# Riparian Management and Effects on Function

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## INTRODUCTION: RIPARIAN MANAGEMENT IN BRITISH COLUMBIA

### Riparian Ecotones: Functions and Values

Riparian areas are the complex interface between aquatic and terrestrial environments within watersheds. These areas have been described as three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems, and that extend down into the groundwater, up above the forest canopy, outward across the floodplain, laterally into the near-slopes to various distances into terrestrial areas, and along watercourses at variable widths (Ilhardt et al. 2000).

Riparian meadows and forests extend from the smallest headwater tributaries to the mouths of the highest-order streams within watersheds. A riparian zone thus forms the key boundary that moderates all hydrological, geomorphological, and biological processes associated with this interconnected fluvial corridor (Swanson et al. 1988; Figure 15.1). Streamside zones are highly vulnerable to disturbance from processes and events occurring upslope and upstream because of the relatively small size of these zones and the extensive longitudinal and lateral connections with associated aquatic and terrestrial ecosystems (Swanson et al. 1988). These areas maintain ecological linkages throughout the forest landscape, connecting hillsides to streams and upper headwaters to lower valley bottoms (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a). No other landscape features within forests provide linkages that are as extensive and complex as those provided by riparian ecotones.

Riparian areas contain and support many of the highest-value resources in natural forests (Hartman and Scrivener 1990). The plant and animal communities in riparian areas frequently have the highest species richness found in forests (Gregory et al. 1991). Riparian habitats are also critical for several obligate species and for numerous others that use riparian areas for home ranges, travel corridors, and other purposes for at least a part of their life histories (McComb 1989). Raedeke (1988) indicated that 60% of the 480 species of wildlife in Washington State are found in wooded riparian habitats; 68 species of these mammals, birds, amphibians, and reptiles require riparian ecosystems to satisfy a vital habitat need during all or part of the year; and 103 species achieve their maximum abundance in riparian zones.

Streamside riparian areas may contain excellent growing sites for trees (Mouw and Dixson 2008). At the same time, these areas support aquatic ecosystems and associated fish populations through several functions (see Chapter 13, “Stream and Riparian Ecology,” and Chapter 14, “Salmonids and the Hydrologic and Geomorphic Features of Their Spawning Streams in British Columbia”). Riparian vegetation stabilizes streambanks, provides shade to help regulate stream temperatures, provides a source of wood (“large woody debris” or LWD) for stream

FIGURE 15.1 *The riparian zone forms the key boundary that moderates all hydrological, geomorphological, and biological processes associated with interconnected fluvial corridors. Class S1 stream shown with riparian reserve. (Photo: R.G. Pike)*

channels, and supplies both organic detritus (leaves, twigs, and other plant material) that drives aquatic food webs and terrestrial invertebrates that serve as a direct source of food for fish (Gregory et al. 1991; Naiman and Décamps 1997; Naiman et al. 2000).

Although a significant amount of riparian research has been undertaken in the past 30 years, the debate about how to best manage these areas continues to dominate current riparian management in British Columbia and elsewhere. This is no wonder, given the intrinsic values riparian areas provide, and the diversity of riparian types and functions across the province.

The multitude of riparian values is at the centre of this debate because these values not only represent important ecological and environmental services, but also economic and social opportunities. For example, some stakeholders are concerned that certain levels of riparian protection will result in losses of forestry opportunities, wood and wood products, water withdrawals for agriculture and domestic use, grazing and cropland, access to minerals and mining, and freedom to manage private land (Verry 2000). Representatives of other interests believe that riparian areas require sufficient protection to avoid impacts to water quality and quantity, fish populations and habitat, native plant and animal species and communities, opportunities for recreation, aesthetic values, hydrological connections within watersheds, and ecological connections within watersheds and across landscapes. Riparian management often attempts to strike a balance among these often competing domains.

**Legislation and Regulations in British Columbia**

In British Columbia, several legislative statutes apply when working in and around water and, consequently, riparian areas. The *Water Act* regulates changes in or around streams to ensure that water quality, water quantity, fish and wildlife habitat, and the rights of licensed water users are not compromised. The *Water Act* applies to all streams regardless of the presence or absence of fish. Provisions under the *Water Act* are currently administered by the British Columbia Ministry of Environment. Federally, Fisheries and Oceans Canada has responsibility for all fish and fish habitat in Canada. The federal *Fisheries Act* prohibits the harmful alteration, destruction, or disruption of fish and fish habitat, as well as the deposition of deleterious substances in fish-bearing waters. For further details from the *Fisheries Act*, go to: http://laws.justice.gc.ca/en/ShowFullDoc/cs/F-14/.

