > 3 m wide. Marine shores are given 100 – 150-m reserves depending on their exposure and shore height. 50 m represents one site potential tree height in Clayoquot Sound.

The BC Forest Practices Code (FPC; BC 1995) aims to protect riparian function. It bases its classification and subsequent management primarily on protection of fish habitat and community water supplies. Streams are classed first by presence/absence of selected fish species and then by channel width. Riparian management areas vary in width across stream types, although the FPC also defines management areas based on ecological relevant boundaries such as flood plains and slope breaks. Small streams, and streams without fish, have no reserve zones, but have 20 – 30-m wide management zones where from 5 – 25% of trees are retained. Bigger streams with fish have 20 – 50 m reserves and 20 m management zones with 50% retention. Management areas around wetlands and lakes vary from 10 – 50 m based on the size of the wetland or lake. The extensive bog complexes of the North Coast do not require management areas. Although streams on fans are buffered, the fans themselves are not treated as special geomorphic landscape units. Forested swamps (canopy cover >15%) are not protected. Designated Marine Sensitive Zones, primarily fish and shellfish habitat, are offered some protection, but do not require management areas. Other marine hydroriparian ecosystems are unprotected.

Management emphasis varies among jurisdictions. In Alaska, slope stability and fish are the only stated concerns; the FPC and Washington State regulations both list a variety of important riparian functions, but base classification and management primarily on the presence or absence of selected fish species. Only the Clayoquot Sound Scientific Panel bases classification on ecosystem units.

The ecological relevance of defined management zones also varies among jurisdictions. In Washington (federal and state regulations) and in Clayoquot Sound, the height of a site potential tree is considered an important indicator of the extent of the influence of land on water. Floodplains are considered important indicators of the extent of the influence of water on land and of biodiversity in Washington and BC (FPC and CSSP). Definitions of floodplain reserves, differ: in Washington, federal regulations require a reserve to the edge of the 100 year floodplain; Clayoquot Sound recommendations require a reserve to the edge of the contemporary floodplain; the FPC requires a management area (but not reserve) to the edge of the active floodplain (flooding more than once every five years).

Slope breaks are considered indicators of the influence of the land on water in BC (FPC and CSSP) and Alaska, although in BC they are used to extend prescribed management areas, while in Alaska, they can be used to reduce management areas. Regulations in Washington and Clayoquot Sound acknowledge landscape links; those in Alaska and the rest of BC do not. Because of this recognition, or lack thereof, small, non-fish bearing seasonal streams are considered worthy of protection in Washington and Clayoquot Sound, but not in Alaska or elsewhere in BC.

These differences in policy do not reflect different ecological situations in the different jurisdictions, but rather reflect the risks a jurisdiction is willing to take (Peter Tschaplinski, Andy MacKinnon, personal communication). For example, in Washington, riparian reserves on federal land extend for two tree heights whereas management areas on state land extend one tree height.[9] Thus riparian regulations vary with jurisdiction and are evolving rapidly, as understanding of the ecology and functions hydroriparian ecosystems expands.

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[9] Scientists from a variety of disciplines in the US PNW and BC will be meeting in December 2001 to discuss a cross-jurisdictional scientific base for riparian management, focussing on small streams. Contact Peter Tschaplinski or Andy MacKinnon.

Since the Protected Areas Strategy (RPAT 1996), protected areas have also played a role in protecting representative ecosystems and special features within BC (as they have in other jurisdictions). Parks also provide opportunities for public recreation, and park policies strive to identify appropriate levels of recreation that meet conservation goals. Current representation goals focus on representation by biogeoclimatic variant, but also consider other values, including hydroriparian ecosystems. Parks sometimes include intact watersheds, but more often protect hydroriparian sub-systems. Although hydroriparian ecosystems were considered as part of the analysis of protected areas in the North Coast (RPAT 1996), the inventory available at the time did not allow for detailed examination. The North Coast contains one large protected area, the Khutzeymateen Grizzly Sanctuary, designed specifically to protect a hydroriparian ecosystem and its organisms (particularly grizzly bears).

