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RIPARIAN ECOSYSTEM MANAGEMENT LITERATURE REVIEW

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Prepared by:

Mark Kepkay

John Cathro

Working to protect, maintain, and restore forests

P.O. Box 9, Slocan Park, British Columbia, Canada V0G 2E0 Phone 250-226-7222 Fax 250-226-7446

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1. Introduction

The value of a fully functioning ecosystem cannot be overstated. Sensitive ecosystems, such as riparian zones, are especially valuable because of the unique and essential ecological functions they perform. From high elevation sub-alpine tarns to wide intertidal estuaries, riparian ecosystems and the adjacent upland slopes provide protection to a natural system that performs a range of essential ecological functions from providing wildlife habitat to distributing nutrients across the landscape. One study suggests that the cleansing action alone of aquatic zones supported by riparian areas is worth anywhere from $ 400 to $ 1,500 per acre, per year (Tellman et al 1993).

This review encompasses a wide body of current literature on the ecological function of riparian ecosystems. The purpose is to examine the scientific rationale behind establishing protected riparian ecosystems, and discuss riparian zone management options in practice today. Specifically, this review is comprised of the following five sections:

- Section 2 presents several definitions of the term *riparian ecosystem* and explores the particular role this ecosystem plays in the fully functioning forest including wildlife habitat, nutrient cycling, temperature regulation, and movement corridors for plants and animals.
- Section 3 examines a number of studies which help us to understand the ecological sensitivity to disturbance of riparian ecosystems, including windthrow, stream bank wasting, and downstream sedimentation.
- Section 4 discusses the effects of modification, in particular logging, on riparian ecosystem ecological function. Several studies that focus on the impact of industrial modification on the ecological function of riparian ecosystems are examined.
- Section 5 documents selected riparian ecosystem management policies in place in North America today, with special attention paid to the protective riparian buffer widths recommended in the Forest Practices Code of British Columbia.

We hope that this literature review will help clarify the importance of protecting fully functioning riparian ecosystems within an adequate margin of safety. In this light, timber management may progress towards truly ecologically responsible practices.

2. The Role of Riparian Ecosystems in Forest Functioning

Definitions

Riparian ecosystems, which are also called riparian areas or riparian zones, are crucial elements of the forest ecosystem. The Silva Forest Foundation (Silva) defines the **riparian ecosystem** as consisting of the riparian zone and the riparian zone of influence**.** **The riparian zone** is the wet forest adjacent to creeks, rivers, lakes, and wetlands. It is recognized by plant species and physical features that depend on the site's relatively abundant moisture that is absent from the drier surrounding forest types. **The riparian zone of influence** is the drier upland forest immediately adjacent to the riparian zone. These upland areas are important buffers that protect riparian zone functioning and also provide drier, more open habitat that is used as a movement corridor by upland species.

Gregory and Ashkenas (1990) define the riparian area as:

> *The aquatic ecosystems and the portions of the terrestrial ecosystem that directly affect or are affected by the aquatic environment. This includes streams, rivers, and lakes and their adjacent side channels, floodplains and wetlands. The riparian area includes portions of hillslopes that serve as streamside habitat for wildlife.*

Thomas et al (1979) state that, "riparian zones can be identified by the presence of vegetation which requires free unbound water, or conditions that are more moist than normal".

The Forest Practices Code of British Columbia Riparian Zone Management Area Guidebook provides a similar definition, and put these zones in the context of their contribution to the larger ecosystem:

> *Riparian zones occur next to the banks of streams, lakes and wetlands and include both the area dominated by continuous high moisture content and the adjacent upland vegetation that exerts an influence on it. Riparian ecosystems contain the highest value non-timber resources in the natural forest. The majority of fish food organisms come from overhanging vegetation and bordering trees while leaves and twigs that fall into the streams are the primary nutrient source that drives aquatic ecosystems* (p. 1).