The *Fish Protection Act* and the Riparian Areas Regulation are two additional legislative tools used to protect fish and fish habitat in British Columbia. The four major objectives of this Act are to: (1) ensure sufficient water for fish; (2) protect and restore fish habitat; (3) improve riparian protection and enhancement; and (4) strengthen local government powers in environmental planning. It works in concert with the *Water Act* to cover areas not fully addressed through existing legislation. The Riparian Areas Regulation was enacted under the *Fish Protection Act* to ensure that local governments protect riparian areas during residential, commercial, and industrial development. It is used for urban riparian management and does not apply to agriculture, mining, or forestry-related land uses.

Two provincial statutes apply specifically to forestry practices, including riparian management, on the timber harvesting land base. The *Private Managed Forest Land Act* applies to activities conducted on privately owned (non-Crown) forest lands, whereas the *Forest and Range Practices Act* (FRPA) and its predecessor, the *Forest Practices Code of British Columbia Act*, apply to all activities on Crown land in British Columbia including privately owned portions of Tree Farm Licences. In this chapter, we focus on the riparian management provisions under the latter two statutes. Knowledge of riparian management under the FRPA and FPC is important because many of the riparian provisions within the current results-based FRPA have been retained from the prescriptive FPC as default approaches in regulation.

This chapter provides a summary of the different riparian management systems and practices applied in British Columbia's forested watersheds. We discuss how forest management is conducted and how it can potentially affect riparian areas, streams, and fish habitats. We conclude with a summary of current efforts to evaluate the effectiveness of riparian management practices in British Columbia.

## RIPARIAN MANAGEMENT OBJECTIVES AND FRAMEWORK

### Objectives, Values, and Principles

Recommendations for ecosystem-based approaches to riparian management have been advanced since the early 1990s (Gregory et al. 1991; Forest Stewardship Council 2005; Richardson et al. 2005). However, all jurisdictions in the Pacific Northwest of North America use fish as the principal, if not dominant, foundation for riparian management in forested areas. For example, the Forest Stewardship Council of Canada's riparian standards address various environmental values and ecosystem processes at watershed and site scales, but retain fish presence or absence as the main determinant for its stream classification and management system (Forest Stewardship Council 2005). Water for domestic use is the other most frequently identified management objective in the Pacific Northwest and elsewhere in North America.

No scientifically sound basis exists for managing riparian and aquatic values on the presence of game fish alone. Nevertheless, some jurisdictions, such as the State of Alaska and the United States Department of Agriculture Forest Service Region 10 (Alaska), explicitly emphasize the importance of anadromous salmonids or "high-value" resident fish (i.e., trout and char) and require higher levels of protection for waters used by these species. The foundation for determining riparian practices in British Columbia is largely fish-based (see next section), but riparian management objectives generally encompass a broader, watershed-process perspective to maintain and protect riparian functions. For example, objectives for managing riparian areas under the FPC looked beyond a fish-focussed view and were implemented to:

1. minimize or prevent impacts of forest and range uses on stream-channel dynamics, aquatic ecosystems, and water quality of all streams, lakes, and wetlands;
2. minimize or prevent impacts of forest and range use on the diversity, productivity, and sustainability of wildlife habitat and vegetation adjacent to streams, lakes, and wetlands with reserve zones, or where high wildlife values are present; and

3. allow for forest and range use consistent with 1 and 2 above (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a).

These principles remain consistent with the objective set by government in FRPA's Forest Planning and Practices Regulation (FPPR) for water, fish, wildlife, and biodiversity within riparian areas, which is: "without unduly reducing the supply of timber from British Columbia's forests, to conserve, at the landscape level, the water quality, fish habitat, wildlife habitat and biodiversity associated with those riparian areas" (Forest Planning and Practices Regulation).

Riparian management objectives vary broadly across the Pacific Northwest. In federally managed forests in the United States (i.e., USDA Forest Service Region 6), riparian management is focussed on the protection and enhancement of riparian ecosystems and habitats for species that rely on late-successional and old-growth forests (e.g., Northern Spotted Owl), and for the Aquatic Conservation Strategy in the Northwest Forest Plan (see Tuchmann et al. 1996). Accordingly, conservative riparian provisions are in place to ensure compliance with the United States *Endangered Species Act* and the *Clean Water Act*.