5.0 LRMP Strategic Planning Issues

Hydroriparian ecosystems often exist in areas of shared interest, with associated issues for planning and management of resources. Because of their extent and position in the landscape, hydroriparian ecosystems and productive, accessible forests overlap. Valley bottoms in steep landscapes contain hydroriparian ecosystems and also provide the easiest locations for road building and access to the largest timber. Because of their diversity and attractive scenery, many hydroriparian ecosystems have high potential as recreational areas. Hydroriparian ecosystems were and are important to First Nations peoples and often have cultural sites.

Section 5 presents a set of strategic planning issues that the LRMP table may want to consider. Each issue is followed by a short rationale refering to earlier sections of the report for details.

5.1 General Principles

5.1.1 Management Objectives for Hydroriparian Ecosystems Related to Natural Disturbance

Should resource management in hydroriparian ecosystems use natural disturbance regimes (size, frequency and intensity) and recovery regimes as a guide?

Hydroriparian ecosystems in the North Coast are adapted to natural disturbance regimes in relation to flood frequency, flow regimes, blowdown, and landslides. Forest harvesting and road building can alter the size and frequency of debris flows, increase blowdown and bank erosion, and, in watersheds with extensive commercial cover, increase streamflow. These effects have important implications for hydroriparian functions (see sections on landscape links and influence of land on water).

Other jurisdictions of coastal British Columbia propose to use natural levels and patterns of disturbance as a management guide in riparian areas (CSSP 1995, Central Coast LRMP[10]). The Biodiversity Guidebook (BC Ministry of Forests 1995) also expresses the principle and intention of using natural disturbance regimes to guide management.

A current analysis of natural disturbance and recovery regimes for the North Coast is beyond the scope of this report. No reliable assessments of landscape-level natural disturbance regimes exist at present.

[10] Unpublished worksheet by Mike Church and others.

5.1.2 Scale of Consideration

What spatial and temporal scales are appropriate for planning within hydroriparian landscapes?

Our review emphasises that hydroriparian ecosystems encompass entire watersheds. Although current forest management considers both site and landscape scales, it does not develop plans for entire watersheds in advance, but instead examines potential impacts of proposed cutblocks. Landscape Unit Planning tries to address more ecologically relevant areas.

As well as considering appropriate spatial scales, the LRMP table may wish to consider appropriate temporal scales. Some hydroriparian processes occur over long time periods (e.g. channel migration, growth of trees sufficiently large to influence channel structure), and large-scale natural disturbances are rare. Five or twenty-year time horizons cannot consider patterns of disturbance over time or the risks of cumulative impacts of disturbance.

5.1.3 Hydroriparian Classification

What classification system should be used as a framework for managing hydroriparian ecosystems?

We have used the concept of hydroriparian ecosystems in this report because it emphasises the land – water connection and landscape connectivity. The riparian classification used in the Forest Practices Code focusses on fish presence, human water use and stream width. These categories do not reflect the spectrum of hydroriparian values outlined in the report. In addition, sediment, water and organic material all travel downstream to fish habitat, challenging the artificial distinction between fish-bearing and non-fish-bearing streams. While there is no accepted ecological classification for riparian ecosystems, the principles of a good system are known (Naiman 1998, Montgomery and Buffington 1998). For example, channel gradient and confinement can be used to estimate frequency and magnitude of ecological relevant disturbance processes. The classification example described in this report (see Tables 2a, b, and c) is modified from an ecologically-based system developed for Clayoquot Sound (CSSP 1995). The Central Coast LRMP and Tlell LRUP are currently adapting similar classification systems for their regions. Current work in BC is developing a wetland/riparian classification system (MacKenzie and Banner 2000, unpublished manuscript).

5.1.4 Fixed versus Flexible Management Prescriptions

Should management of hydroriparian ecosystems be based on local conditions and landscape patterns or on fixed prescriptions throughout the landscape?

The last decade has witnessed an increase in protection afforded hydroriparian ecosystems, both in British Columbia and in adjacent US states (see Section 4; Naiman *et al*. 2000). This increase in protection is based on a growing awareness of the ecological functions hydroriparian ecosystems play, as well as the potential impacts forest harvesting can have on these functions (Naiman and Bilby 1998). Protection has been principally through prescriptions of set buffers widths for streams of various sizes and classes.

