Impacts of Forest Harvesting on Terrestrial Riparian Ecosystems of the Pacific Northwest

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Preface

This report was prepared for the Joint Solutions Project reporting to the Central Coast Land and Resources Management Plan. It is one of a series of documents prepared as background for development of a "Riparian Decision Tool" guiding ecosystem-based riparian management in the Central and North Coast of British Columbia. Our report was commissioned to complement another Background Report (Bunnell et al. 2001) describing riparian-associated vertebrates of the Central and North Coast. Hence, it focuses on describing non-vertebrate riparian associates and on summarising studies of impacts of forest harvesting on all riparian organisms. This paper is designed to be considered with the other Background Reports rather than in isolation.

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Introduction

Functions of Riparian Ecosystems

Riparian ecosystems[1] 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 forest canopy where precipitation first drips (Gregory et al. 1991, Naiman et al. 2000). They continually change, modified by disturbance effects of flooding, erosion and sedimentation. In the wet Central and North Coast, the distinction between upland and wetland is often unclear, and riparian ecosystems extend considerably beyond channels and wetlands.

As the interface between water and land, riparian 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 surficial materials determine water chemistry and channel form. Second, water influences adjacent land: flow erodes banks, deposits sediments and affects soil chemistry; abundant water in well-drained soils creates mosaics of diverse and productive communities; accumulated water in poorly drained soils slows decomposition and creates special plant communities. Third, riparian ecosystems link landscapes by transporting water and solutes, sediment, food, structure and organisms. Fourth, because of their diverse forms, frequent disturbance and productivity, riparian ecosystems are home to a rich array of plants and animals, including rare communities and species—they are hotspots of biodiversity.

A series of Background Reports prepared for the Central Coast LRMP describe the four riparian functions in detail:

	Central Coast LRMP Background Report			
Function	This report	Bunnell et al.	Young	Church and Eaton
Land-on-water effects			X	
Water-on-land effects	X			
Biodiversity	X	X		
Landscape links			X	X

Regions of the Central and North Coast

The Central and North Coast divide into three subregions—Hecate Lowland, Outer Coast Mountains, and Inner Coast Mountains—differing in topography, climate, hydrology, natural disturbance regimes and ecosystems (Pojar et al. 2000, Price and McLennan 2001, Trainor Background Report). The Hecate Lowland is a narrow, low-lying, boggy strip along the coast and adjacent islands. The Outer Coast Mountains feature steep, rugged mountains, large watersheds and ocean fjords. The Inner Coast Mountains are equally rugged; distinguished by a drier climate.

[1] A note on terminology: Because land and water are tightly coupled, we prefer the term "**hydroriparian ecosystems**". This report, however, focuses on the terrestrial aspects of hydroriparian ecosystems; hence we retain the more traditional "**riparian ecosystems**" except for specific references to the entire system.

Geomorphic disturbances (avalanches, debris flows and landslides) and flooding are common in the Inner and Outer Coast Mountains; fire is only significant in the Inner Coast Mountains; wind is a minor disturbance agent throughout.

Approach

The approach complements another Background Report, describing riparian-associated vertebrates of the Central and North Coast (Bunnell et al. 2001), by focusing on describing non-vertebrate riparian associates and on summarising studies of impacts of forest harvesting on all riparian organisms.

Riparian ecosystems include all organisms (bacteria, protists, plants, fungi, animals) living and interacting where water meets land. Hence, we approach our investigation of riparian associates broadly. Unfortunately, many riparian organisms, particularly the small, numerous ones, are either difficult to study, or (to the uninitiated) lacking charisma. Because studies are biased towards the relatively large (e.g. vertebrates) or easily visible (e.g. ground-dwelling plants), it is impossible to discuss all groups equally. For groups where the exact nature of association with riparian habitats is unknown, we elect to discuss what is known about their general ecology rather than ignoring them and assuming unimportance.

The body of our report is organised by taxonomic group. This structure does not imply support for a species-by-species approach to managing riparian areas. Such an approach would be complex, costly, and, due to a lack of omniscience, always incomplete. Instead, our presentation reflects first, real differences in the ecology of vagile vs. sessile organisms and second, an artificial framework created by disciplinary boundaries and by differences in knowledge. The discussion section draws out commonalties.

For each group of organisms, we describe the state of knowledge for the Central and North Coast, briefly list important ecological functions, define riparian associates, where known, and analyse impacts of forest harvesting. Where information about riparian associates exists, we focus solely on that literature; faced with a dearth of information, we expand our focus to include other relevant ecological data. We have not delved into the vast literature looking at impacts of management on biodiversity in general. Bunnell et al. (1998) reviews studies on fragmentation, corridors, edge and other related topics.

Because few data exist from the North and Central Coast, we have collected information from studies performed within the Pacific Coastal Ecoregion, from Oregon to Alaska (Naiman and Bilby 1998). At least four large-scale studies of terrestrial impacts of forest harvesting have been initiated in this area over the past few years. We have information from two studies in Washington State (including unpublished data). Although data from BC and Alaska studies are not yet available, we found sufficient studies from the Pacific Coast to complete preliminary meta-analyses of data on the impacts of harvesting on amphibians, birds and mammals. Due to time limitations, our literature search was not exhaustive; we have likely missed much from the “grey” literature and from theses.

Riparian Associates of the Central and North Coast

Vascular Plants

Riparian Plants of the North and Central Coast

BC's biogeoclimatic ecosystem classification system (BEC; Pojar et al. 1987) provides a practical way of distinguishing plant communities. BEC does more than just list plant communities, however: late seral forest ecosystems integrate differences in climate, topography and soil, and represent habitat for other organisms—BEC site series indicate more general ecological units. Descriptions of forest ecosystems in the Central and North Coast are based on hundreds of vegetation plots. The Central and North Coast include hypermaritime, maritime and submaritime subzones of the CWH (Coastal Western Hemlock) and MH (Mountain Hemlock) zones, approximately matching the physiographic regions of the Hecate Lowlands, Outer Coast Mountains and Inner Coast Mountains, respectively (Pojar et al. 1999). Within each subzone, a site has the potential to support a particular late seral plant community based on available moisture and nutrients. Riparian ecosystems support distinctive plant communities.

Because BEC was designed for classifying forested ecosystems, it does not consider hydrological features, provide landscape context or combine sites into ecosystem complexes—all important aspects of riparian ecosystems. A new classification framework, based on the Canadian Wetland Classification System, BEC site units and other sources, is being designed specifically for hydroriparian ecosystems (MacKenzie and Banner, draft 2001). Because this system is not yet available, we have summarised information for specific hydroriparian ecosystems that commonly occur in the North and Central Coast (Table 1).

In the watersheds of the Central and North Coast, riparian plant communities change fairly predictably from steep headwaters to valley bottoms. Headwater streams influence moisture regimes over a short distance from the water and plant communities near these streams may be those found in any upland ecosystem. Conversely, valley-bottom streams influence riparian ecosystems considerably.

<u>Small Streams</u>
Small headwater streams are most often flanked by mesic subalpine and montane ecosystems dominated by mountain hemlock *(Tsuga mertensiana)*, amabilis fir *(Abies amabilis)* and yellow-cedar *(Chamaecyparis nootkatensis)* in the subalpine zones, and by western redcedar *(Thuja plicata)*, western hemlock *(Tsuga heterophylla)* and Douglas-fir (*Pseudotsuga menziesii)* in montane zones. Understory vegetation is often mostly feathermosses, with scattered herbs and heath shrubs. Because small streams account for most of the length of stream networks, these mesic ecosystems are the most common riparian forests on the coast.

Although the influence of water on land occurs over a relatively short distance, small streams do influence adjacent conditions and vegetation. A study in western Washington found microclimatic gradients around small (2 – 4m) streams extending between 31 – 62m from the stream (Brosofke et al. 1997). Where channels are unconstrained, the highly variable flow periodically enriches adjacent land and leads to narrow bands of larger trees and diverse vegetation, including devil's club

(*Oplopanax horridus)*, salmonberry *(Rubus spectabilis)* and ferns. In Clayoquot Sound, more species of plants grew within the first 10m of small streams (Kim 1997), and vegetation communities were influenced by moderately sized streams (3 – 30m) for 100m (Chan-MacLeod 1996). Plant communities within gullies are obviously influenced by the continuously moist, cool microclimate, but impacts beyond the gully are not intuitively obvious. Interestingly, a preliminary study in Clayoquot Sound found that the number of species next to entrenched streams (3 – 30m wide) continued to change over 100m, even though the transects began on top of 20 – 50-m high cliffs (Chan-MacLeod 1996).

Table 1. Stream Riparian Ecosystems that commonly occur in the North and Central Coast

Riparian Ecosystem	*Ecosystem Characteristics*	*Biogeoclimatic Site Series*
Small steep streams (gradient >20%; width < 3m; flow perennial, seasonal or ephemeral)	• network of perennial, seasonal and ephemeral streams expanding and shrinking with precipitation • narrow floodplain or seepage ecosystems often occur along the stream; range of site conditions and understory vegetation, including devil's club, salmonberry, or red alder • common in Outer and Inner Coast Mountains	CWHvh2/04,06 CWHvm/01,05,08 CWHws/01,04,06 CWHwm/01,03,04
Torrented gullies (gradient >20%; width < 3m; flow perennial or seasonal)	• steep streams, often cut into deep glacial till or bedrock • unique vegetation community within gully due to continuously cool and damp microclimate; 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 may have small floodplain with abundant shrubs, herbs, red cedar and amabilis fir • common along larger valleys throughout Outer and Inner Coast Mountains	CWHvh2/04,06 CWHvm/01,05,08 CWHws/01,04,06 CWHwm/01,03,04
Small, low gradient streams (gradient <20%; width < 10m; flow perennial or seasonal)	• streams in low gradient areas • adjacent vegetation varies from dry to wet sites • common in Hecate Lowland, draining organic terrain in forested and non-forested ecosystems; often connected to a range of small and medium sized lakes and pools; further inland, found as seasonal streams in backchannel areas on major floodplains or fans	CWHvh2/01,11,12,13 CWHvm/variable CWHws/variable CWHwm/variable
Fans (gradient 8 - 20%; width < 10m; flow perennial or seasonal)	• characteristic fan formations that develop where streams reach the valley floor and deposit mineral sediment and organic debris; highly dynamic ecosystems • 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; • feature abundant berries and herbs and are important wildlife habitat • common in Outer and Inner Coast Mountains where they form a characteristic valley floor complex with floodplains; rare in Hecate Lowlands	CWHvh2/06,07 CWHvm/05,08 CWHws/04,06 CWHwm/03,04
Floodplains (gradient <8 %; width variable; flow perennial or seasonal)	• complex ecosystems built from sediment deposited in low gradient reaches; constantly created and eroded; range from very narrow along small streams to 1 km wide or more • changing mosaic of high productivity ecosystems; forests range from impressive stands of widely-spaced Sitka spruce and western hemlock, to red alder or black cottonwood stands on younger surfaces, 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 or at the toes of fans • feature abundant berries and herbs and are important wildlife habitat • infrequent and small in Hecate Lowlands; common in Inner and Outer Coast Mountains on valley floors of larger valleys; where they meet the seas, floodplains on medium and large rivers often grade into estuaries	CWHvh2/08,09,10 CWHvm/09,10,11 CWHws/07,08,09 CWHwm/05,06,07
Karst landscapes (gradient and width variable; some entirely underground)	• complex three-dimensional landscape with water travelling underground through channels and caves • 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 • found only in Hecate Lowlands	CWHvh2/05