In Oregon and Washington, tree retention targets in riparian management zones have been based on multiple objectives around managing for riparian and aquatic values, riparian ecosystem functions, and rehabilitating inadequately stocked forest stands (Adams 1996; Oregon Secretary of State 2010a, 2010b; Washington State Department of Natural Resources 2010).

### Classification of Streams, Lakes, and Wetlands in British Columbia

Before we describe the different riparian management systems used in British Columbia, it is useful to summarize the water-body classification system used in forestry management, and to review some of the commonly used terms and concepts associated with both the FPC and FRPA approaches for streams, lakes, and wetlands.

The principal management unit is the riparian management area (RMA), which has been in continuous and consistent use across the province since 1995. This unit consists of a riparian management zone (RMZ) and, sometimes, a no-harvest riparian reserve zone (RRZ) located immediately adjacent to the water body (Figures 15.2, and 15.3). The widths of

FIGURE 15.2 *Riparian management area tree retention by basal area applied within 10 m of a small stream. (Photo: R.G. Pike)*

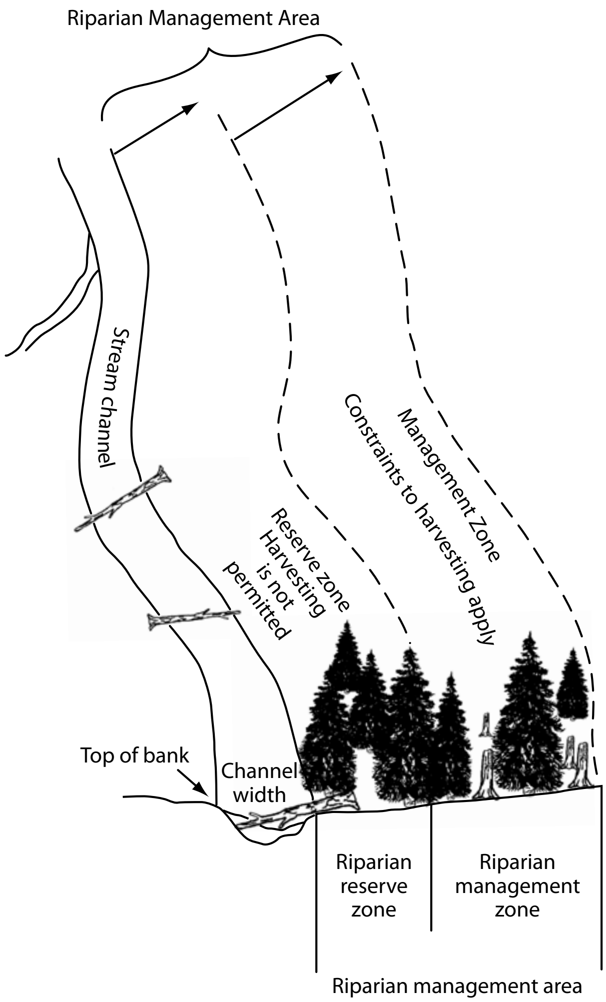


FIGURE 15.3 *Riparian management area for streams showing a management zone and a reserve zone along the stream channel (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a).*

these zones are determined by specific attributes of streams, wetlands, or lakes, and sometimes by the characteristics of the adjacent terrestrial ecosystem. Constraints to forest practices are imposed within the management zone.

A riparian classification system was established in FPC regulations for streams, wetlands, and lakes, and is continued under the FRPA (see Forest Planning and Practices Regulation). In this system, streams are classified from S1 to S6 based on:

- fish presence,
- location in a community watershed, and
- average channel width.

Stream classification is based on the "reach" concept. A reach is understood to be a relatively homogeneous length of stream having a sequence of repeating structural characteristics (or processes) that also correspond to fish habitat types. The key physical factors used to determine reaches in the field are channel pattern, channel confinement, gradient, and streambed and streambank materials. Stream reaches generally show uniformity in these characteristics and in discharge (see B.C. Ministry of Forests and B.C. Ministry of Environment 1995a). The characteristics of stream reaches are described further in the *Fish-stream Identification Guidebook* (B.C. Ministry of Forests and B.C. Ministry of Environment 1998).