Simple management rules, such as fixed buffer widths, provide consistency and ease of enforcement, but may increase operational cost without achieving desired ecological results. For example, creating reserves on all steep, small streams creates a linear network of riparian reserves that do not resemble natural disturbance patterns, that are vulnerable to windthrow, and that make harvesting and road building expensive and difficult. A more flexible approach designs management for entire watersheds (or larger areas) based on local topography and natural disturbance regimes (Naiman 1998). For example, Cissel *et al*. (1998) demonstrate a watershed-level approach where harvesting plans are based on natural patterns of disturbance at different places in a watershed. Benda *et al*. (1992) partition a valley into areas of high and low risk to salmon habitat based on physical characteristics. A flexible approach will be more challenging to plan and implement, but may better achieve both social and ecological goals. Such a process is a logical extension of the Biodiversity Guidebook (BC Ministry of Forests 1995). Watershed-level assessments of hydroriparian ecosystem structure, function and disturbance processes could be important components of Landscape Unit Plans.

5.2 Issues by Hydroriparian Class

5.2.1 Small Steep Streams (Headwater Streams)

Do headwater streams need special management consideration?

Small headwater streams are common in the North Coast, on gentle to moderate slopes in the CWHvh2 (Hecate Lowland), and on moderate to steep slopes in the CWHvm (Outer Coast Mountains). These small streams, the most influenced by riparian vegetation (see sections on shade, downed wood, sediment, transport of fine organic material) are offered the least protection by current management policy (S4 – S6 streams; FPC). Protecting vegetation around all small streams would remove a large percentage of forest from the harvestable landbase. Conversely, removing vegetation around all small streams could lead to a variety of undesirable downstream impacts, including changes in temperature, sediment loading, increases in downed wood input, accelerated changes to channel morphology, and altered food webs.

Potentially high stream densities in harvest areas, and variation in flow persistence complicate management of headwater streams. Streams can be ephemeral (carrying storm runoff), seasonal (dry for periods, but with a stable source) or continuous (flowing year-round; CSSP 1995). The Forest Practices Code does not reserve riparian areas around seasonal or ephemeral channels; the Clayoquot Scientific Panel recommends reserves around seasonal, but not ephemeral, channels.

Downstream impacts of removing vegetation around small streams are unknown. Impacts of individual streams have been documented (e.g. Carnation Creek), but cumulative effects over entire watersheds have not been studied, in part because people have recognised the ecological role of headwater streams only in the past decade[11].

5.2.2 Floodplains and Fans

Do floodplains and fans need special management consideration as dynamic, hazardous landscape units?

Do CDC-listed ecosystems need special management consideration?

Oldgrowth ecosystems on floodplains and fans provide a range of biodiversity conservation and habitat values, and are the centre of anadromous fish spawning. The lowest elevations of medium and large sized valleys in the Outer Coast Mountains are dominated by floodplains in the bottom, with fan ecosystems occurring along the floodplain and valley sidewalls. Both floodplains and fans are highly productive and biologically-diverse ecosystems (see sections on Ecosystem Productivity and Coarse Filter Biodiversity). Canopies of oldgrowth forests on fans and floodplains are often quite open, so trees are often large.

Because of their rarity on the landscape, most fan and floodplain hydroriparian ecosystems in the North Coast are red- or blue-listed by the CDC (see Section on Rare Ecosystems). Current guidelines under the FPC do not restrict harvesting of rare ecosystems.

Under the Forest Practices Code there are no riparian reserves on floodplains with large rivers (>100m). On rivers between 20 and 100m wide (S1), there is a 50m reserve and a management zone that extends either 20m, or to the edge of the 'active floodplain'. The active floodplain is defined as that area flooded frequently (i.e., once every 5 years), as evidenced by clay skins on tree trunks and flood debris caught in bushes. This definition gives different answers from year to year, relies on flood evidence that disappears as the time since flooding increases, and excludes high bench floodplain forest ecosystems (as defined in Banner *et al*. 1993). As discussed in Section 4, Washington federal regulations require a reserve to the edge of the 100 year floodplain, and Clayoquot Sound recommendations require a reserve to the edge of the contemporary floodplain. Both of these definitions would reserve high bench floodplain forest ecosystems.