Significantly, the Riparian Zone Management Area Guidebook goes on to identify riparian zones as the most important part of the ecosystem because they:

> *frequently contain the highest number of plant and animal species found in forests, and provide critical habitats, home ranges, and travel corridors for wildlife. Biologically diverse, these areas maintain ecological linkages throughout the forest landscape, connecting hillsides to streams and upper*

> *headwaters to lower valley bottoms. There are no other landscape features within the natural forest that provide the natural linkages of riparian areas* (P. 1).

Scientific Research Into Riparian Ecosystem Functioning

The enormous importance of fully functioning riparian ecosystems is well established in the scientific literature. The unique and critical functions served by riparian ecosystems can be categorized as follows:

- Large Fallen Trees: Riparian ecosystems are the primary source of large fallen trees for downstream watercourse reaches, estuaries, open seas, and beaches. (Gonor et al 1988, Sedell et al 1988, FEMAT 1993) In these ecosystems fallen trees that originally stood near banks of inland and upstream watercourses provide unique food, cover, storage of sediment and organic matter, and structural diversity (Bisson et al 1987). Sedell et al (1988) found, for example, that stream reaches in Alaska with large fallen trees supported 5 to 50 times the amount of juvenile salmon as reaches where logging had removed large fallen trees. Large fallen trees of different species have different effects on aquatic environments (Bisson et al 1987).
- Nutrient Source: Trees, shrubs, and other plants growing within riparian ecosystems are the primary source of nutrients in the form of fallen leaves, flowers, and twigs to aquatic environments (FEMAT 1993, Franklin 1991). Different tree and other plant species provide leaves and twigs of different nutrient quality, timing, and longevity (Franklin 1991). These differences of quality, timing and longevity probably result in differences in function as food for invertebrates and other organisms.
- Temperature Regulation: The shade and wind protection provided by the forest canopy within riparian ecosystems maintains cool stream temperatures (Sedell et al 1988, FEMAT 1993). Stream temperature is an important regulator of aquatic life (Beschta et al 1987), including salmon populations. Across a wide variety of forest types studied in the USA, removal of the canopy has caused significant increases of up to 10 degrees in summer maximum stream temperatures (Beschta et al 1987 and references therein).
- Wildlife Habitat: Large living and dead trees in riparian ecosystems provide essential and prime habitat for many vertebrates (Marcot 1997, Della Sala et al. 1995). Over 90% of terrestrial vertebrate species use riparian ecosystems during part of their life cycles (Thomas 1979 as cited in Della Sala et al. 1995). Gregory (1997) states, "Wildlife dependence on riparian resources extends over diffuse gradients extending well into upslope terrestrial environments."

  Many species of amphibians appear especially dependent on old, moist forest sites such as those provided by unmodified riparian ecosystems. Bury and Corn (1988b) found an average of 3.7 amphibians per square meter in Pacific Northwest headwaters. Burton and Likens (1975) as referenced in Welsh and Lind (1988) found that in a New Hampshire forest one species of salamander accounted for more biomass than any other vertebrate group. In these two very different forest types and locations, amphibians function as important converters of invertebrate biomass — by eating bugs and plants, and in turn being eaten — to prey for many larger vertebrates (Welsh and Lind 1988).

Bury and Corn (1988a) designated two and Raphael (1988) tentatively designated three more amphibians as sensitive to logging in the Pacific Northwest. Buhlmann et al. (1988) discuss the significant decline of one salamander's numbers after clearcutting in Virginia, and gives references to studies that found similar declines in salamanders after logging in New York deciduous forests and in Pacific Northwest redwoods. Welsh and Lind (1988) found the greatest diversity of amphibian (mostly salamander) species in old, moist sites.

Habitat features most common to riparian ecosystems that are essential to many amphibian (especially salamander) species include humidity and soil moisture (Bury 1983 as cited in Welsh and Lind 1988, Buhlmann et al 1988), proximity to open water for rearing and breeding (Bury and Corn 1988a), and large fallen trees (Bury and Corn 1988a, Raphael 1984). Small mammals that may depend on undisturbed riparian ecosystems for long-term population viability include the Pacific marsh shrew. Corn et al (1988) found an association between the integrity of older wet forests, small streams, and swamps and small mammal population density.