Streams and reaches were defined separately in the FPC. Only the definition of stream has been retained for the FRPA, and is modified slightly to include a 100-m minimum channel length, which corresponds to the 100-m minimum reach length specified in the FPC. Under Section 1 of the Forest Planning and Practices Regulation:

> *"'stream' means a watercourse, including a watercourse that is obscured by overhanging or bridging vegetation or soil mats, that contains water on a perennial or seasonal basis, is scoured by water or contains observable deposits of mineral alluvium, and that*
> *(a) has a continuous channel bed that is 100 m or more in length, or*
> *(b) flows directly into*
> *(i) a fish-stream or a fish-bearing lake or wetland, or*
> *(ii) a licensed waterworks."*

Watercourses failing to meet this definition are not subject to the management provisions presented in Table 15.1, which summarizes the riparian classification system for streams and the width and retention standards for the associated riparian reserves and management zones. Riparian classes S1–S4 are fish-bearing streams or streams in community watersheds. Classes S5 and S6 are streams without fish.

Similarly, prescribed classifications for reserve and management zones of lakes and wetlands depend on water-body size and other characteristics (Figures 15.4 and 15.5; Tables 15.2 and 15.3). The four riparian classes of lakes (L1–L4) are determined by:

- lake size, and
- the biogeoclimatic ecosystem classification (BEC) unit in which they occur.

TABLE 15.1 *Riparian management area standards for streams under the FPC and FRPA. Widths of reserve and management zones are slope distances measured from the streambank perpendicular to the channel. This classification framework developed for the FPC has been retained under the FRPA.*

| Riparian class | Average channel width (m) | Reserve zone width (m) | Management zone width (m) | Total width of RMA (m) | Retention in RMZ (%)[a] |
|---|---|---|---|---|---|
| S1-large (FPC) = S1-A (FRPA) | > 100 (for > 1 km of stream length) | 0 | 100 | 100 | ≤ 70[b] |
| S1 (FPC) = S1-B (FRPA) | > 20 | 50 | 20 | 70 | 50 |
| S2 | > 5 to ≤ 20 | 30 | 20 | 50 | 50 |
| S3 | 1.5 to ≤ 5 | 20 | 20 | 40 | 50 |
| S4 | < 1.5 | 0 | 30 | 30 | 25 |
| S5[c] | > 3 | 0 | 30 | 30 | 25 |
| S6[c] | ≤ 3 | 0 | 20 | 20 | 5 |

a Recommended in the *Riparian Management Area Guidebook* for FPC only as maximum and averaged over large operating areas, not specific to each cutblock (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a).
b Softwood retention = 50% within 20 m of island perimeters and channel banks (see Table 6, B.C. Ministry of Forests and B.C. Ministry of Environment 1995a). Hardwood retention as per active floodplains = 70% (see Table 6, B.C. Ministry of Forests and B.C. Ministry of Environment 1995a).
c Non-fish-bearing streams.

The specified distances for the reserve zone and management zone of each lake riparian class is presented in Table 15.2. The outer edge of the lake is measured from the high-water mark or the edge of an immediately contiguous wetland.

Wetlands include shallow open water, swamps, marshes, fens, and bogs (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a). The FPC definition of wetland has been retained under FRPA as: "a wetland is a swamp, marsh, or other similar area that supports natural vegetation, that is distinct from the adjacent upland areas" (Forest Planning and Practices Regulation). The *Riparian Management Area Guidebook* (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a) further described wetlands as areas where "the water table is at, near, or above the surface or where soils are water-saturated for a sufficient length of time that excess