Currently, fans are not recognised as distinct management units, and there are no requirements for riparian management areas. There is, however, emerging recognition that fans are as hazardous to forestry and fisheries values as steep, unstable hillslopes: activities that do not consider the hydrogeomophic processes of flooding and debris flows

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[11] Scientists from a variety of disciplines in the US PNW and BC will be meeting in December 2001 to discuss a cross-jurisdictional scientific base for riparian management, focussing on small streams.

can lead to damage to road and drainage structures, erosion or sediment deposition on the fan surface, changes in channel stability and impacts on fish habitat downstream (Dave Wilford, personal communication). Ongoing research near the North Coast is using cover, site and watershed attributes to develop a hazard classification for forestry on fans[12].

5.2.3 Shoreline Hydroriparian Ecosystems

Do shoreline forests need special management consideration?

Do marine hydroriparian ecosystems need special management consideration?

Some shoreline forests are unique, rare ecosystems (see Section on Rare Ecosystems). Ecological relationships between terrestrial and saltwater systems are complex due to physical features and large diversity of species (CSSP 1995). The impact of riparian vegetation on nearshore subtidal and intertidal organisms is largely unknown, but likely varies with shore type (low shore or beach vs. rocky cliffs). In places, vegetation filters sediment running into the ocean (see Section on Transportation and Storage of Sediment).

Current practices do not offer protection to the unique physical features and diversity of organisms using shoreline hydroriparian ecosystems, apart from guidelines about debris and impacts next to designated Marine Sensitive Zones. Washington State has 30 – 70-m management zones along marine shores. Clayoquot Sound recommendations leave 100 – 150-m reserves depending on exposure to wind and shore type. The 150-m width was based on measurements of wind effects in lower Alaska (CSSP 1995). Because much of the North Coast is accessed from the water, road building will also be an important management consideration.

There is international scientific agreement that fish farming can severely impact sensitive marine hydroriparian ecosystems through discharge of effluents (review in Naylor *et al*. 1998). Many studies exist examining the impacts of fish farming on various aspects of hydroriparian ecosystems, but consideration of this vast topic is beyond the scope of this report.

5.2.4 Estuaries

Do estuaries need special management consideration?

The North Coast coastline is extensive, forming a maze of islands, fiords and channels. Much of this shoreline is rocky, with a limited, though productive, intertidal zone. A small percent of watersheds however, form estuaries—perhaps the most endangered of BC's ecosystems (Foster 1993). Estuaries are rich and productive hydroriparian

[12] Regional Ministry of Forests project with sampling around Terrace is testing classification retroactively on logged and roaded fans and compiling an operational knowledge document. Contact Dave Wilford.

ecosystems at the junction of land, fresh and marine water. They are important to a variety of organisms (see Biodiversity section). First Nations people have used, and continue to use, estuaries for cultural activities. Recreational use of estuaries for nature viewing, boating, hunting, fishing and crabbing is high.

Because of their proximity to forests, their calm water and shallow gradient, estuaries have been used as bases for industrial activity. In the past, log sorting and booming threatened estuaries by changing currents, scouring intertidal areas, adding debris and changing chemical composition of the water (Toews and Brownlee 1981). Although log handling has moved to land or to deeper waters adjacent to estuaries, and although road-building tries to avoid estuaries, some estuaries are still used for camps and roads. Human presence can threaten sensitive plant communities and change use by wildlife (e.g., estuaries are important to grizzly bears for early spring forage, but bear behaviour changes around people).

Lagoons are special cases of estuaries with reduced tidal flushing, and other unique physical properties.

Although the biggest and most important estuaries have been identified (MacKenzie *et. al*. 2000, Remington 1993), the North Coast coastline has not been inventoried.