<u>Maintenance of Microclimate</u>: Research from Rosenberg and Raphael (1986) found a significant reduction in numbers of two amphibian species in late successional stands of less than 10 hectares—that is, in stands where almost all of the habitat is influenced by one or more edge effects. The **edge effect** is caused by the penetration of wind, light, and humidity (as well as sound, predation, and visibility) creating differences in microclimatic conditions, such as air and soil temperature, beyond and into the vegetation bordering a zone of disturbance (Dunster and Dunster 1996). While natural openings such as rock and lakes create their own natural edge effects, riparian ecosystems maintain microclimatic conditions.

Chen (1991) as cited by FEMAT (1993) found that in Cascade sites relative humidity can be reduced and wind speed can be increased, even 150 meters from a clearcut edge. Soil moisture was found to be largely unaffected at distances of more than 20 meters from an edge, while soil temperature could be significantly higher than natural within approximately 50 meters. Corresponding results in old-growth Douglas fir from Jiquan and Franklin (1990) as cited in Hopwood (1992) are 120 to 180 meters for air temperature and relative humidity and 60 to 120 meters for soil temperature and moisture.

An extreme and controversial edge effect is cowbird parasitism on bird nests, which Terborgh (1992) reports can extend up to 7 km into forest edges. Haskell (1995) cites evidence that in fact nest predation may be just as high in the interior as at the edge, but simply by mammals like chipmunks or mice whose mouths are too small to eat the chicken and quail eggs used in Terborgh's experiments.

- Movement Corridors: Riparian ecosystems provide travel corridors for a large number of species (Della Sala et al. 1995, Franklin 1991). Riparian ecosystems are essential movement corridors for fish, invertebrates, mammals, microorganisms, and plants.

The ecological functions of riparian ecosystems described above are some of the most important functions that these ecosystems provide. Additional ecological functions of riparian ecosystems would include the storage of water by floodplains for release in drier periods, thereby more evenly distributing water flow over the year, and the stabilization of stream banks and river channels to allow for the deposition of sediments during floods.

What is more, these are only the ecological functions performed by riparian ecosystems that we have identified and described to date. The unique and complex nature of riparian ecosystems may perform a number of essential ecological functions that are as yet beyond our understanding.

3. Ecological Sensitivity to Disturbance

Riparian ecosystem functioning is known to be very sensitive to disturbance. The special sensitivities of these ecosystems include:

- Windthrow: Riparian ecosystems generally exhibit a high risk of windthrow due to moist or wet soils and shallow rooting (Franklin 1991). While very low levels of logging may be designed to avoid unnaturally high levels of windthrow (Stathers et al. 1994 give guidelines), even this amount of cutting may be considered high-risk.
- Sedimentation: Riparian ecosystems in general present a high risk of sediment transport from sites of exposed mineral soils due both to proximity to watercourses and water bodies and to the often steep slopes adjacent to watercourses.
- Mass Wasting: On steep slopes adjacent to watercourses and floodplains, as well as in their headwaters there is generally a high risk of mass wasting (Dietrich and Dunne 1978 as cited in FEMAT 1993). Sidle et al. (1985) indicate that tree harvest and other disturbances can reduce slope stability through loss of root strength. For this reason Franklin (1991) states that retention of many live trees on upland areas may reduce

mass-wasting hazard significantly. This would include smaller natural events such as stream bank wasting where stabilizing structures, such as tree roots and boulders, are removed (FEMAT 1993).

- Soil Compaction: Riparian ecosystems generally have a high risk of soil compaction due to moist and wet soils composed of fine alluvial deposits. Human forest use activities that would potentially compact the soil may have a negative impact on the ecological functioning of the riparian ecosystem .