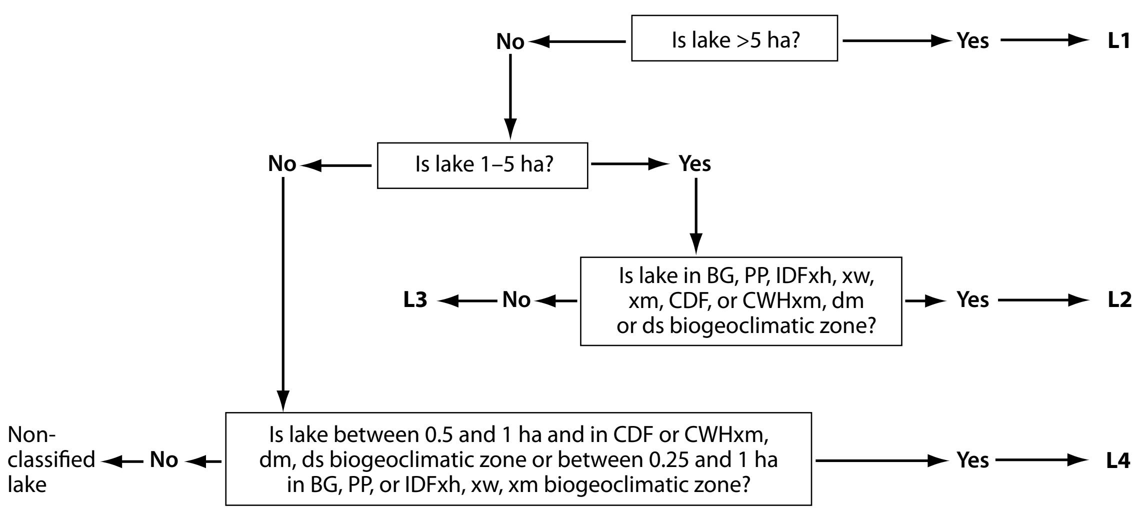


FIGURE 15.4 *Riparian classification key for lakes under the FPC and FRPA (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a). Interior BEC zones: BG = Bunchgrass, PP = Ponderosa Pine, IDF = Interior Douglas-fir. Coastal BEC zones: CDF = Coastal Douglas-fir, CWH = Coastal Western Hemlock. BEC subzones: xm = very dry (xeric), maritime; xw = very dry, warm; dm = dry, mild; ds = dry, submaritime.*

TABLE 15.2 *Riparian management area standards for lakes under the FPC and FRPA. Management zone widths for class L1 lakes of less than 1000 ha were established by the district manager (DM) under the FPC, and by the Minister or delegated decision maker (DDM) under the FRPA.*

| Riparian class | Reserve zone width (m) | Management zone width (m)[a] | Total width of RMA (m) |
|---|---|---|---|
| L1 > 1000 ha (FPC) = L1-A (FRPA) | 0 | 0 | 0 |
| L1 < 1000 ha (FPC) = L1-B (FRPA) | 10 | Set by DM (FPC) or by Minister/DDM (FRPA) | 10 (+ RMZ set by DM/DDM) |
| L2 | 10 | 20 | 30 |
| L3 | 0 | 30 | 30 |
| L4 | 0 | 30 | 30 |

a Maximum overall RMZ retention guideline under the FPC was 25% by tree basal area for all lake and wetland classes combined within an area covered by a Forest Development Plan. Limits are not given under the FRPA except for minor tenure holders (≥ 10%).

TABLE 15.3 *Riparian management area standards for wetlands under the FPC and FRPA*

| Riparian class | Reserve zone width (m) | Management zone width (m)[a] | Total width of RMA (m) |
|---|---|---|---|
| W1[b] | 10 | 40 | 50 |
| W2 | 10 | 20 | 30 |
| W3 | 0 | 30 | 30 |
| W4 | 0 | 30 | 30 |
| W5[b] | 10 | 40 | 50 |

a Maximum overall riparian management zone retention guideline under the FPC was 25% by tree basal area for all lake and wetland classes combined within an area covered by a forest development plan. Limits are not given under the FRPA except for minor tenure holders (≥ 10%).

b Under the FPC, no riparian reserve or riparian management zone was required for upland terrain within a bog-dominated or muskeg-dominated wetland larger than 1000 ha in boreal, sub-boreal, or hypermaritime climates. However, where a reserve or management zone was established by the district manager, the RMA was recommended to reflect the landscape-level management strategy that was outlined in the *Biodiversity Guidebook* (B.C. Ministry of Forests and B.C. Ministry of Environment 1995b). Under FRPA, these considerations are specific to W1 wetlands, and the reserve and (or) management zone that may be required by the Minister or DDM are restricted in width to ≤ 10 m and ≤ 40 m, respectively (see Forest Planning and Practices Regulation).