5.2.5 Hydroriparian Ecosystems in Organic Terrain

Do hydroriparian ecosystems in organic terrain need special management consideration?

Little is known about the baseline processes and potential impacts of forest harvesting and road building in the organic terrain of the Hecate Lowland. Is plantation forestry possible? How does harvesting disturbance effect site drainage, tree productivity, and stream flow? What effects might site drainage have on the structure and function of peaty soils? How might these changes impact the ecology of adjacent hydroriparian ecosystems? Are riparian regulations designed for mineral soil landscapes suitable for landscapes dominated by organic terrain? Research to answer some of these questions is presently underway by the Forest Sciences Section, Prince Rupert Forest Region (Banner *et al*. 1999).

5.2.6 Wetlands

Should more ecologically-based criteria be used for identifying wetlands that will receive protection?

The Forest Practices Code defines wetlands based on the presence of gleyed and/or organic soils, and the presence of a list of ‘obligate hydrophytes’ (water-loving plants that are restricted to permanently flooded environments). Obligate hydrophytes must make up 20% cover of the plant community, based on an optical assessment of plant cover (BC 1995). There are practical, operational problems in applying the criteria, and the rules mean that forested wetlands, forested bogs, and some shrub wetlands are not included under the definition of a FPC wetland, and therefore receive no reserves.

5.2.7 Karst

Do karst landscapes need special management consideration?

Karst landscapes are underlain by limestone bedrock. They have unique 'solution' properties, where rainwater dissolves bedrock and streamflow is directed underground through extensive channels and caves. Karst ecosystems are productive but fragile (Baichtal *et al*. 1995). The nutrient-rich soil and well-developed drainage support productive forests. The pH buffered, even temperature streams support diverse and abundant invertebrate communities and rapidly growing fish (Baichtal *et al*. 1995). Fish, birds and mammals use caves for protection from predators, for hibernation, for denning and resting. Red-listed Keen’s long-eared myotis, listed, but not surveyed, within the North Coast, has been recorded in caves in SE Alaska (Parker and Cook 1996). Unique invertebrates live in caves (Scudder 1996).

Because of their extensive underground connections, karst ecosystems are vulnerable to disturbance due to forest harvesting and road building (Baichtal *et al*. 1995). Soil particles, especially in areas of high rainfall, easily travel through fissures to the underground channels. Once underground, the sediment is carried throughout the network. There are two implications of this surface – underground link. First, karst soil is often a thin organic mat. This soil is subject to loss into the underground channels after canopy removal; in some cases, declines in soil depth and fertility result in permanent deforestation (Baichtal *et al*. 1995). Second, sediment from one location can be transported underground for long distances before appearing, unpredictably, at distant springs. Canopy removal and road building also increase water flow into the underground channels, potentially flooding passages that have been dry for centuries. Sediment and debris often fill cave entrances. Cumulative impacts of past forest harvesting on karst ecosystems are unknown (Baichtal *et al*. 1993).

Several islands in the North Coast contain karst ecosystems as does Chappel Inlet, which is within the North Forest District, but not included in the North Coast LRMP. Appropriate management of karst ecosystems will be an issue because of their productivity (including mature, well-developed forests), their importance to biodiversity as unique ecosystems, and their fragility. Similar concerns in south-eastern Alaska, have led to the development of an ecologically-based approach to karst management based on mapping the susceptibility of karst ecosystems to disturbance (Baichtal *et al*. 1995).

5.2.8 Hotsprings

Do hotsprings need special management consideration?

There are several hotsprings in the North Coast. Because of their thermal and chemical properties, hotsprings are home to unique, rare communities of microbes, plants and invertebrates. Vertebrates often use hotsprings, feeding on the predictably available vegetation and licking minerals. Hotsprings are also valued by people for recreation and nature viewing. Recreational development is not always compatible with protecting hotspring communities.

5.3 Other Issues

5.3.1 Global Warming:

Does global warming need to be considered in developing strategies to maintain hydroriparian ecosystem function?