4. Effects of Modification on Riparian Ecosystem Functioning

The effects of modification on the ecological functioning of riparian ecosystems is widely debated, poorly understood, and relatively undocumented. While log-jammed stream channels and clearcuts down to the beach are powerful images, there has yet to be a comprehensive study made on the full range of impacts of modifying riparian ecosystems.

This section describes the findings of studies made into the effects of human-made modifications on the ecological functioning of riparian ecosystems.

- Large Fallen Trees: Andrus and Froehlich (1988) found that in riparian stands younger than 80 years in the Oregon Coast Range large snags (over 30 centimeters) are largely absent, while in stands older than 80 years large snags averaged approximately 3 per acre.

  This would mean that the conversion of old growth riparian forests to younger forests through logging would seriously reduce the supply of large fallen trees to riparian and downstream ecosystems for a long time.

- Temperature Regulation: Andrus and Froehlich (1988) found that shading of streams in the Oregon Coast Range can reach near old-growth levels within 10 years of logging, although it should be noted that the productivity of these sites are probably higher than the British Columbia average, so the regeneration of younger stands may take longer in most forests.
- Maintenance of Microclimate: The ability of a riparian forest to maintain microclimatic conditions can be reduced by the creation of logged openings. The edge effect, described above, is responsible for a number of impacts that limit the full functioning of a riparian ecosystem. These edge effects would increase where logging removed forest from areas adjacent to riparian buffers on all sides of watercourses or water bodies (FEMAT 1993, CSSP 1995).

Additional effects on ecological functioning of riparian ecosystems caused by human modification would include the increased risk of windthrow, mass wasting, stream bank erosion, and downstream siltation. What is more, the removal of large living and dead trees in the riparian ecosystem would reduce the amount of available wildlife habitat.

5. Selected Approaches to Riparian Ecosystem Management

The ecological function performed by, and the ecological sensitivity to disturbance of, riparian ecosystems provide two compelling reasons to select management options that will have the most limited potential impact. This section describes various approaches to riparian ecosystem management as presented in the current literature. In particular the BC Forest Practices Code standards are evaluated in terms of their ability to define and protect riparian ecosystem functioning. In addition, a recent riparian ecosystem protective buffer width literature review conducted in Washington State is summarized.

Riparian Zone Management in British Columbia

Regulation of land development is the jurisdiction of a number of different government agencies in BC. Table 1 describes the federal legislation that pertains to riparian ecosystem management (Chillabeck 1993).

Table 1. Partial List of Federal Agency Approvals for Land Development Projects

Agency	Legislation	Description
Department of Fisheries and Oceans	Fisheries Act	Approval for activities which impact fish and fish habitat.
Transport Canada Canadian Coast Guard	Navigable Waters Protection Act	Permit for activities in navigable waters for commerce, transportation or recreation.
Department of Indian and Northern Affairs	Indian Act	Approval for lands under jurisdiction
Department of Energy, Mines and Resources	Explosives Act	Use and transport of explosives.
Federal Environmental Review Office	Environmental Assessment and Review Process Guidelines	Requirement for environmental Impact Assessment
Environmental Protection Branch	Environmental Protection Act	Environment and human health, toxic substances, water and air quality standards.
Canadian Wildlife Service	Canadian Wildlife Act	Permission for activities affecting wildlife and wildlife habitat in wildlife areas
Inland Waters Branch	International River Improvements Act	Approval of work environment of rivers flowing outside Canada

While the above federal agencies have jurisdiction over activities that may occur in riparian ecosystems, they are for the most part limited to specific, and relatively narrow areas of influence. The human use in riparian ecosystems with the greatest potential of negative impact is industrial logging. Logging in Canada is a provincial concern.

Table 2 describes the range of British Columbian legislation that pertains to riparian ecosystem management (Chillabeck 1993).