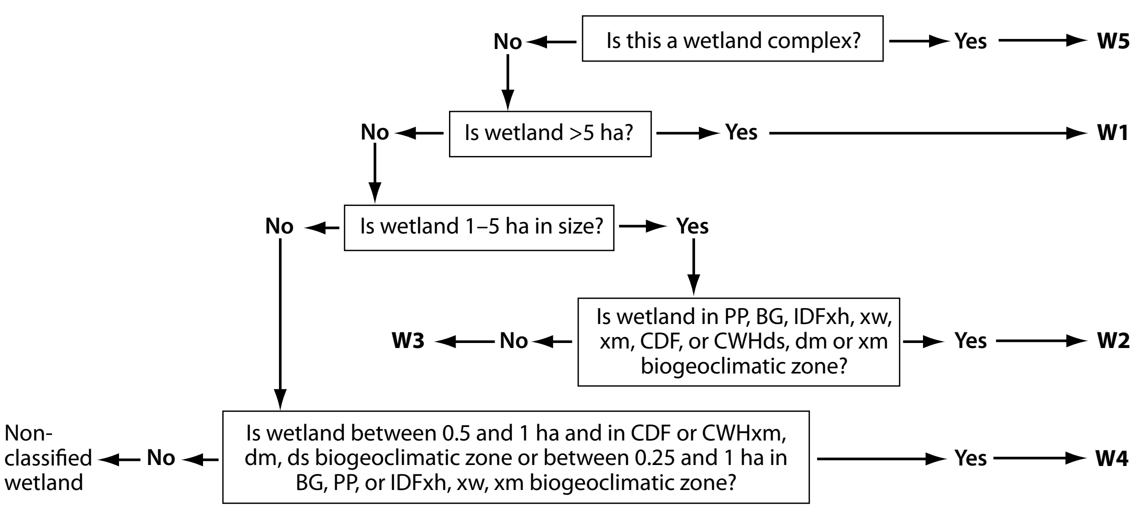


FIGURE 15.5 *Riparian classification key for wetlands under the FPC and FRPA (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a).*

water and resulting low oxygen levels are principal determinants of vegetation and soil development."

The five riparian classes of wetlands (W1-W5) are based on:

- whether the wetland is a simple wetland or a wetland complex,
- wetland size, and
- the biogeoclimatic unit in which the wetland occurs.

A wetland complex exists where the riparian management area of one wetland overlaps that of one or more other wetlands. Class W1-W4 wetlands are simple wetlands, whereas class W5 is a wetland complex.

**Fisheries-sensitive and Marine-sensitive Zones or Features**

Since the implementation of the FPC, two additional areas have been addressed within British Columbia's riparian management systems: (1) fisheries-sensitive zones and (2) marine-sensitive zones (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a, 1998). Fisheries-sensitive zones were defined in the FPC to include "side and back channels, ponds, swamps, seasonally flooded depressions, lake littoral zones, and estuaries that are seasonally occupied by over-wintering fish." This definition was problematic because it included a mix of stream and non-stream features. Accordingly, the definition was revised for FRPA to manage those sites occupied by fish but not covered by the definitions of stream or wetland. Under FRPA, fisheries-sensitive zones are called "fisheries-sensitive features" and include:

- the littoral zone of a lake;
- a freshwater area where the water is less than 10 m deep; and
- a flooded depression, pond, or swamp that is not a stream, wetland, or lake, but
  - either perennially or seasonally contains water, or
  - is seasonally occupied by a species of fish referred to in paragraph (a) of the definition of fish-bearing stream (Forest Planning and Practices Regulation).

Marine-sensitive zones were defined under the FPC to include herring spawning areas, shellfish beds, marsh areas, existing aquaculture sites, juvenile salmonid-rearing areas, and adult salmon–holding areas. All of these locations are retained under the current "marine-sensitive features" definition in the FRPA, with the addition of the littoral zones of marine and estuary systems and marine areas where water is less than 10 m deep. For further information on the classification of riparian management areas for streams, lakes, and wetlands, see the *Riparian Management Area Guidebook* (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a), the *Fish-stream Identification Guidebook* (B.C. Ministry of Forests and B.C. Ministry of Environment 1998), and the FRPA Forest Planning and Practices Regulation.

**Achieving Riparian Management Area Objectives**

In British Columbia, riparian management area objectives were achieved under the FPC with a mixture of prescriptive standards (e.g., streamside reserves with specified minimum widths) and planning and practices requirements under the Operational Planning Regulation and Timber Harvesting Regulation, as well as non-prescriptive guidance. The *Riparian Management Area Guidebook* (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a) identified considerations for practices around the different riparian classes of streams. Where a stream had both an inner reserve zone and outer management zone (fish-bearing classes S1–S3), the guidebook recommended practices that:

- reduced the risk of windthrow into the reserve zone (Figure 15.6); and
- retained 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 had only a management zone (e.g., fish-bearing class S4 streams; non-fish-bearing classes S5 and S6 streams), practices were recommended to:

- retain sufficient vegetation along streams to provide shade (Figure 15.7), reduce bank microclimate changes, maintain natural channel and bank stability and, where specified, maintain important attributes for wildlife; and

FIGURE 15.6 *Riparian management area windthrow on small stream. (Photo: R.G. Pike)*

FIGURE 15.7 *Provision of shade. (Photo: R.G. Pike)*

- retain key wildlife habitat attributes adjacent to wetlands and lakes that were characteristic of natural riparian ecosystems.