Over the past century, the temperature on the North Coast has risen by 0.6°C (BC average = 1°C) and precipitation has increased by 20% (Environment Canada 1999). The increase in precipitation has been reflected by increased rates of sedimentation in lakes (Beak-Aquafor 2000). Potential impacts of continuing climate change for the North Coast include rising sea level (and loss of shoreline), increased spring flooding, increased landslides and levels of sedimentation and decreased opportunities for waterfowl nesting (Environment Canada 1999). These impacts have implications for long-term maintenance of hydroriparian function.

5.3.2 Blowdown

Does blowdown need to be considered in developing strategies to maintain hydroriparian ecosystem function?

The North Coast is subject to strong winds; blowdown is the principal natural disturbance in the area (see Section 1.4, Natural Disturbance Regimes). Newly exposed forest edges are particularly sensitive to blowdown, depending on their orientation relative to episodic storm winds (Nowacki and Kramer 1998). Blowdown risk increases in buffer strips. When buffers blow down, trees can destabilise streambanks, expose soil to erosion and reduce future wood supplies (Kelsey and West 1998).

Blowdown becomes a strategic issue when it prevents management strategies from achieving their goals. Although operational tactics can help mitigate the effects of blowdown, they are unlikely to solve the problem in areas susceptible to strong winds. In Clayoquot Sound (prior to 1995) most buffers left to protect riparian function blew down. The Clayoquot Sound Scientific Panel recommended leaving additional buffers in places to reduce the impacts of blowdown on hydroriparian ecosystems (CSSP 1995). A variety of strategies are available to decrease the probability of blowdown (Steinblums *et al*. 1984, Kelsey and West 1998).

6.0 Information Gaps

Currently, very little is known about hydroriparian ecosystems in the North Coast. Results from studies performed in other areas give guidance, to be interpreted in light of differences between the ecosystems studied and the North Coast. The extent of hydroriparian ecosystems (across landscapes, above and below land) means that many studies are complex to interpret. Principle information gaps include

- North Coast hydroriparian disturbance regimes and recovery regimes.

  This is a huge task: natural disturbance patterns have yet to be defined for any landscape in the North Coast (or elsewhere). However, in mountainous regions, channel gradient and confinement give a rough guide to the frequency and magnitude of ecologically relevant disturbance processes. Probabilities of windthrow and of landslides are unknown for the North Coast.

- Cumulative effects over space and time of exceeding the natural range of variability in disturbance regimes.

  There is currently no credible method for predicting cumulative effects, because of the need to extrapolate small-scale landscape behaviour (e.g. stream reach behaviour over a few years) to large landscapes evolved over long periods (Benda *et al*.1998).

- The effectiveness of fixed-width buffers in protecting entire hydroriparian ecosystems.

  Landscape-level planning exercises are underway in the interior of BC and the US, investigating more flexible approaches.

- The importance of small streams to downstream ecosystems.

  Scientists from BC, Alaska and Washington will meet this year to discuss research in this field and possible management implications. Active research in is currently all outside the North Coast.

- The influence of shoreline vegetation on nearshore ecosystems

  Knowledge about the interface between land and sea is in its infancy. Scientists with Department of Fisheries and Oceans are preparing a Working Paper examining this information gap for BC.

- The ecology of, and potential impacts of management on, low productivity forests in organic terrain

There is currently a 5-year project underway in the North Coast to investigate this issue.

- The effectiveness of Forest Practices Code guidelines in dealing with blowdown along riparian buffers.

- The effectiveness of Forest Practices Code guidelines in maintaining natural inputs of large wood to hydroriparian ecosystems.

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Appendix 1:

Map

Appendix 2:

Red- and blue-listed ecosystems in the North Coast Forest District

CDC listed rare ecosystems in the North Coast (HL = Hecate Lowland; OCM = Outer Coast Mountains).