Table 2. Partial List of Provincial Agency Approvals for Land Development Projects

Agency	Legislation	Description
Ministry of Environment, Lands and Parks: Regional Operations	Fisheries Act	Approval for activities that impact fish and fish habitat.
Water Management Branch	Water Act	Approval for use, storage or diversion of water.
Environmental Protection Division	Waste Management Act	Permit the discharge or emission of effluent into air, land, or water.
Crown Lands Branch	Land Act	Regulation of sale, lease or license of Crown Lands.
Environmental Assessment Branch	Environment Management Act	Requirements for impact assessment and environmental protection, as ordered.
Ministry of Agriculture Fisheries and Food	Soil Conservation Act	Permit for the removal of soil from an ALR. Regulations to prevent soil erosion
Agricultural Land Commission	Agricultural Land Commission Act	Approval to use land in the ALR for other than farm use.
Ministry of Health	Health Act	Approval of camp standards; potable water supply, sewage disposal, food operations.
Ministry of Attorney General:	Fire Service Act	Approval for more than 22.5 litres of fuel storage on site and dispensing.
Ministry of Municipal Affairs, Recreation, and Housing	Heritage Conservation Act	Approval to excavate or alter sites of archaeological or historical significance.

While each of these provincial agencies has authority within its own jurisdiction for defining and implementing riparian ecosystem management measures, there are many complications involved in having so many regulations attempting to accomplish essentially the same task. The legislation touted by some as the comprehensive solution to previous inter-governmental duplication is the Forest Practices Code of British Columbia.

The Forest Practices Code of British Columbia

Starting in June 1995, all timber development activities in BC are regulated by the Forest Practices Code of British Columbia Act (the Code). The Code establishes mandatory requirements for planning and forest practices, sets enforcement and penalty provisions, and specifies administrative arrangements. More than 30 Code guidebooks have been developed to support the regulations. The following Code guidebooks directly or indirectly address the issue of riparian ecosystem management:

1. Channel Assessment Procedure Guidebook
2. Community Watershed Guidebook
3. Lake Classification and Lakeshore Management Guidebook
4. Fish-stream Identification Guidebook
5. Interior Watershed Assessment Guidebook (IWAP): Level 1 Analysis
6. Riparian Management Area Guidebook

The Riparian Management Area Guidebook provides guidance on planning and conducting operations within the riparian-, fisheries-, and marine-sensitive zones. The Code divides riparian management area into two distinct sub-zones; the riparian management zone and the reserve zone. In the **riparian management zone** there are constraints to forest practices, and in the **reserve zone**, where it is required by regulation, all logging is prohibited.

According to the Riparian Management Area Guidebook, in order to achieve riparian management area objectives, forest practices within the management zone should:

- where a riparian management area has both a management area and a reserve zone:
  ⇒ reduce risk of windthrow to the reserve zone, and
  ⇒ retain important wildlife habitat attributes including wildlife trees, large trees, hiding and resting cover, nesting sites, structural diversity, coarse woody debris, and food sources characteristic of natural riparian ecosystems.
- where a riparian management area has only a management zone:
  ⇒ retain sufficient vegetation along streams to provide shade, reduce bank microclimate changes, maintain natural channel and bank stability and, where specified, maintain important attributes for wildlife, and

⇒ adjacent to wetlands and lakes, retain key wildlife habitat attributes characteristic of natural riparian ecosystems.

While these definitions appear to compare favourably with the Silva definition of riparian ecosystem given at the beginning of this report, it must be noted that the key is not how these ecological functions are defined, but rather how adequately they are protected.

The Code recognizes three different types of riparian management area:

1. Streams
2. Wetlands
3. Lakes

The following methodology is employed in establishing riparian management boundaries in these three types of riparian management areas.

Streams

The Code defines a stream as a watercourse having an alluvial sediment bed, formed when water flows on a perennial or intermittent basis between continual definable streambanks (Riparian Management Area Guidebook, p. 4.). The Code recognizes two broad categories of streams (Fish Stream Identification Guidebook): fish streams and non-fish streams.