A set of recommended "best management practices" was provided for the management zones of streams, wetlands, and lakes to help meet riparian objectives (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a); however, a wide range of acceptable practices was possible for any site depending on factors such as windthrow hazard (Chatwin et al. 2001). This generated considerable debate around the adequacy of best management practices for water bodies protected solely with riparian management zones—that is, for small fish-bearing streams (class s4) and those streams without fish (class s6) as well as the larger, non-fish-bearing streams (class s5) (Chatwin et al. 2001).

One reason for supplanting the prescriptive FPC with the results-based FRPA was to increase management efficiency by allowing forest licensees more latitude to identify and implement practices on the ground that are best suited to specific conditions. Within the legal framework of the FRPA, licensees are provided with the ability and responsibility to manage within a regime based on professional reliance and accountability (see subsection, "Site- and Watershed-level Approaches under the *Forest and Range Practices Act*," below). The expected environmental outcomes or "results" of management practices remain essentially the same between the FPC and FRPA. Within the FPC, the methods to achieve government objectives were largely prescribed, except that more flexibility was permitted within the riparian management areas of smaller streams (classes s4–s6). This prescriptive regime also required government review and approval of all forestry plans, from 5-year forest development plans, which covered relatively large operating areas, to site-level harvest plans. Furthermore, any amendments during the life of the plans had to be reviewed and approved by government. The cost and administrative encumbrances of this system were other reasons to establish a results-based system in which the only step involving government review and approval is at the initial forest stewardship plan stage (replacing the forest development plan) when licensees identify the strategies and (or) results that will ensure that their operations are consistent with government's stated objectives in the FPPR to: "conserve water quality, fish habitat, wildlife habitat and biodiversity in those riparian areas" (Forest Planning and Practices Regulation). More details on the contrasts between FRPA and FPC are provided in the next section.

## RIPARIAN MANAGEMENT SYSTEMS IN BRITISH COLUMBIA

Since 1995, three riparian management schemes have emerged for wide application in British Columbia. Two of these schemes are the legislated management systems under the *Forest Practices Code of British Columbia Act* and its successor, the current *Forest and Range Practices Act*. The third scheme was developed by the Forest Stewardship Council of Canada, a non-government body that offers environmental certification for land-use practices. All of these schemes are generally based on the water-body classification system developed for the FPC.

The prescriptive FPC and the results-based FRPA differ primarily in that FRPA provides more explicit latitude to vary riparian management standards from legislated defaults. Departure from default standards would be based on site-level and watershed-level characteristics. The Forest Stewardship Council system is generally a more conservative approach that requires higher levels of riparian retention for all water-body classes, in particular for small streams (classes s4–s6). This system is voluntary, and can be one of the alternative approaches approved by government under a FRPA forest stewardship plan.

In British Columbia, small streams included within the s4–s6 categories have been the focus of attention and debate because these streams are particularly challenging to manage. Within each class, these streams exhibit a diverse array of channel sizes, channel types, drainage-system linkages, and ecological functions. Collectively, s4–s6 streams may make up 80% or more of the total length of the drainage network within a given watershed. Because of this abundance and diversity, riparian management strategies for small streams ideally need to be flexible, adaptable, and tailored to the operating area and specific environments.

A "landscape-level" approach has also received some conceptual attention in British Columbia in recent years. In this section, we summarize all of these approaches and concepts.

**Forest Practices Code Approach to Riparian Management**

In various forms, the site-level, rules-based approach for riparian management is common to all jurisdictions in northwestern North America. These schemes are the easiest to implement and administer and have been presumed to provide consistent and reasonable levels of protection for aquatic resources, although few jurisdictions have implemented systematic and widespread post-harvest effectiveness assessments (see "Riparian Assessments in British Columbia," below). The FPC's prescriptive approach, based on riparian classification, legislatively specified the minimum widths for riparian management areas and the associated reserve and management zones. For streams, these widths varied on the basis of channel width, stream gradient, community watershed use, and fish presence. These limited attributes were meant to identify appropriate levels of vegetation retention and management activities that minimized the introduction of sediment (especially fine sediments) and woody debris into water bodies, which included a wide array of stream types within many different environmental settings. The intention was to provide protection for a broad range of riparian values, including wildlife, biodiversity, channel and aquatic habitat integrity, and water quality.

In reality, the FPC approach for riparian management was a mixture of rules and results-based elements. The rules-based system of riparian reserves and management zones of prescribed minimum widths was established as a surrogate for desired riparian management outcomes (results) because the exact thresholds for riparian, channel, and aquatic ecosystem responses to streamside management activity, site disturbance, and vegetation retention were (and remain) unknown. Rules were also contained within practices regulations (e.g., Timber Harvesting Practices Regulation) to govern activities in riparian management zones. The objective was to maintain the integrity of the reserves, and for those streams where no reserves were prescribed, to maintain the integrity of channels and aquatic habitats (e.g., machine-free zones within 5 m of the channel bank).