Scientific name	**Biogeoclimatic Ecosystem Classification Unit(s)**	**location**	**Provincial Rank**	**Provincial List**	**Successional Status**	**Structural Stage**	**Hydroriparian class**
Abies amabilis - Picea sitchensis / Oplopanax horridus	CWHvm1/08 CWHvm2/08	OCM	S3	Blue	EC	7	fan
Picea sitchensis / Calamagrostis nutkaensis	CWHvh2/16	HL	S3	Blue	DC	7	shoreline
Picea sitchensis / Carex obnupta	CWHvh2/18	HL	S3	Blue	EC	7	estuary
Picea sitchensis / Kindbergia oregana	CWHvh2/15	HL	S3	Blue	EC	7	shoreline
Picea sitchensis / Maianthemum dilatatum Wet Hypermaritime 1	CWHvh2/08	HL	S2	Red	EC DC	7	floodplain
Picea sitchensis / Malus fusca	CWHvh2/19	HL	S3	Blue	EC DC	7	estuary
Picea sitchensis / Polystichum munitum	CWHvh2/17	HL	S3	Blue	DC	7	shoreline
Picea sitchensis / Rubus spectabilis Very Wet Maritime	CWHvm1/09	OCM	S2	Red	EC DC	7	floodplain
Picea sitchensis / Trisetum cernuum	CWHvh2/09	HL	S2	Red	EC DC	7	floodplain
Populus balsamifera ssp. *trichocarpa / Cornus stolonifera*	CWHvm1/10 CWHwm/06* CWHws1/08* CWHws2/08*	OCM	S3	Blue	EC DC	6	floodplain
Thuja plicata - Picea sitchensis / Oplopanax horridus Very Wet Hypermaritime 2	CWHvh2/07	HL	S3	Blue	CC	7	seepage
Thuja plicata - Picea sitchensis / Polystichum munitum	CWHvh2/05	HL	S2S3	Blue	CC	7	limestone
Thuja plicata - Tsuga heterophylla / Polystichum munitum	CWHvm1/04	OCM	S3?	Blue	CC	7	limestone

13 Natural Plant Communities Listed

The natural plant community tracking list is incomplete since there is not yet enough data available for the CDC to rank all of the rare natural plant communities in B.C. This applies especially to many wetland, alpine, and grassland plant communities.

Please note that all ranks reflect the rarity of plant community occurrences that have not been disturbed by humans or domestic animals, and are in a natural or "climax" state. Do not confuse these natural plant communities with successional plant communities (e.g. second-growth Douglas-fir and salal forests), or with degraded plant communities (e.g. a weedy bluebunch wheatgrass and junegrass grassland). However, be aware that for the purposes of conservation, disturbed occurrences of rare plant communities may be ecologically valuable if there are few or no natural, undisturbed occurrences left in the Province (e.g. Garry Oak plant communities). Please visit the CDC's Ecology web page (www.elp.gov.bc.ca/rib/wis/cdc/ecology.htm) or contact the CDC for more information on rare natural plant communities and rare natural plant community conservation.

Biogeoclimatic Ecosystem Classification (BEC) Unit(s): This column gives the BEC unit(s) in which each plant community can occur. These units are described in the Ministry of Forests' "Field Guide to Site Identification and Interpretation" for the appropriate Forest Region..

Successional Status: This column indicates the successional status of each natural plant community. Natural plant communities are, almost without exception, climax plant communities. Younger successional stages are considered to be different plant communities, though they may eventually develop into climax plant communities. For more information on successional status, visit the CDC's Ecology web page (www.elp.gov.bc.ca/rib/wis/cdc/ecology.htm) or consult the Field Manual for Describing Terrestrial Ecosystems (www.for.gov.bc.ca/RIC/Pubs/teEcolo/fmdte/deif.htm).

Code	**Successional Status**	**Definition**
CC	Climatic climax	The oldest expression of an ecosystem, where succession has been unimpeded by edaphic (site) limiting factors or ecological disturbance. This state is self-perpetuating in the absence of disturbance.
ED	Edaphic climax	The oldest possible expression of an ecosystem given edaphic (site) limiting factors atypical for the landscape which arrest or redirect succession so that the climatic climax is never achieved. Edaphic limiting factors include extremely dry soil, extremely wet soil, and very poor nutrient regime, relative to the landscape norms.
DC	Disclimax	The oldest possible expression of an ecosystem given a natural disturbance regime which arrests or redirects succession so that the climatic climax is never achieved. Natural disturbances include periodic surface fires and annual flooding.