Table 1 continued. Wetland, lake and marine riparian ecosystems

Riparian System	***Ecosystem Characteristics and Notes***	***Biogeoclimatic Site Series***
Forested swamps	• forested wetland ecosystems with mineral seepage that increases productivity compared to other wetlands • support western hemlock, Sitka spruce, and western redcedar on elevated mounds, skunk cabbage in depressions; open canopies with dense herb and shrub communities • uncommon in Hecate Lowland on lower slopes and depressional areas; common in Outer and Inner Coast Mountains on depressions on larger floodplains adjacent to valley walls or at the base of fans	CWHvm/14
Sedge fens	• sedge-dominated wetlands occurring in landscape depressions with variable amounts of mineral seepage; soils mostly fibric and mesic peat over fluvial deposits • fringed by low and tall shrub communities, grading into forested swamp or upland ecosystems • relatively uncommon in Hecate Lowland near river channels and small lakes where lateral seepage occurs; common to infrequent in Outer and Inner Coast Mountains in depressions on floodplains, as fringes around lakes, at fan bases or back channels	CWHvh,vm,ws,wm/31
Slope/blanket bogs	• level to sloping, large bogs; mostly organic veneers and blankets over bedrock and till; • supports sphagnum, sedges and heath shrubs, with scattered stunted western and mountain hemlock, and yellow-cedar at higher elevation • very important landscape feature in Hecate Lowland, covering >50% of the landscape, and forming a mosaic with forested ecosystems on organic soils; rare further inland in areas transitional to the Hecate Lowland (CWHvm2, MHmm1)	CWHvh2/31
Ponds	• small, shallow freshwater ecosystems, often with organic banks; forms complex of ponds and streams; hydrology determined by flows in adjacent organic soils • abundant algal and macrophytic vegetation • common in Hecate Lowland in forested and non-forested landscapes, including blanket bog ecosystems; rare further inland, associated with slope wetlands (CWHvm2, MHmm1) and infilling stream meanders	not classified
Lakes	• freshwater ecosystems providing an important component of regional biodiversity • very abundant small lakes in Hecate Lowland, often connected with ponds and small, low gradient streams to form a network of diverse freshwater habitats; several deep, medium-sized lakes occur in faulted bedrock structures in Outer and Inner Coast Mountains	not classified
Shoreline saltspray forests	• seaside forests that 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 • Sitka spruce dominates; understory varies with landform and marine effects; unique and productive epiphytic lichen communities because of wind and salt spray • common in Hecate Lowland on windy, unprotected shores; rare in Outer Coast Mountains	CWHvh2/14,15,16,17
Estuaries	• extremely rich and productive ecosystems created where tidal marine water and sediment mixes with freshwater and river sediment • mosaic of unique forest wetlands, shrub thickets, sedge and grassland ecosystems, salt, brackish, and freshwater marshes, and mudflats • uncommon in Hecate Lowland (small because of small contributing areas and low sediment transport); common in Outer Coast Mountains (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

The structural attributes of riparian plant communities are important to other organisms. In general, in the Pacific Coastal region, riparian forests next to moderately small streams (order 2 – 3, 2 – 20m wide) include more deciduous trees, fewer conifers (though sometimes with equal or higher basal area), a more open canopy, more berry-producing shrubs, fewer evergreen shrubs and fewer snags than adjacent upland forest (Pearson and Manuwal 2001, Rot et al. 2000, McComb et al. 1993, Lock and Naiman 1998, Andrus and Froelich 1987, Pabst and Spies 1999).

Floodplain and Fan Communities

Floodplain and fan forest ecosystems 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 (Pollock et al. 1998, Naiman et al. 2000). Floodplains and fans feature the largest trees in the Central and North Coast. Berry-producing shrubs and palatable herbs are abundant. The diversity of forest ages, plant species compositions, structural attributes, and proximity to water provides shelter and food for a diversity of animals (Bunnell et al. 1999, Kelsey and West 1998).

Floodplain ecosystems in the North and Central Coast are classified within BEC into high, middle and low floodplain benches, that reflect differences in flood frequency, duration and seasonality as a function of bench height (Banner et al. 1993). Low bench ecosystems experience prolonged flooding and are dominated by red alder (*Alnus rubra)* in the Hecate Lowlands and black cottonwood (*Populus balsamifera* ssp. *trichocarpa)*, red alder and willow (*Salix* spp.) further inland. Middle bench ecosystems, most common on large rivers such as the Skeena and Klinalkini, support larger deciduous trees and, sometimes, conifers. High bench ecosystems (the "dry floodplain" described in Church and Eaton Background Report) are flooded above the surface infrequently, and, in the oldgrowth stage, are characterised by large, well-spaced Sitka spruce (*Picea sitchensis)*, western redcedar, western hemlock, and amabilis fir, with highly productive shrub and herb communities. Subsurface irrigation accounts for the high productivity of high bench floodplain ecosystems.

Because of frequent disturbance, some floodplains never reach their potential climax community. For example, glacially-headed watersheds experiencing frequent hydrogeological disturbance may be dominated by young red alder and black cottonwood stands with shrub and herb understories. Less active floodplains become complex and harbour a variety of communities at different places, including old, structurally complex spruce forests.

Fans in the Central and North Coast support a mosaic of seral shrub-herb communities, interspersed with very productive oldgrowth forest ecosystems that are very similar in composition and structure to floodplain forests. Productivity can again be attributed to subsurface seepage that provides abundant moisture and nutrients. Large trees on fans play an important role in stabilising these dynamic landforms.

Marine Forest Ecosystems

Another group of riparian plant communities grows along exposed coasts in the Hecate Lowlands (CWHvh). These communities form a narrow fringe of shoreline forest dominated by salt-tolerant Sitka spruce and supporting unique communities of epiphytic lichens. Other special forested ecosystems, including communities of spruce, crab-apple and slough sedge, grow along the fringes of the larger estuaries.

Wetlands

Non-forested bog ecosystems, interspersed with scrubby bog woodlands, blanket more than half of the Hecate Lowlands. The high rainfall and low rates of evapotranspiration in this region mean that soils on all but steep slopes tend to be saturated year round. Because much of the Central and 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 (Kayahara and Klinka 1996). Other riparian ecosystems include swamp forests, growing on low slopes or level areas with some movement of water, and sedge and willow-dominated fens and marshes, most common in low elevation valley bottoms.

Rare Plant Communities and Species

The Conservation Data Centre of BC (CDC) lists over 200 rare plant communities across the province (red-listed communities are typically represented by fewer than 20 occurrences in the province; blue-listed communities are represented by 20 – 100 occurrences). Fifty rare plant associations occur within the Central and North Coast (Appendix I). Most represent oldgrowth forests; about half are components of the riparian ecosystems described in Table 1 (mostly floodplain, fan, marine ecosystems). CDC-listed ecosystems are considered rare for two reasons: either they are naturally rare in BC, or they have been harvested preferentially, so that they are now rare. For example, in the Central and North Coast, shoreline forest ecosystems are naturally rare, while floodplain and fan ecosystems have been preferred targets of forest harvesting throughout BC. Thus, as a result of being specifically targeted for harvesting, most of those oldgrowth fan and floodplain ecosystems that remain are considered rare. CDC-listed floodplain and fan ecosystems in the North Coast district have been mapped based on 1:15,000 aerial photographs (Ronalds and McLennan 2001).

Other rare (though not CDC-listed) riparian ecosystems in the region include karst ecosystems, seabird islands, estuaries and tidal wetlands, rich fens and marshes, and hotsprings (Pojar 2002). Additionally, the extensive blanket bog mosaic of the Hecate Lowlands is globally rare (Pojar 2002).

Twenty-eight plant species are identified as red- or blue-listed by the CDC for the Central and North Coast (Appendix 2). Of the 28 species listed, 18 (64%) use riparian ecosystems as habitat. This emphasises the important role riparian ecosystems play as repositories of watershed biodiversity.

Impacts of Forest Harvesting on Plants

Riparian forests provide many terrestrial and aquatic ecological functions, primarily because of the structure provided by large live and dead trees. As well as changing aquatic conditions (see Young Background Report), removal of riparian trees changes the microclimate, the levels of light, water, nutrients and large and small organic materials reaching the ground and, consequently, the habitat features of terrestrial ecosystems. Plant communities shift to early seral shrubby ecosystems. Harvesting and road development throughout the watershed changes hydrological regimes (see Church and Eaton Background Report). Increased high or reduced low stream flows have the largest impacts on riparian vegetation via drought, flooding, sedimentation or erosion (Naiman et al. 1998). Removal of adjacent upland forest can influence remaining riparian vegetation by creating edge and changing the microclimate (Brosofke et al. 1997).

Any change to downed wood deposition, resulting from upstream or local forest harvesting, impacts floodplain structure and vegetation. 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 on a river in western Washington (Steel et al. 1999). While red alder and black cottonwood rapidly colonise exposed mineral surfaces, conifers establish mostly in protected sites, either on or behind downed wood (Rot et al. 2000). Large pieces of downed wood, as well as being critical for providing instream habitat complexity, are also necessary to maintain conifers in some riparian forests (Naiman et al.1998).