Fish streams are included within four separate stream classes (S1 to S4) based on mean channel width, are designated for the purpose of riparian management, and are those streams or particular reaches of streams that:

1. are community watersheds
2. are known to contain at any time of the year, any of the fish species listed in Table 1 (from the Fish-Stream Identification Guidebook) or, if this information is not known
3. are less than 20% average gradient, and flow directly into:
   ⇒ a fish bearing stream containing the species listed in the Guidebook,
   ⇒ the Pacific Ocean, or
   ⇒ a lake known to support fish.

A stream is considered to be fish bearing if it contains any of the following species at any time of year (Fish Stream Identification Guidebook):

1. anadromous salmonids: coho, chinook, pink, chum, sockeye, steelhead trout, rainbow trout, cutthroat trout, bull trout, and Dolly Vardon char
2. freshwater game species:
   ⇒ non-anadromous salmonids: Kokanee (sockeye) salmon, rainbow trout (includes Kamploops trout), cutthroat trout, brown trout, lake trout, brook trout, bull trout, Dolly Vardon Char, mountain whitefish, lake whitefish, and Arctic grayling.

⇒ other species: largemouth bass, smallmouth bass, walleye, yellow perch, black crappie, burbot, northern pike, and white sturgeon.

3. threatened or endangered fish identified as *red listed* by the BC Conservation Data Center
4. regionally important fish determined by the Ministry of Forests district manager and the Ministry of Environment, Lands and Parks deputy minister or a person authorized by the deputy minister.

Non-fish bearing streams are those streams or specific reaches of streams that:

1. are not in community watersheds
2. are less than 20% average gradient but are proven to contain no anadromous salmonids, freshwater game fish, threatened or endangered fish, or regionally important fish at any time of year
3. are greater than 20% average gradient, with some exceptions.

Stream classification constrains forest management by requiring a certain size of riparian management area.

Table 3 describes the specified riparian zone management recommendations contained in the Riparian Management Area Guidebook.

Table 3. Minimum Stream Riparian Management Areas in British Columbia

Riparian Class	Channel Width (m)	Reserve Zone Width (m)	Management Zone Width (m)	Total RMA[1] Width (m)
S1	> 100	50	20	70
S2	>5<20	30	20	50
S3	1.5<5	20	20	40
S4	<1.5	0	30	30
S5	>3	0	30	30
S6	<3	0	20	20

Fish bearing streams or community watersheds

Non-fish stream and not in community watershed

[1] RMA = Riparian Management Area

Wetlands

The Riparian Management Area Guidebook defines a wetland as:

> *a swamp, marsh, or other similar area that supports natural vegetation that is distinct from the adjacent upland areas. More specifically, a wetland is an area where a water table is at, near, or above the surface of where soils are water-saturated for a sufficient length of time that excess water and resulting low oxygen levels are principal determinants of vegetation and soil development.*

The Code identifies 5 classes (W1 to W5) of wetlands based on its size, its complexity, and the biogeoclimatic unit in which the wetland occurs. Wetlands greater than 5 hectares have a riparian class of W1. Wetland classes W2, W3, and W4 are determined by the biogeoclimatic unit, with W4 being between 0.25 and 1 hectare in size, and W2 and W3 being up to 5 hectares in size. Wetland complexes have a riparian class of W5. Wetlands less than 0.25 hectares are unclassified.

Table 4 describes the specified minimum slope distances for wetland riparian management areas.

Table 4. Minimum slope distance for Wetland Riparian Management Areas

Riparian Class	Reserve Zone Width (m)	Management Zone Width (m)	Total RMA Width (m)
W1	10	40	50
W2	10	20	30
W3	0	30	30
W4	0	30	30
W5	10	40	50

Lakes

The Code identifies four riparian classes of lakes (L1 to L4) as determined by the lake size and the biogeoclimatic zone in which they occur. Lake class L1 is for lakes greater than 5 hectares in size. Lake classes L2 and L3 are for lakes between 1 and 5 hectares in certain biogeoclimatic units. Lake class L4 is for lakes between 0.25 and 1 hectare in size in certain biogeoclimatic units. Lakes that are less than 1 hectare and which do not occur in certain biogeoclimatic zones are unclassified.