Structural Stage: This column indicates the structural stage(s) of each natural plant community. Similar plant communities at younger structural stages are considered to be different plant communities, though they may eventually develop into natural plant communities. For definitions, see the Field Manual for Describing Terrestrial Ecosystems (www.for.gov.bc.ca/RIC/Pubs/teEcolo/fmdte/deif.htm).

Code	**Structural Stage**	**Code**	**Structural Stage**
1	Sparse/bryoid	3	Shrub/Herb
1a	*Sparse*	*3a*	*Low shrub*
1b	*Bryoid*	*3b*	*Tall shrub*
2	Herb	4	Pole/Sapling
2a	*Forb-dominated*	5	Young Forest
2b	*Graminoid-dominated*	6	Mature Forest
2c	*Aquatic*	7	Old Forest
2d	*Dwarf shrub-dominated*		

Appendix 3:

CDC Red- and blue-listed plant species that may occur in the North Coast Forest District

Red- and blue-listed plant species that may occur in the North Coast Forest District. Bolded species are associated primarily with hydroriparian ecosystems.

Scientific name	Common name	Global Rank	Prov. Rank	Prov. List
Agrostis pallens	**Dune bentgrass**	G4G5	S2S3	Blue
Arnica chamissonis ssp. *incana*	**Meadow arnica**	G5T?	S2S3	Blue
Aster ascendens	Long-leaved aster	G5	S2S3	Blue
Calamagrostis montanensis	Plains reedgrass	G5	S1	Red
Callitriche heterophylla ssp. *heterophylla*	**Two-edged water-starwort**	G5T5	S2S3	Blue
Caltha palustris var. *palustris*	**Yellow marsh-marigold**	G5T?	S2S3	Blue
Carex glareosa var. *amphigena*	**Lesser saltmarsh sedge**	G4G5T?	S2S3	Blue
Carex gmelinii	**Gmelin's sedge**	G4G5	S2S3	Blue
Cornus suecica	**Dwarf bog bunchberry**	G5	S2S3	Blue
Eleocharis kamtschatica	**Kamtschatica spike-rush**	G4	S2S3	Blue
Enemion savilei	Queen Charlotte isopyrum	G3	S3	Blue
Hippuris tetraphylla	**Four-leaved mare's-tail**	G5	S2S3	Blue
Juncus arcticus ssp. *alaskanus*	**Arctic rush**	G5T?	S2S3	Blue
Juncus stygius	**Bog rush**	G5	S2S3	Blue
Leucanthemum arcticum	**Arctic daisy**	G5	SH	Red
Ligusticum calderi	**Calder's lovage**	G3	S3	Blue
Lilaea scilloides	Flowering quillwort	G5?	S2S3	Blue
Malaxis paludosa	**Bog adder's-mouth orchid**	G4	S2S3	Blue
Polystichum setigerum	Alaska holly fern	G2G3	S2S3	Blue
Sanguisorba menziesii	**Menzies' burnet**	G3G4	S2S3	Blue
Senecio moresbiensis	Queen Charlotte butterweed	G3	S3	Blue
Triglochin concinnum var. *concinnum*	**Graceful arrow-grass**	G5T?	S2	Red

Appendix 4:

Glossary

fan: Fans are active landforms that develop at the base of slopes as a result of the deposition of materials from upslope. Fan is used in the report to include both alluvial fans and colluvial fans. On alluvial fans accumulated materials are deposited primarily by water action. Colluvial fans material is transported primarily by gravity.

floodplains: Floodplains are depositional landforms that form along the lowest gradient portions of streams and rivers. Floodplain deposits accumulate as benches and bars.

colluvial material: Generally coarse mineral materials deposited downslope under the influence of gravity.

morainal material: Mineral material that includes a wide range of particle sizes deposited in direct contact with a glacial ice.

till: morainal material

terrace: a relatively level landform deposited as a plain and subsequently eroded by river or lake downcutting to form a bench along valley sidewall

glaciofluvial terrace: A medium to coarse-textured terrace where the material was deposited by rivers flowing in front of a wasting glacier.