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). Development, particularly roads, near floodplains has the potential to introduce weeds that could travel along the floodplain. Few weeds have reached the North and Central Coast, yet.

In the low productivity bog and forest mosaic of the Hecate Lowland, forest harvesting and road building could change ecosystem productivity: disturbance and mixing of organic and mineral horizons could increase tree productivity, while canopy removal and increased soil moisture could 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 in these forests (Banner et al. 1999)[2].

Oldgrowth forests in the Central and North Coast contain live trees and decaying wood over 1,000 years old; many dominant trees are 300 – 600 years. Once harvested, the structural and functional equivalents of these oldgrowth ecosystems cannot be replaced within a meaningful management timeframe. A number of oldgrowth riparian ecosystems are listed as threatened or vulnerable. The conservation of plant communities aims to maintain biodiversity at a “coarse filter” level—protecting all of the organisms within the ecosystem, including unclassified bacteria, fungi and invertebrates. Harvesting listed oldgrowth ecosystems threatens the biodiversity of the Central and North Coast.

[2] 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).

Bryophytes

Bryophytes of the Central and North Coast

The ready abundance of water has encouraged development of a rich bryoflora in the Central and North Coast. Bryophytes comprise about half of the plants in the region, compared with about a quarter in BC and less than a tenth in the world[3]. 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 Central and 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 bryophytes in bogs and poor fens and a study of epiphytes (bryophytes and lichens) living on western red cedar leaf scales[4]. Foliicolous (living on leaves) bryophytes and lichens are relatively rare in temperate latitudes, and, in Canada, are limited to riparian ecosystems (the outer coast and waterfalls) of western BC (Patrick Williston, unpublished manuscript).

Riparian associates

Mosses and liverworts carpet the forest floor and festoon trees throughout the temperate rainforest. Riparian ecosystems, however, do have special communities: *Sphagnum* spp. cover and control the extensive bogs of the Hecate Lowlands and “stream banks probably harbour the richest moss flora in BC” (Schofield 1976).

In the coastal forests of western Washington and Oregon, bryophyte diversity was particularly high in riparian habitats, and five of eight rare species were limited to riparian areas (FEMAT 1993). The richest riparian bryophyte communities in western Oregon were found on low elevation terraces and medium-sized stream channels (including active channels and floodplains). Low elevation streams and high elevation small streams harboured fewer species (Jonsson 1996). Within sites, bryophyte species composition changed with distance from the stream and amount of downed wood; between sites, composition varied with elevation and stream size (Jonsson 1997).

Impacts of forest harvesting

Very few studies have examined the impacts of forest harvesting on bryophytes, and even fewer have looked at the impacts on riparian bryophytes. In the temperate rainforests of the US, many bryophytes did not become established until stands were >100 years old, and reached their greatest development in 400-year-old stands (FEMAT 1993). Clearcutting, patch cutting and green tree retention changes bryophyte community composition, and drastically reduces cover in riparian or upland forests (Andrus and Froelich 1987, Ryan and Fraser 1993 cited in Ryan 1996, Beese and Bryant 1999). In upland Douglas-fir forests, corticolous (trunk-living) bryophytes decreased following thinning, perhaps due to changed wind-flow patterns and reduced stem flow (Thomas et al. 2001). Although bryophytes recover as the tree canopy regrows, there are concerns that poor dispersal coupled with short-rotation forestry might hamper re-establishment; forest harvesting has been implicated in the decline of bryophytes in Europe (citations in Ryan 1996).

[3] Calculated from Wilson 1986, Pojar and MacKinnon 1984, Pojar 1983)
[4] Three draft papers in progress. Contact Patrick Williston.

Fungi

Fungi of the North and Central Coast

Provincial studies of fungal ecology are in their infancy. There is no information on fungi by biogeoclimatic site series, and BC lacks even species lists for most groups (Redhead 1997). The North and Central Coast are essentially unexplored, but are likely to host unique species (Redhead 1997).

Fungi play important ecological roles. The trees of the North and Central Coast depend on mycorrhizal fungi (primarily ectomycorrhizal fungi) for nutrients (Redhead 1997). Some small mammals depend on underground ectomycorrhizal fungi seasonally for food; in turn, the fungi depend on the mammals for dispersal. Fungi feed invertebrates, rodents, squirrels and ungulates. Decay fungi provide habitat by softening wood, and provide food to stream communities by decomposing riparian leaves.

Riparian Associates

Nothing is known about the association of macrofungi with riparian areas in coastal forests. There may be fewer ectomycorrhizal species in rich, wet areas because trees have less need for their symbiont and because fungi prefer well-drained soils (Marty Kranabetter personal communication).

Microfungi live within a community of microorganisms in a polysaccharide matrix covering sediment surfaces. This epilithic (living on rocks) community dominates the hyporheic zone (see Invertebrates).

Impacts of Forest Harvesting

Nothing is known about the impacts of forest harvesting on riparian fungi of coastal forests. In the temperate rainforests of the US, over 500 macrofungi species are listed as oldgrowth associates (USDA 1994). Studies of impacts of harvesting on ectomycorrhizal fungi of transitional coastal/interior forests (Interior Cedar Hemlock, near Hazelton) found that the number of species declined following harvesting and remained low for several years even in small (< 0.5 ha) openings (Kranabetter and Wylie 1998). Species richness and abundance increase over time: by 75 years, a mature forest community returns; abundance continues to increase with age (Marty Kranabetter unpublished data). Recovery is based on the time needed to form a dense tree root network and on fungal dispersal ability. A study of partial cutting detected no significant impacts on ectomycorrhizal communities (Kranabetter and Kroeger 2001).

Lichens

Lichens of the North and Central Coast

As a symbiotic marriage of two or three kingdoms (fungi, algae and sometimes bacteria), lichens do not fit neatly into traditional taxonomic groupings. Lichens have been collected and described for parts of the North and Central Coast, but not exhaustively. The Coastal Western Hemlock zone is listed as the top priority biogeoclimatic zone for lichen conservation in BC; most rare species have been found on Haida Gwaii or Vancouver Island (Goward 1996).

Epiphytic lichens play important ecological roles in coastal forests. They contribute to nutrient cycling by absorbing elements from the air and releasing them through decomposition or leaching (Knops et al. 1991). Some species fix atmospheric nitrogen (Pike et al. 1972, Pike 1978). Other species provide important winter food for sciurids and ungulates (Edwards et al. 1960, Richardson and Young 1977, Stevenson 1978, Maser et al. 1985), as well as nesting material for birds. All epiphytic lichens form habitat and food for invertebrates (Gerson and Seaward 1977), which in turn feed birds (Pettersson et al. 1995).

Riparian Associates

Coastal riparian areas have rich lichen communities. Shoreline spruce forests and spruce floodplains are particularly rich in epiphytic species; rocky shores and bogs harbour specially-adapted species (Brodo et al. 2001). Different suites of species live on deciduous and coniferous trees due to differences in bark chemistry, light and moisture; hence, the variety of substrates in riparian ecosystems allows development of a rich epiphytic lichen community. In southwest Vancouver Island, epiphytic lichen biomass in oldgrowth Sitka spruce riparian forests was 680 kg/ha, almost twice as high as the biomass in upland forest (Price and Hochachka 2001).

Impacts of Forest Harvesting

No studies specifically investigate the impacts of forest harvesting on riparian lichens of the Pacific Northwest. Studies in upland areas of BC and Oregon suggest, first, that lichen abundance increases and community composition changes with increased structure (Price et al. 1998, Neitlich and McCune 1997, Peck and McCune 1997), and second, that leaving structure is not a substitute for time (Price and Hochachka 2001). Slow growth, inefficient dispersal ability and requirements for particular microclimates and substrates mean that epiphytic lichen abundance and diversity increases with forest age. On southwest Vancouver Island, even small (< 1 ha) 120-year-old stands, surrounded by oldgrowth and containing considerable structure in the form of remnant large trees, did not contain the same abundance or composition of epiphytic lichens as did paired oldgrowth stands (Price and Hochachka 2001). Similarly, in Scandinavia, 100 – 130-year-old selectively cut stands contained less lichen than paired oldgrowth (Esseen et al. 1996). In moist Interior Cedar Hemlock forests in BC, lichen diversity continues to increase for centuries (Goward and Pojar).

Terrestrial Invertebrates

Riparian Invertebrates of the Central and North Coast

Nothing is known about terrestrial riparian invertebrates of the North and Central Coast. Coastal temperate rainforests, in general, have very high invertebrate diversity (Lattin 1990), although riparian 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 riparian invertebrate communities living in hot springs and caves (ecosystems present in the Central and North Coast) include uniquely adapted organisms (review in Scudder 1996).

Because of their importance as fish food, aquatic invertebrates (see Young Background Report) have received more attention than their terrestrial counterparts. Terrestrial invertebrates may be equally important as food for coho salmon and cutthroat trout in some coastal systems (Wipfli 1997). Terrestrial, as well as aquatic, invertebrates drift from fishless headwater streams to fish-bearing reaches (Wipfli and Gregovitch 2001). In addition, most insects with aquatic larvae use terrestrial riparian habitats as adults, moving up to 150 m from the water (Jackson and Resh 1989). Deciduous trees and shrubs support high invertebrate abundance (citations in Wiplfi 1997). The variety of plants, microclimatic conditions and light levels in riparian areas encourage a rich invertebrate community.

Some flying insects use riparian openings as travel corridors (John Richardson, personal communication). Many insects with aquatic larvae 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).

The saturated sediment beneath streams and floodplains ("hyporheic zone") supports a rich and productive community of invertebrates, bacteria, fungi and protozoa. The hyporheic community purifies water, retains and processes solutes efficiently and speeds up decomposition (review in Edwards 1998). Studies found up to 165 species of invertebrates in hyporheic zones of Montana rivers, some 2 – 3 km from the nearest surface water (Stanford and Gaufin 1974 in Edwards 1998). Although not yet investigated, large streams and rivers of the Central and North Coast with alluvial gravel beds and relatively fast currents likely have extensive hyporheic zones. Hyporheic communities beneath floodplains depend on the large amounts of slowly decomposing buried wood for food (Edwards 1998).