Table 5 describes the minimum slope distances required under the code for these four lake classes.

Table 5. Specified Minimum Slope Distances for Lake Riparian Classes

Riparian Class	Reserve Zone Width (m)	Management Zone Width (m)	Total RMA Width (m)
L1	10	0	10
L2	10	20	30
L3	0	30	30
L4	0	30	30

The scope of this literature review does not permit a complete evaluation of the Code standards for riparian ecosystem management. However, two important distinctions that should be understood are:

1. The classification of water bodies as fish bearing or non-fish bearing greatly influences the amount of protective riparian buffer required. Not seeing fish does not mean that the stream is non-fish bearing.
2. Recommended buffer widths are measured in slope distance and not horizontal distance. On steep slopes, the slope distance represents a much shorter horizontal distance.

As with all legislation, the true test of the Code is at the point of application and enforcement. It is still too early to tell how the language contained in the code will look on the ground. In addition, there is little agreement on whether changes to the Code made in April, 1998, will result in improved practices.

Other Related Riparian Ecosystem Management Options

A literature review concerned specifically with recommended buffer widths to maintain the various functions of stream riparian areas has been prepared for the King County (Washington) Surface Water Management Division (Johnson and Ryba, 1992). This review found that, "the buffer widths recommended by 38 separate investigators to maintain seven riparian functions ranged from 3 to 200 meters," and that, "except for grazing, the results from various studies from across the nation and from Europe consistently ranged from 15 to 50 meters".

Table 6 describes the recommended buffer widths to maintain specific riparian functions.

Table 6. Recommended Buffer Widths to Maintain Specific Riparian Functions

Riparian Function to be Maintained	Range of Buffer Widths (m)	Number of Studies to Determine Width
Miscellaneous buffer functions	30 to 122	9
Sediment removal	30 or more	7
Stream temperature	30 or more	6
Nutrient control	15 to 30	8
Protection of salmonid habitat	30 or more	-
Protection of small mammal habitat	67 to 93	-
Protection of breeding bird habitat	75 to 200	- 15 (for all habitat studies)
Protection of large mammal habitat	100	-
Protection of aquatic insect communities	30 or more	-

In addition, much of the current literature on riparian ecosystem management has resulted in a greater understanding of the role of protective buffer strips. Some of these results include the following:

- Large Fallen Trees: McDade et al. (1990) found that a 30 meter no-logging buffer would provide 85 percent of natural levels of large fallen trees in riparian old growth conifer stands of western Oregon and Washington. A 10 meter buffer, on the other hand, was determined to supply less than 50 percent. Where trees are bigger, it is thought that buffers would also need to be larger in order to supply similar percentages. FEMAT (1993) and CSSP (1995) consider that a 30 meter buffer is required to supply approximately 75% of the large fallen trees found in a natural system.

  It needs to be added that in British Columbia, the retention of high levels of snags for future stream inputs of fallen trees reduces the amount of logging that can take place in accordance with Workers Compensation Board regulations, which require no-work zones around all snags that pose a significant safety hazard.

- Nutrient Source: Franklin (1991) recommends maintenance of all riparian tree species in order to maintain the diversity of nutrient quality, longevity, and timing. Erman et al (1977) as cited in FEMAT (1993) found that where riparian buffers are greater than 30 meters, invertebrate communities that depend on fallen leaves and twigs are indistinguishable from those in unlogged watersheds.

- Habitat: Corn and Bury (1988) found that even 20 to 40 years after clearcutting, modified streams in the Pacific Northwest had much lower numbers (2 to 10 times lower) and much fewer species (less than half) of amphibians than unlogged streams. Silva considers such a degradation of amphibian populations for such a long time to be far outside the range of ecologically responsible timber management practices; therefore logging, if any, in protected riparian ecosystems will be minimal.