Impacts of Forest Harvesting

Because deciduous vegetation supports, at least seasonally, more species of terrestrial invertebrates, management activities that encourage deciduous vegetation will provide for richer invertebrate communities. In Alaska, fish living in 31-year-old stands dominated by red alder ate more terrestrial invertebrates than fish living in oldgrowth stands with closed coniferous canopies (Wipfli 1997). Because of sampling biases, studies of terrestrial riparian invertebrates have not allowed further inferences (Wipfli 1997).

There have been no studies on impacts of harvesting on the invertebrate community of the hyporheic zone. Potential impacts include decreased volume of woody debris, changed distribution and volume of the hyporheic zone, soil compaction, altered riparian nutrient input, altered stream primary production and altered soil chemistry (Edwards 1998).

Vertebrates

Riparian Vertebrates of the Central and North Coast

Bunnell et al. (Background Report) summarise information on terrestrial vertebrates associated with coastal riparian ecosystems for the North Coast and Central Coast area. About 90 species of terrestrial vertebrates (~53% of total species) show strong affinities for riparian areas during the breeding season, and more than 10 upland and inland species migrate to coastal riparian habitat in winter. Of the breeding species, most show no preference for a particular stand age, but many show affinities for particular habitat elements including deciduous trees or shrubs, edge, conifers and cavities. Refer to Bunnell et al. (Background Report) for a full discussion of riparian associates and their links with riparian structure.

Vertebrate communities vary with riparian type (see Table 1) 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 (see Bunnell et al. Background Report). A variety of vertebrates use lakeshores and marine shores. Nearshore subtidal and intertidal riparian 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.

Impacts of Forest Harvesting and Effectiveness of Buffers

We found sufficient studies to complete a preliminary meta-analysis of impacts of harvesting and buffer effectiveness for amphibians, birds and small mammals living around small streams in the Pacific Coastal region. Results from ongoing studies in BC and Alaska should be incorporated into these analyses as they become available over the next few years. Young (Background Report) describes the use of meta-analysis to synthesise studies addressing the same subject.

The following sections present comparisons of species richness and abundance as response ratios (transformed ratio of richness or abundance after and before harvesting). It is important to consider what to measure in meta-analyses as results vary considerably with analyses and taxa studied. For example, richness can obscure changes in community composition, and abundance in buffers can increase after harvesting due to packing of individuals into smaller remaining habitat (a short-term impact that decreases over 2 – 3 years; Darveau et al. 1995) or to arrival of edge/open ground species. Because species richness and abundance provide only a partial picture at best, we also compared community composition before and after harvest, using a measure of community dissimilarity to show how different a community is from a mature or oldgrowth control. We followed the methods described by Young (Background Report), where possible, to ensure complementary approaches. Detailed methods are listed in Appendix 3.

We treat these analyses as descriptive tools rather than rigorous tests of inferences because of small samples and missing information.

<u>Amphibians</u>

Six studies of terrestrial amphibian communities met the selection criteria described in Appendix 3 (Dupuis et al. 1995, Gomez and Anthony 1996, Vesely and McComb 1996, Kelsey 2000, Maxcy 2000, Raphael et al. unpublished). The studies, from southwestern BC, western Washington and western Oregon, all looked at communities around small streams (order 1 – 4). Four studies were retrospective; two were experimental. Four examined buffers. Seven species were consistently associated with riparian areas; two species were associated with uplands.

The total number of species did not change consistently with time since harvest or buffer presence (1a; age: $F_{1,4} = 0.2$, $p = 0.7$; buffer: $F_{1,4} = 1.1$, $p = 0.4$). Relative abundance of amphibians increased with forest age (Figure 1b; age: $F_{1,5} = 12.2$, $p = 0.02$; buffer: $F_{1,5} = 1.7$, $p = 0.2$).

Communities in older forests tended to be more similar to communities in oldgrowth (Figure 1c; $F_{1,7} = 3.9$; $p = 0.09$). Although communities within buffers were more similar to oldgrowth communities in 3 of 4 studies, there was no consistent trend with buffer width (Figure 1d; $F_{1,7} = 1.3$, $p = 0.3$).

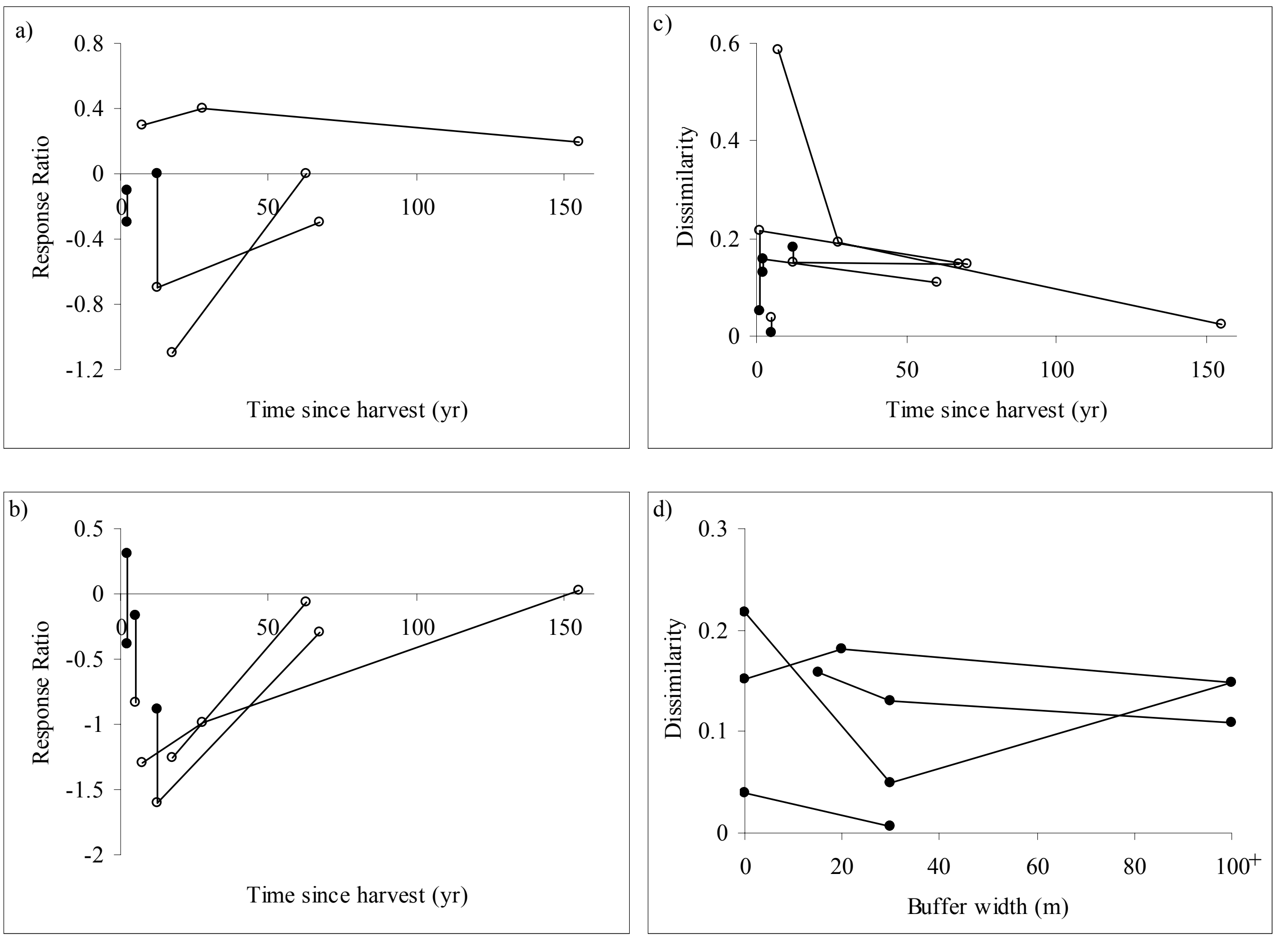

Figure 1. Results of meta-analyses for terrestrial riparian amphibians: a) change in species richness with treatment against time since harvesting; b) change in abundance or riparian associates against time since harvesting; c) change in community against timesince harvesting; d) change in community against buffer width. Solid point are buffered; hollow points are not. Each line represents a single study. Some studies are only appropriate for some analyses.

Seven species decreased following harvesting in at least one study; western red-backed salamanders (*Plethodon vehiculum)* and torrent salamanders (*Rhyacotriton variegatus)* decreased in two or more studies. No species increased in abundance, although ensatina (*Ensatina eschscholtzi)* increased in 30-m buffers in one study.

<u>Birds</u>
Four studies met the selection criteria (Carey 1988, Hagar 1999, Pearson and Manuwal 2001, Raphael et al. unpublished). Of these, three were retrospective and one experimental. Three examined buffers, one extensively. All studies looked at small streams (order 1 – 3). Four common species were associated with riparian habitat (a single study compared riparian and upland species). No common species were associated with upland areas, but 5 uncommon species were only found in upland habitat.

There were no consistent patterns in species richness or total abundance with either time since harvest or buffer presence (Figure 2a, b; richness: age: $F_{1,3} = 0.1$, $p = 0.8$; buffer: $F_{1,3} = 0.8$, $p = 0.4$; abundance: age: $F_{1,3} = 0.3$, $p = 0.6$; buffer: $F_{1,3} = 0.1$, $p = 0.7$).

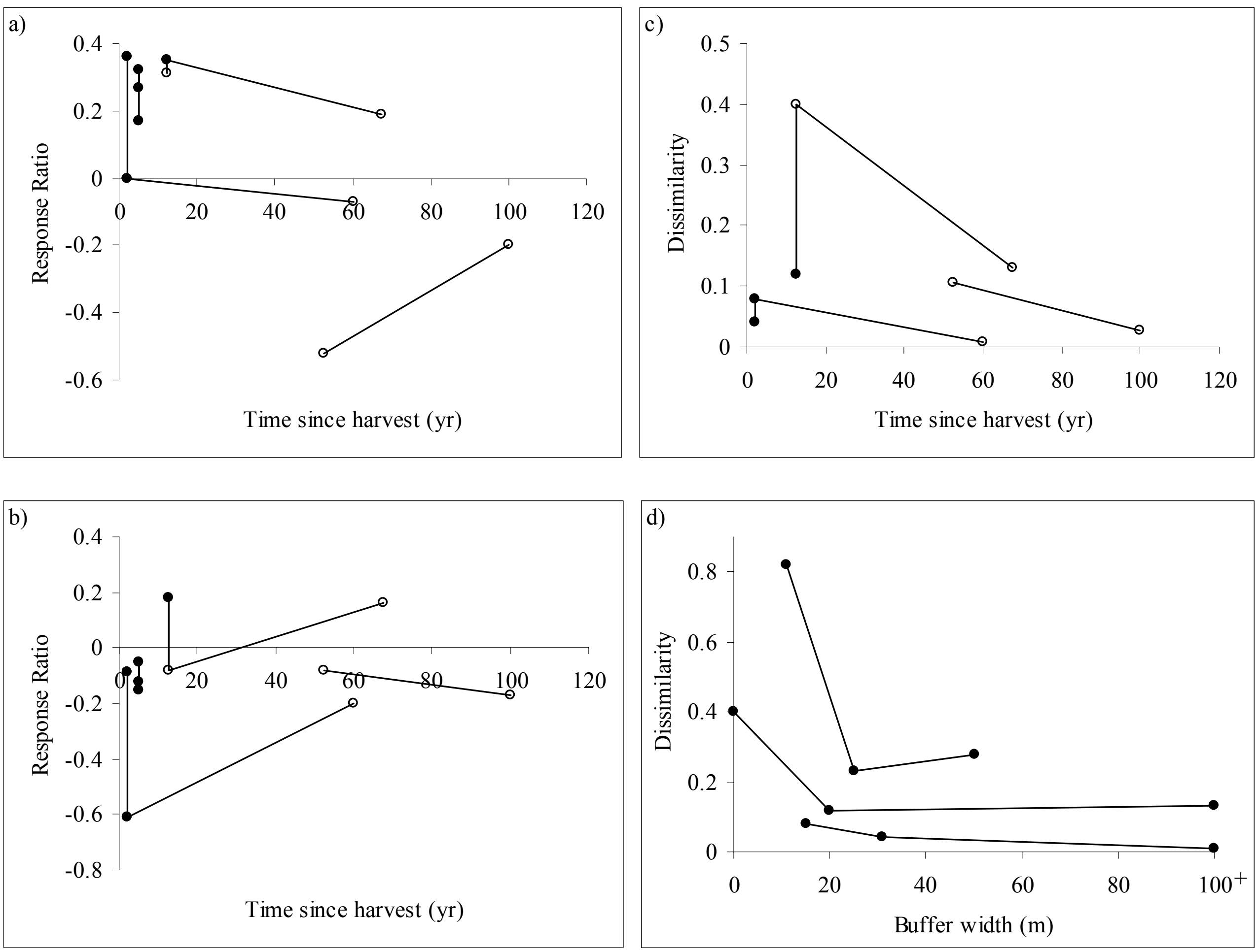

Figure 2. Results of meta-analyses for terrestrial riparian birds a) change in species richness with treatment against time since harvesting; b) change in abundance or riparian associates against time since harvesting; c) change in community against time since harvesting; d) change in community against buffer width. Solid point are buffered; hollow points are not. Each line represents a single study. Some studies are only appropriate for some analyses.

Communities in older riparian forests were more similar to oldgrowth communities than were communities in young stands (Figure 2c; $F_{1,3} = 12.8$, $p = 0.04$). There was also a significant effect of buffer presence ($F_{1,3} = 9.6$, $p = 0.05$). Further, in the studies examining more than one buffer width, communities in wider buffers were more similar to those in oldgrowth than were communities in narrow buffers. There may be a threshold at about 20 – 30 m (Figure 2d).

Five species decreased in abundance with harvesting in two or more studies (black-throated gray warbler *Dendroica nigrescens*, Pacific slope flycatcher *Empidonax difficilis*, brown creeper *Certhia americana*, winter wren *Troglodytes troglodytes*, golden-crowned kinglet *Regulus satrapa*); five species increased in two or more studies (dark-eyed junco *Junco hyemalis*, song sparrow *Melospiza melodia*, Steller's jay *Cyanocitta stelleri*, spotted towhee *Pipilo maculatus*, Wilson's warbler *Wilsonia pusilla*).

In the most detailed exploration of buffer width, Hagar (1999) found that six species increased with increased buffer width and five decreased. Neither Pacific slope flycatchers, brown creepers nor winter wrens reached their mean abundance levels in unlogged areas, even in 70-m buffers. Four other species (Hammond's flycatcher *Empidonax hammondii*, golden-crowned kinglet, varied thrush *Ixoreus naevius*, hermit warbler *Dendroica occidentalis*) were rarely observed even in the widest buffers. Two studies found that Steller's jays were more abundant in buffers than in old forest; in addition, Hagar (1999) found that Steller's jay abundance peaked in buffers 30 – 50-m wide.

<u>Small Mammals</u>
Seven studies met the selection criteria (Cross 1985, Anthony et al. 1987, Cole et al. 1998, Gomez and Anthony 1998, West 2000a, b, Raphael et al. unpublished). All examined small mammal communities around small streams (order 1 – 4) in western Washington and Oregon. Five were retrospective analyses; two were short-term experiments. Four studies examined buffers. The two experimental studies used young-mature (40-65-yr-old) forests rather than oldgrowth as the initial condition. Twelve species were associated with riparian habitat; five were associated with upland habitat.

Neither the total number of small mammal species nor the number of riparian associates changed consistently with the time since harvest (Figure 3a; total species: $F_{1,5} = 1.3$, $p = 0.4$; riparian associates: $F_{1,3} = 0.6$, $p = 0.5$). Similarly, we detected no relationship between the abundance of riparian associates and time since harvest (Figure 3b; $F_{1,6} = 0.3$, $p = 0.7$).

Within four studies with sufficient data, community dissimilarity tended non-significantly to decrease with riparian forest age (Figure 3c; $F_{1,8} = 3.9$; $p = 0.09$). Buffers of increased width mitigated impacts in all studies (Figure 3d; $F_{1,5} = 12.5$, $p = 0.02$).

Species that consistently decreased in abundance across studies with harvesting include northern flying squirrel (*Glaucomys sabrinus)*, shrew-mole (*Neurotrichus gibbsi)*, boreal red-backed vole (*Clethrionomys gapperi)*, Trowbridge shrew (*Sorex trowbridgii)*; species that consistently increased in abundance include Pacific jumping mouse (*Zapus trinotatus)*, deer mouse (*Peromyscus maniculatus)* and Oregon vole (*Microtus oregoni)*.

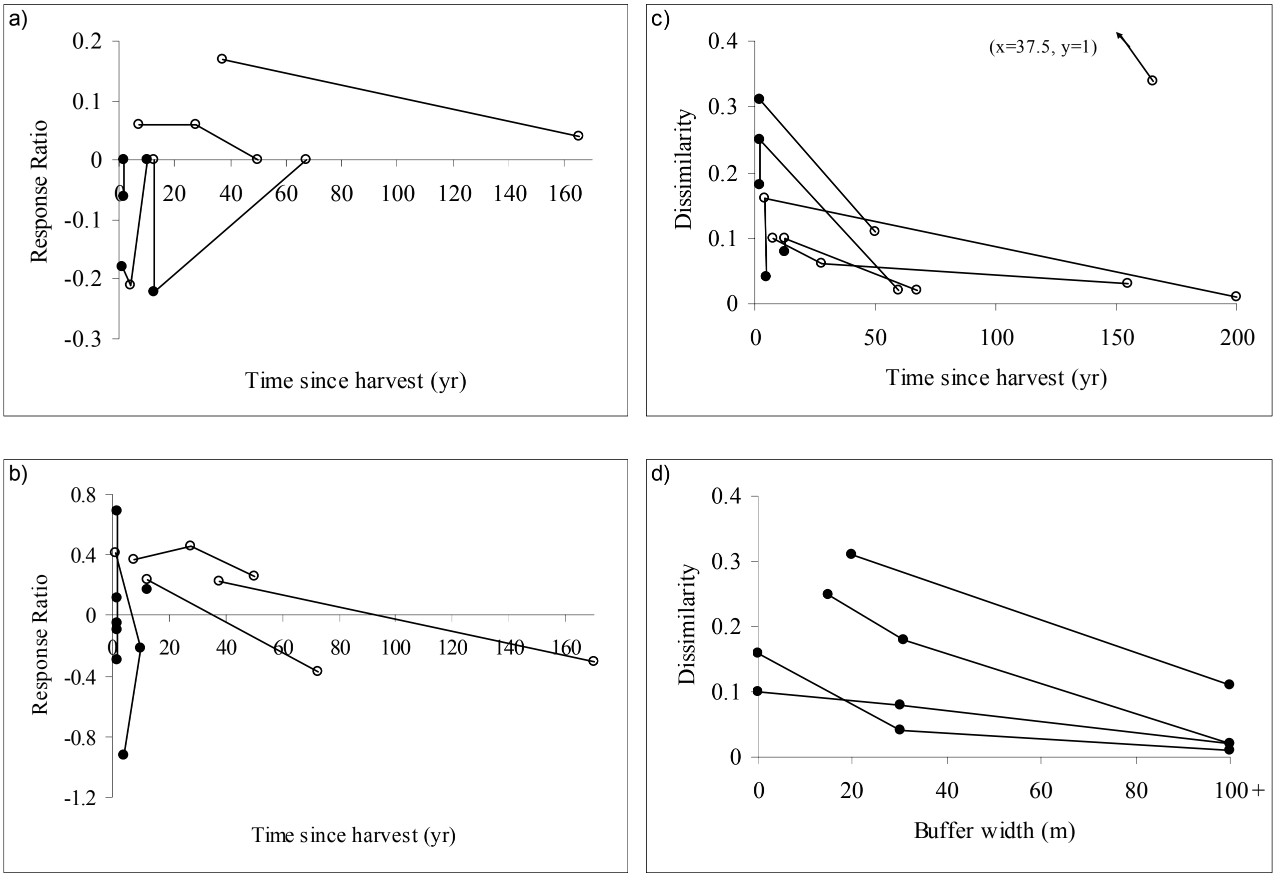

Figure 3. Results of meta-analyses for riparian small mammals a) change in species richness with treatment against time since harvesting; b) change in abundance or riparian associates against time since harvesting; c) change in community against time since harvesting; d) change in community against buffer width. Solid point are buffered; hollow points are not. Each line represents a single study. Some studies are only appropriate for some analyses.