- Temperature Regulation: Beschta et al (1987), while noting that the efficacy of riparian reserve areas depends as much on the tree species, age, and density as it does on width of reserve areas, state that in general a buffer of 30 m will provide old-growth levels of shading.

  Steinblums (1977) as cited in FEMAT (1993) found that riparian buffers of approximately 30 m will generally provide as much shade as undisturbed old growth forests, although variations in topography, stream orientation, and forest structure can affect this figure significantly. CSSP (1995) used similar figures.

- Maintenance of Microclimate: Noss and Cooperider (1994) and Della Sala (1995) recommend that protected riparian ecosystems be large enough to prevent the edge effects that threaten the long-term viability of riparian species.

- Movement Corridors: Della Sala et al. (1995) consider that FEMAT (1993) and PACFISH (1994) standards for riparian management zones sized 90 meters on either side of stream are probably adequate to accommodate movements of small mammals and neotropical migrants with small home ranges. However, they also state that corridors for animals sensitive to microclimatic variations (e.g., salamanders) will need to be at least as wide as relevant edge effects. Chen et al.'s (1990) figure of 787 feet (240 meters) is mentioned specifically.

  Machtans et al. (1996) verified the continued and preferential use of a 100 m riparian buffer as a corridor by birds in a logged boreal forest of Alberta. Juvenile use, probably for dispersion, actually increased.

- Stability of Slopes: Franklin (1991) states that retention of many live trees on upland areas may reduce mass-wasting hazard significantly, although the research is not conclusive.

Clayoquot Sound Scientific Panel, FEMAT, and PACFISH Recommendations

The Clayoquot Sound Scientific Panel (CSSP 1995) recommendations for Clayoquot Sound, simplified here, include reserves of 50 meters for most channels wider than 3 meters and reserves of 30 meters for most of those narrower than 3 meters. Most channels with a seasonal or perennial flow are given reserves of 20 meters. Ephemeral streams are given no protection. CSSP makes extensive recommendations for adapting these basic sizes to account for terrain, floodplain, stream gradient, and other site specific factors.

FEMAT (1993) and PACFISH (1994) as cited in Gregory (1997) both recommend a no-logging riparian management zone of 90 meters for fish-bearing streams, 45 meters for non-fish-bearing permanent streams, and 30 meters for seasonally flowing streams. FEMAT (1993) also states the distances in terms of ‘site-potential trees’. This means that in areas other than the Pacific Northwest, where trees generally grow taller than in other parts of Cascadia, these no-logging zones would be slightly smaller. Gregory (1997) considers the FEMAT recommendations “major advances in the management of aquatic ecosystems”.

6. Summary

There is much that we do not know about the ecological functioning of riparian ecosystems. However, there is wide agreement that the unique functions of riparian ecosystems are as sensitive as they are essential. Riparian ecosystem functions are many and do not need to be repeated here, except to say that ongoing research increasingly supports the idea that most, if not all, riparian ecosystems should be reserved from timber cutting, and other potentially degrading industrial activities. Furthermore, this body of research suggests that this protective measure is particularly important because of the high ecological sensitivity to disturbance of riparian ecosystems.

In light of this riparian ecosystem management research, the central question remains: how big should protected riparian ecosystems be?

Franklin (1991) warns that no simple prescription can be applied to all riparian ecosystems and that protected areas should be designed to match the shape and size of landforms, especially the tops of stream entrenchment slopes. There is general agreement in the literature that protective buffers of 30 to 50 meters on each side of creeks, lakes, and wetlands are required to maintain and protect most of the riparian ecosystem functions.

In addition, past experience shows that we have generally underestimated the required width of these protective buffers. The more we learn, the more apparent it becomes that these sensitive riparian ecosystems must be afforded the maximum level of protection in order to ensure their long-term functioning.

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