<u>Discussion of Results</u>

We found no consistent pattern in the numbers of species of vertebrates following forest harvest. This result is unsurprising. Species richness is a poor measure of changes in communities, masking large changes in underlying species composition (Rice et al. 1983) as, for example, generalists replace specialists.

We found that the abundance of terrestrial riparian amphibians, but not birds or mammals, dropped after harvest and increased over time. We treat the pattern in amphibians as a hypothesis rather than a conclusion, but note that, of the riparian organisms analysed, amphibians have the strongest requirements for moist microclimates. Although some small mammalian and avian riparian associates prefer young seral stages and increased drastically in the early years post-harvest, no amphibians showed this pattern.

Mammalian, avian and amphibian riparian communities all changed following harvest and recovered over time. It is not possible to infer at what age communities approach oldgrowth communities as some studies used 40 – 70-year-old forests rather than oldgrowth as controls. It is apparent, however, that recovery takes decades. Buffers mitigated impacts of harvest consistently for birds and mammals (i.e. communities in riparian areas with buffers were more similar to controls than were communities in riparian areas without buffers). Very few studies compared more than one buffer width, making statements about effective widths difficult. It is interesting to note the apparent effectiveness of quite small (20 – 30m) buffers at minimising changes in bird communities relative to the gentler slope for mammals and flat pattern for amphibians. Although bird communities were similar between narrow buffers and controls, some species disappeared in even 70-m buffers (Hagar 1999). For amphibians, buffers seem to influence abundance rather than change community composition (compare buffer/non-buffer points on Figure 1); for birds and mammals, they influence communities.

All analyses found large variation among studies. This result shows that riparian communities vary among areas and is not surprising given the variation in plants and habitat structure that likely underlies vertebrate distribution patterns. Some studies used structurally complex oldgrowth as controls while others used relatively young second growth. Even within an age, plant communities vary with local disturbance regimes and microtopography (Pollock et al. 1998). For example, the proportion of coniferous basal areas in 80 – 135-year-old second growth stands varied from 0 – 92% depending on downed wood and site location (Andrus and Froehlich 1988), and, in Clayoquot Sound, riparian plant communities in adjacent watersheds shared less than half of the species (Chan-MacLeod 1996).

We caution that the meta-analyses are based on very few studies and that they apply only to communities of vertebrates around small streams in coastal ecosystems.

Impacts not available for meta-analysis

Although we could find no studies examining the impacts of roads on terrestrial riparian organisms, there is no reason to assume that roads in riparian areas are more benign that roads elsewhere. Vehicles kill animals; some predators (including people) travel along roads; many organisms, from beetles (Mader 1984) to grizzly bears (*Ursus horribilis*; McLellan and Shackleton 1988), avoid roads; non-native weeds disperse along roads (review of road impacts in Bunnell et al. 1998). Because of the abundance of animals using rich, productive floodplains, roads along valley bottoms, separating upland and riparian ecosystems, likely have high impacts.

A limited number of studies has compared the impacts of thinning on vertebrates. In young upland stands, some bird species were more, and some were less, abundant in thinned stands (Hagar et al. 1996, Dellasala et al. 1996). In the boreal forest, removing 33% of the basal area of a 20-m riparian buffer resulted in a 20% reduction in the number of pairs or breeding birds relative to an unthinned buffer of similar width (Darveau et al. 1995). In coastal Washington, riparian amphibian, bird and mammal communities in thinned mature stands were less similar to oldgrowth than were communities in unthinned mature stands (Raphael et al. unpublished data). No data are yet available comparing communities in stands harvested with different levels of retention.

Discussion

Terrestrial riparian ecosystems are different than upland ecosystems because water influences the land, changing ecosystem productivity and microclimate. Certain riparian ecosystems are special: some are biodiversity hotspots, structurally complex, spatially heterogeneous, productive and supporting rich communities; some are rare. Forest harvesting changes terrestrial riparian ecosystems. Some riparian functions recover quickly (e.g. shrub growth, shade; Andrus and Froehlich 1988); others may not (e.g. floodplain formation or hyporheic communities following loss of large downed wood; Naiman et al. 2000, Edwards 1998).

Defining Riparian Ecosystems

If goals of management are to maintain the four functions of hydroriparian ecosystems (land-on-water influence, water-on-land influence, landscape links, biodiversity; Price and McLennan 2001), riparian areas should be defined with these functions in mind.

Land-on-water influences extend at least one site-specific tree height from the water (see Young Background Report).

Water-on-land influences extend a variable distance depending upon landform and surficial materials. Small, incised headwater channels may influence vegetation and structure for a few metres, while floodplains can extend for several kilometres. Plant communities indicate the extent of direct influence. Hyporheic flow and movement of riparian-associated animals may extend further. Animals that depend on water for some resources may travel away from water to avoid edge or find snags. Aquatic-breeding amphibians and riparian small mammals range at least 200m from water; large mammals like grizzly bears and fishers (*Martes pennanti)* range over huge areas. Our review suggests that while it may be possible to define coastal riparian ecosystems from the perspective of plants, it is not possible to define a distinct boundary for animals, and too little is known about riparian fungi and microbes even to list riparian associates. The strength of the association with riparian ecosystems varies by species along a continuum from riparian obligates (e.g. aquatic mosses, beaver *Castor canadensis*) to generalists and edge species—there is no all-species boundary between riparian and upland ecosystems. For most organisms, these associations vary among geographic regions and are less well defined in cool, wet climates such as the North and Central Coast. As a further complication, for animals, the association varies among years due to variation in annual weather and to stochasticity (Rice et al. 1983).

The entire riparian network, along with upland areas that provide water, sediment, downed wood and organisms, **links the landscape** (see Church and Eaton Background Report). Particularly on the coast, riparian ecosystems are products of entire watersheds. Sediment, water and downed wood travels down steep slopes into small streams, larger streams, lakes and wetlands. Organisms travel along riparian ecosystems and between riparian and upland ecosystems. Salmon and eulachon link the ocean with riparian forest. Their carcasses, loaded with marine nutrients feed bacteria, fungi, algae, invertebrates, vertebrates and terrestrial plants (e.g. Willson and Halupka 1995, Ben-David et al. 1998, Helfield and Naiman 2001). At the landscape level, many of the impacts on terrestrial riparian ecosystems depend on hydrogeomorphic impacts as these disturbances define the land and influence of water on the land.

Important riparian areas for **biodiversity** include estuaries and tidal wetlands, floodplains and fans (productive hotspots), and shoreline forests, karst ecosystems, rich fens and marshes (regionally rare ecosystems) and bogs (globally rare ecosystems). Within the broader context of maintaining biodiversity over the watershed, it is important to recognise that although some riparian ecosystems are biodiversity hotspots, special communities are associated with even the smallest riparian ecosystems. Other organisms are associated with upland ecosystems and avoid riparian areas.

How Much to Harvest

We have little relevant data on how much forest harvesting can occur within the above-defined riparian areas while maintaining terrestrial riparian function. Natural disturbance regimes provide some guidance, based on the assumption that organisms have adapted to the landscapes and structures created by disturbance (Bunnell 1995). On the outer coast of BC, fire return intervals of 3000+ years (Gavin et al. 1997) lead to landscapes dominated by forests over 300 years old (> 98% over 140 years; CSSP 1995); forest structure and microclimate is determined by small-scale gap dynamics (Lertzman et al. 1996). Some riparian areas, particularly those within glacier-headed watersheds, are disturbed considerably more frequently, and intensely, than upland areas. Natural disturbance regimes have not yet been described for riparian ecosystems of the North and Central Coast.

Moving away from a harvest amount based on natural disturbance regimes increases uncertainty and risk to ecosystem function by an unknown amount. Modelling exercises on uniform landscapes, supported by reviews of studies on birds and mammals, provide guidance about how changes in habitat abundance influence biodiversity: theoretical landscapes are physically well-connected when 60% remains and become functionally unconnected at 30% (Stauffer and Aharony 1991, Andrén 1994). These numbers, with different associated levels of risk (see Figure 4), could be used to provide first estimates of the amount of riparian habitat to reserve. On particularly sensitive hydroriparian ecosystems or site series, management could be restricted to no more area than disturbed naturally. Red- and blue-listed fan and floodplain ecosystems should be reserved. On less sensitive areas, somewhere between 30 and 60 % could be retained. It is unclear, however, how these thresholds apply to linear riparian habitats.

Ecosystem failures (e.g. lost salmon runs, channelised floodplains) may provide information about risks to other riparian functions, although cause of failure is often ambiguous because of the nature of cumulative effects and long time lags (Harris 1988). The level of selective cutting that will maintain floodplain structure, for example, is unknown. Most productive floodplains (rare riparian ecosystems and biodiversity hotspots) on the coast have already been logged without the benefit of long-term monitoring. Current research is comparing the complexity of floodplain ecosystems in logged and unlogged drainages in the Central Coast (Audrey Pearson, personal communication).

At the stand level, it is possible to list structural attributes (e.g. large deciduous trees, large snags) required by a limited number of well-known species (e.g. Bunnell et al. 1998). It is harder to ensure that these resources will be continuously available over a managed rotation (due, for example, to blowdown), and impossible to know whether these attributes will maintain non-target species. While it is *necessary* to take special management action for species of concern (as listed in Bunnell et al. background document), these actions are *not sufficient* because our knowledge is not, and never will be, complete. For example, the role of downed wood in floodplain development and the myriad ecological functions served by the hyporheic community have only been recognised in the past decade (Naiman et al. 2000) and we have no information on the impacts of management of these important aspects on terrestrial riparian ecosystems.

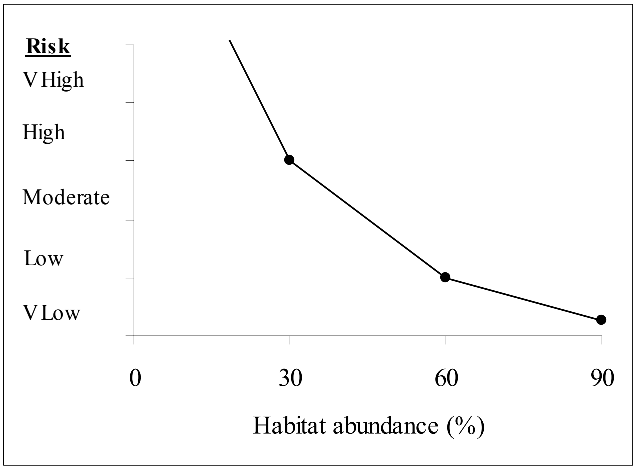

Figure 4. Theoretical risk to biodiversity with different habitat abundances. 90% approximates natural disturbance regimes in the Central and North Coast, 60% and 30% represent threshold in connectivity (see text).

It is not possible to predict responses to management activities, other than saying that some species will benefit and others will lose from any management practice. Maintaining biodiversity does not mean maximising the number of species in an area, however. Instead, it means keeping the natural distribution of species across the landscape—able to interact and evolve in response to new environmental conditions. Maintaining terrestrial riparian biodiversity is no different, although riparian ecosystems may be more problematic than upland oldgrowth forests: because of the variety of habitats available, different suites of riparian organisms will prefer different habitats and will vary in their response to disturbance. This variation in response, coupled with a general lack of knowledge, suggests that, except for a few important species, management should take an ecosystem approach to maintaining biodiversity. This approach entails maintaining a natural distribution of riparian ecosystems across the landscape. Natural disturbance regimes offer the only guidance.

Issues related to managing special riparian ecosystems of the North Coast (floodplains, fans, shoreline forest, estuaries, hydroriparian ecosystems in organic terrain, wetlands, karst and hotsprings) are discussed in Price and McLennan 2001 (attached as Appendix 4).

Allocating Conservation: Are Buffers The Best Bet?

Theoretical and empirical studies suggest that the total area of habitat available is more important that its configuration (Fahrig 1997, McGarigal and McComb 1995). For terrestrial riparian associates, the question of how much riparian habitat to conserve cannot be separated from the question of how much of the watershed to conserve.

Even though, in coastal climates, the number of species associated with riparian and upland areas are similar (Pearson and Manuwal 2001, McComb et al. 1993), community composition differs. The meta-analyses discussed in this report suggest that the communities of vertebrates around small coastal streams change following harvest, that they take several decades to recover and that buffers mitigate impacts. These results seem to support the creation of buffers around small headwater streams. However, strips of oldgrowth around small streams may not be the best way to conserve terrestrial riparian associates. First, animals associated with riparian areas also use upland habitat daily or seasonally. Second, whereas the edge on one side of undisturbed riparian ecosystems merges into continuous forest away from the water, linear buffers provide only edge. Creating edge changes microclimate within the buffer, changes structure (due to blowdown) and changes community composition. Nest predation rates may increase near edges (evidence is strong for agricultural settings in eastern North America, but not for forested ecosystems in the west; Paton 1984, Cotterill and Hannon 1999, Bunnell et al. 1998), and corridors may become population sinks, attracting breeding pairs of birds, but providing low reproductive success. Increases in Steller's jay abundance in buffers in the Pacific Coastal region (see meta-analyses) suggest that nest predation risk may increase in western riparian buffers. Third, narrow buffers often blow down, altering structure beyond the natural range of variation (Reid and Hilton 1998).

A recent comprehensive study of mammal communities in the fragmented forests of northwestern Washington suggests that riparian forest corridors are an effective *supplement* to continuous forest for maintaining biodiversity (Perault and Lomolino 2000, Lomolino and Perault 2000). Variation in community was related to structural attributes and landscape features. In particular, in riparian corridors, forest mammal communities were related to the proportion of adjacent oldgrowth, corridor width and isolation. There was evidence for reproduction in corridors, but at lower levels than in continuous oldgrowth.

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. Forest managers have moved away from fixed-width buffers over the past decade. 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. Other reserve targets in a watershed-level approach include listed ecosystems and important habitats.

Management Recommendations

Our recommendations focus on terrestrial riparian functions.

Because we know so little about so many riparian organisms, generally,

1) **Adopt the precautionary principle in managing riparian ecosystems**
2) **Base planning on an ecosystem, rather than species-by-species, approach**
3) **Accompany management with monitoring and adaptive management**
   a) **Base adaptive management decisions on data from several years because of inherent stochasticity**
   b) **For terrestrial riparian organisms, monitor community composition as well as richness**

Because riparian ecosystems serve many functions,

4) **Define the extent of riparian ecosystems as the sum of all functions:**
   a) **land-on-water influences: one site potential tree height (see Young Background Report)**
   b) **water-on-land influences: floodplains, fans, wetlands, shoreline forests, estuaries located by site series (see Table 1)**
   c) **landscape links: areas of potential sediment, water and downed wood input (see Church and Eaton Background Report)**
   d) **biodiversity: rare riparian ecosystems by site series and biodiversity hotspots (estuaries, floodplains, fans)**

Watershed planning offers opportunities for classifying sensitive and/or important riparian areas, and for noting possible sources of sediment, downed wood and water.
Because riparian organisms also use upland areas, because riparian ecosystems reflect watershed-scale process (e.g. movement of sediment, water and downed wood), and because strands of linear buffers do not offer the best protection of riparian associates,

5) **Plan riparian management within a watershed context**
6) **Use listed ecosystems and important habitats to locate reserves**
7) **Delineate riparian and upland management units simultaneously**
8) **In the origin zone, instead of buffering all small streams, consider protecting a group of small streams and the intervening upland forest**

Because natural disturbance regimes can guide management and because riparian disturbance regimes are yet uncharacterised,

9) **Compile data on natural ecosystem distributions for the North and Central Coast (site series by age class)**
   a) **include riparian ecosystems**
   b) **compare natural ecosystem distribution with current and projected distributions**

Because rare ecosystems are more at risk and because these ecosystems support countless unknown organisms with unknown ecological needs and functions,

10) **Protect all rare riparian ecosystems (CDC red- and blue-listed floodplain, fan and shoreline forest communities as well as karst ecosystems, hotsprings, and blanket bogs)**

Because some riparian ecosystems are particularly rich and productive (biodiversity hotspots),

11) Protect oldgrowth floodplains, fans and estuaries

  a) Maintain sources of input for large downed wood into floodplains, fans and estuaries

  b) Maintain structure and function of the hyporheic zone

Before riparian natural disturbance regimes have been characterised, because risks to biodiversity may increase below 60% habitat abundance, and again below 30%.

12) Maintain >30% of oldgrowth per watershed at any time

13) Maintain > 60% of oldgrowth over larger landscapes at any time

14) If a particular hydroriparian ecosystem or site series has been harvested beyond the planned level, stop harvesting until enough stands have reached an old seral stage

Because site series captures ecological variation for plants and likely some animals,

15) Maintain listed percents (60%, 30%) by site series

Because natural disturbance in coastal riparian ecosystems varies from individual tree death to large debris flows,

16) Use a variety of harvesting patterns (e.g. variable retention) within riparian ecosystems

  a) include single tree selection most often, small group selection less often and larger openings infrequently

  b) occasionally use larger openings in some dense second growth conifer stands to re-establish patches of deciduous trees

Because roads carry multiple long-term ecological costs, and because single tree and small patch cuts require more road access,

17) Minimise road access, particularly parallel to riparian areas

  a) study impacts of roads in more detail

  b) study impacts of large cuts in more detail

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Appendix 1: Rare Ecosystems of the Central and North Coast

Scientific name	Biogeoclimatic Ecosystem Classification Unit(s)	location	Provincial List	Structural Stage	Hydroriparian class
Floodplain and fan forests					
Abies amabilis - Picea sitchensis / Oplopanax horridus	CWHvm1/08 CWHvm2/08	OCM	Blue	7	fan
Abies amabilis – Thuja plicata / Oplopanax horridus	CWHws2/06 CWHms1/06 CWHms2/06	ICM	Blue	7	fan
Abies amabilis – Thuja plicata / Rubus spectabilis	CWHmm2/08 CWHmm1/07	OCM	Blue/ red	7	fan
Abies amabilis – Thuja plicata / Tiarella trifoliata	CWHmm1/05	OCM		7	
Thuja plicata / Oplopanax horridus	CWHds1/07 CWHds2/07	ICM	Red	7	fan
Thuja plicata / Rubus spectabilis	CWHxm1/13 CWHxm2/13 CWHdm/13	OCM	Red	6	fan
Thuja plicata / Tiarella trifoliata	CWHxm1/07 CWHxm2/07	OCM	Red	7	fan
Thuja plicata - Picea sitchensis / Oplopanax horridus	CWHvh2/07 CWHvh1/07	HL	Blue	7	fan
Picea sitchensis / Maianthemum dilatatum	CWHvh2/08 CWHvh1/08 CWHwh1/07	HL	Red	7	high bench floodplain
Picea sitchensis / Rubus spectabilis	CWHvm1/09 CWHms1/07 CWHms2/07 CWHxm2/08 CWHxm1/08	OCM/ ICM	Red	7	high bench floodplain
Picea sitchensis / Trisetum cernuum	CWHvh2/09 CWHvh1/09 CHWwh1/08	HL	Red	7	middle bench floodplain
Populus balsamifera ssp. *trichocarpa / Cornus stolonifera*	CWHvm1/10 CWHdm/09 CWHds1/09 CWHds2/09 CWHmm1/09 CWHms1/08 CWHms2/08 CWHws2/08 CWHxm1/09 CWHxm2/09 CWHwm/06	OCM/ ICM	Blue	6	middle bench floodplain
Tsuga heterophylla – Populus balsamifera ssp. trichocarpa / Rubus spectabilis	CWHds2/08	ICM	Red	7	middle bench floodplain
Alnus rubra / Maianthemum dilatatum	CWHvh2/10	HL	Blue	5,6	low bench floodplain
Thuja plicata - Picea sitchensis / Polystichum munitum	CWHvh2/05 CWHvh1/05 CWHwh1/03	HL	Blue	7	alluvial/ colluvial; limestone
Bogs and Forested Swamps					

Pinus contorta / Sphagnum	CWHxm1/11 CWHxm2/11	OCM	Blue	7	bog
Thuja plicata – Picea engelmannii x glauca / Lysichiton americanum	IDFww/07	ICM	interim red	7	forested swamp
Thuja plicata / Lonicera involucrata	CWHxm1/14 CWHxm2/14 CWHdm/14	OCM	Red	6	forested swamp
Thuja plicata / Carex obnupta	CWHxm1/15 CWHxm2/15 CWHdm/14	OCM	Blue	6	forested swamp
Shoreline and Estuary Fringe Forests					
Picea sitchensis / Gaultheria shallon	CWHvh2/14	HL	Blue	7	shoreline
Picea sitchensis / Kindbergia oregana	CWHvh2/15 CWHvh1/15 CWHwh1/14	HL	Blue	7	shoreline
Picea sitchensis / Polystichum munitum	CWHvh2/17 CWHvh1/17	HL	Blue	7	shoreline
Picea sitchensis / Calamagrostis nutkaensis	CWHvh2/16 CWHvh1/16 CWHwh1/15	HL	Blue	7	shoreline
Picea sitchensis / Carex obnupta	CWHvh2/18 CWHvh1/18 CWHwh1/17	HL	Blue	7	estuary fringe
Picea sitchensis / Malus fusca	CWHvh2/19 CWHvh1/19 CWHwh1/18	HL	Blue	7	estuary fringe
Sidalcea hendersonii – Tidal marsh (not forested)	CWHxm1/00	ICM	Red		estuary
Upland forests (may be riparian in small headwater streams)					
Pinus contorta / Arctostaphylos uva-ursi	CWHws2/02	ICM	Red	7	dry upland
Pseudotsuga menziesii – Pinus contorta / Arctostaphylos uva-ursi	CWHds1/02 CWHds2/02	ICM	Red	7	dry upland
Tsuga heterophylla – Thuja plicata / Gaultheria shallon	CWHmm2/03 CWHmm1/03	OCM	Blue/ Red	7	dry upland
Pseudotsuga menziesii – Pinus contorta / Cladina	CWHxm2/02	OCM	Red	7	dry upland
Pseudotsuga menziesii – Pinus contorta / Rhacomitrium canexcens	CWHxm1/02	OCM	Red	7	dry upland
Pseudotsuga menziesii – Tsuga heterophylla / Gautheria shallon	CWHmm1/02 CWHmm2/02 CWHxm1/03 CWHxm2/03 CWHdm/03	OCM	Blue	7	dry upland
Pseudotsuga menziesii – Tsuga heterophylla / Paxistima myrsinites	CWHds1/03 CWHds2/03 CWHms1/03 CWHms2/03	ICM	Blue	7	dry upland
Tsuga heterophylla – Abies amabilis Rhytidiopsis robusta	CWHmm1/01 CWHmm2/01	OCM	Blue	7	mesic upland
Tsuga heterophylla – Pseudotsuga menziesii / Kindbergia oregana	CWHxm1/01 CWHxm2/01	OCM	Red	7	mesic upland
Tsuga heterophylla – Pseudotsuga menziesii / Rhytidiadelpus triquetrus	CWHds2/01	ICM	Blue	7	mesic upland
Pseudotsuga menziesii / Polystichum munitum	CWHxm1/04 CWHxm2/04 CWHdm/04	OCM	Red	7	mesic-rich upland

Abies amabilis – Thuja plicata / Gymnocarpium dryopteris	CWHms1/04 CWHms2/04 CWHws2/04	ICM	Blue	7	mesic-rich upland
Pseudotsuga – Thuja plicata / Acer circinatum	IDFww/05	ICM	Red	7	mesic-rich upland
Pseudotsuga menziesii / Acer glabrum / Disporum hookeri	IDFww/04 CWHds1/04 CWHds2/04	ICM	Red	7	mesic-rich upland
Thuja plicata / Polystichum munitum	CWHxm1/05 CWHxm2/05	OCM	Blue	7	mesic-rich upland
Thuja plicata / Smilacina racemosa	CWHds1/05 CWHds2/05	ICM	Red	7	mesic-rich upland
Tsuga heterophylla – Thuja plicata / Blechnum spicant	CWHdm/06 CWHxm2/06 CWHxm1/06	OCM	Red	7	subhygric upland
Tsuga heterophylla – Clintonia uniflora	CWHds1/06 CWHds2/06	ICM	Blue	7	subhygric upland
Thuja plicata – Chamaecyparis nootkatensis / Coptis aspleniifolia	CWHmm2/07	OCM	Blue	7	hygric upland
Thuja plicata - Tsuga heterophylla / Polystichum munitum	CWHvm1/04 CWHvm2/04 CWHmm1/04 CWHmm2/04	OCM	Blue	7	limestone
Deschampsia cespitosa – Sidalcea hendersonii	CWHxm1/00	OCM	Red	2	non-forested
Festuca idahoensis – Koelaria macrantha	CDFmm/00 CWHxm1/00	OCM	Red	2	non-forested
Rhododendron macrophyllum – Gaultheria ovatifolia / Cladonia	IDFww/00	ICM	Red	3	non-forested
Pinus contorta / Rhododendron macrophyllum	CWHds1/00 CWHms1/00 IDFww/00	ICM	Red	7	not in area

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.

Appendix 2: Listed Plants for the Central and North Coast

CDC red- and blue-listed vascular plant species possibly occurring the North Coast and/or Mid Coast Forest District. Bold common names indicate primary association with riparian ecosystems.

Scientific name	Common name	Prov. List
Agrostis pallens	**dune bentgrass**	Blue
Arnica chamissonis ssp. *incana*	meadow arnica	Blue
Aster ascendens	long-leaved aster	Blue
Calamagrostis montanensis	plains reedgrass	Red
Callitriche heterophylla ssp. *heterophylla*	**two-edged water-starwort**	Blue
Caltha palustris var. *palustris*	**yellow marsh-marigold**	Blue
Carex glareosa var. *amphigena*	**lesser saltmarsh sedge**	Blue
Carex gmelinii	**Gmelin's sedge**	Blue
Carex lenticularis var. *dolia*	**Enander's sedge**	Blue
Cornus suecica	**dwarf bog bunchberry**	Blue
Eleocharis kamtschatica	**Kamtschatica spike-rush**	Blue
Enemion savilei	Queen Charlotte isopyrum	Blue
Hippuris tetraphylla	**four-leaved mare's-tail**	Blue
Juncus arcticus ssp. *alaskanus*	**arctic rush**	Blue
Juncus stygius	**bog rush**	Blue
Leucanthemum arcticum	**arctic daisy**	Red
Ligusticum calderi	**Calder's lovage**	Blue
Lilaea scilloides	flowering quillwort	Blue
Malaxis paludosa	**bog adder's-mouth orchid**	Blue
Montia chamissoi	**Chamisso's montia**	Blue
Nymphaea tetragona	**pygmy waterlily**	Blue
Polemonium elegans	elegant Jacob's-ladder	Blue
Polystichum setigerum	Alaska holly fern	Blue
Potentilla nivea var. *pentaphylla*	five-leaved cinquefoil	Blue
Sanguisorba menziesii	**Menzies' burnet**	Blue
Saxifraga nelsoniana ssp. *carlottae*	cordate-leaved saxifrage	Red
Senecio moresbiensis	Queen Charlotte butterweed	Blue
Triglochin concinnum var. *concinnum*	**graceful arrow-grass**	Red

Appendix 3: Methods of analysis

We selected studies giving information on the impacts of riparian forest harvest on terrestrial riparian communities performed in the Pacific Northwest (from Oregon to Alaska). We required that studies compared harvested riparian areas with mature or oldgrowth riparian areas (i.e. we did not include comparisons of naturally-disturbed areas) and that they provided information on the time since logging. We accepted experimental, before-after, studies and retrospective studies of riparian ecosystems of different ages. Not all studies identified riparian associates (i.e. species found significantly more in riparian than upland habitats). Some studies had insufficient power to test for differences; others only studied riparian areas and hence had no upland comparison. We were unable to find sufficient studies for analysis that examined the impacts of harvest on identified riparian associates, and did not wish to extrapolate riparian association between studies. Hence, we relaxed our criteria to include studies of the impacts of riparian forest harvest on terrestrial organisms using riparian areas.

We collected data from tables and figures on total species richness, richness of riparian associates, total abundance and abundance of riparian associates for logged and control sites. For each variable, we calculated a response ratio, $R = X_L/X_C$, (where X_L and X_C are the values, or sample means, of the logged and control sites, respectively) and used a log transformation to improve normality (Hedges et al. 1999). We found, as did Young (Background Report), that some papers either reported single observations or did not report measures of dispersion around means. Given the paucity of studies available, we chose to use all information available and calculate unweighted statistics (Gurevitch and Hedges 1999).

We differed from Young (Background Report) in our consideration of before-after designs. Rather than calculating a mean from 2 – 3 years of post-treatment data, we chose to use the longest time after treatment (i.e. year 2 or 3) in the response ratio to minimise ephemeral effects of disturbance.

We were unable to analyse the data by stream gradient or size because all studies that met our criteria were performed on small streams. We classified data by buffer zone presence or absence. We analysed the data using analysis of covariance (response ratio as dependent variable, time since logging as continuous independent variable, buffer presence and study as categorical independent variables). The analysis essentially fits a regression for each study and tests for variation among intercepts. We initially fitted models including interactions between time since logging and buffer presence and removed non-significant interactions.

We measured community dissimilarity using a squared chord distance: $d_{ij} = \Sigma(\sqrt{p_{ik}} - \sqrt{p_{jk}})^2$, (where d_{ij} is the dissimilarity coefficient between two communities i and j; p_{ik} is the proportion of species k in community i and p_{jk} is the proportion of species k in community j) with moderate signal-to-noise properties (i.e. influenced moderately by less common species; Overpeck et al. 1985). Where studies identified riparian associates, we compared these communities; otherwise, we used the entire riparian community. We calculated dissimilarity between logged and control communities for each treatment described (including time since harvesting and buffer width). We then examined patterns in community against time since harvest, classified by buffer presence/absence and study, and patterns in community against various buffer widths, classified by study. We again used analysis of covariance (community dissimilarity as dependent variable, either time since harvest or buffer width as continuous independent variable, study as independent category). No results had significant interactions between age and buffer; hence we removed the interaction term from the model.

Appendix 4: Issues by Hydroriparian Class (from Price and McLennan 2001)

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[5].

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.

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[5] 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.

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 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[6].

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

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[6] 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.

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.

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 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.

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).

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.

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).

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.

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