For water bodies without mandatory riparian reserves, the FPC scheme embodied more of a results-based approach. Forest licensees were permitted wide latitude around riparian retention and management practices to achieve riparian management objectives within the zone (e.g., Table 15.1). Streams managed by these criteria included the smallest inhabited by fish (class S4 streams less than 1.5 m wide), and those without fish (classes S5 and S6). The riparian management area around class S4–S6 streams consisted solely of a management zone in which forestry practices were guided by objectives listed within the *Riparian Management Area Guidebook*, including recommendations for best management practices (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a).

The widths of riparian reserve and management zones under the FPC were established so that streams, lakes, and wetlands of different types and sizes would receive sufficient protection to preserve key functions during and after forestry operations. However, the FPC riparian standards also reflected an attempt to balance riparian tree retention for environmental protection with the economic and social values around access to timber. To manage the impact on timber supply, mandatory no-harvest riparian reserves were provided for streams containing the highest aquatic resource values (i.e., fish-bearing streams greater than 1.5 m but less than 100 m wide) and included within riparian classes S1–S3. One management trade-off with this decision was that no legally mandatory riparian reserves were required for the smallest fish-bearing streams, streams without fish, or large rivers. This also allowed for site-specific flexibility in managing the highly diverse population of small streams. Rivers with reaches more than 100 m wide for more than 1 km were not provided with mandatory reserves because riparian areas have minimal influence on the ecological and hydrological functions of very large watercourses.

The two most commonly voiced criticisms of the FPC's forest management approach focussed on:

1. the use of timber supply impact considerations in establishing the standards for environmental protection, including riparian reserves and the recommended levels of tree retention in riparian management zones; and
2. the lack of mandatory riparian reserves for small fish-bearing streams and the directly associated non-fish-bearing tributaries.

Critics generally advocated more conservative and risk-adverse approaches such as mandatory riparian reserves for class S4 and S6 streams. In response to similar criticisms in the late 1990s, other jurisdictions such as Washington State amended forest practice rules to provide greater protection to these small streams.

The FPC riparian management regime was based on a strategy of acceptable risk and had the goal of achieving effective levels of riparian protection while also allowing for some timber-harvesting opportunities. An area-based analysis[1] of potential impacts on timber harvesting opportunities suggests that riparian reserves and best management practices for tree retention in riparian management zones under the FPC would have reduced the area available for timber harvest by about 11% in coastal British Columbia, by more than 2% in the Interior, and by more than 6% overall (see retention targets in Table 15.1). Using the same analysis method, and to illustrate the factors FPC developers considered in the mid-1990s, estimates from maps of stream channel networks show that implementing no-harvest riparian reserves 30 m wide on all S4 and S5 streams, and 20 m wide on all S6 streams—with no management flexibility regardless of the circumstances—would reduce the amount of land available for harvest by 22% in coastal British Columbia, by nearly 6% in the Interior, and by nearly 14% overall.

Notwithstanding the criticisms of the FPC riparian management standards or any shortcomings of its prescriptive approach, the Forest Practices Board (1998) concluded from its evaluation of FPC and licensee performance in coastal areas that the FPC had significantly improved the protection and maintenance of riparian and stream values over pre-FPC conditions, particularly for the larger fish-bearing streams that received no-harvest riparian reserves. Any problems detected were associated mainly with missed and incorrectly classified small streams, and changes were made to improve stream identification and classification outcomes. In 2000, an interagency survey of classified S4 streams on the central Interior plateau (former Kamloops and Cariboo Forest Regions) concluded that these streams were managed to FPC standards (Chatwin et al. 2001) and were generally meeting the objectives laid out in the *Riparian Management Area Guidebook* (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a). Overall, the study observed a low degree of short-term impacts to stream channels; however, these results were achieved in management regimes where the overall level of riparian tree retention (49%) was substantially higher than the maximum level (25% by basal area) recommended in the guidebook. Full-retention (30 m wide) reserves or similar high-retention riparian treatments were common (Chatwin et al. 2001; Figure 15.8).

FIGURE 15.8 *Smaller stream with full riparian area management retention. (Photo: R.G. Pike)*

1 Wildstone Resources. 1996. Riparian impact assessment. Unpubl. report.

The same central Interior study looked at whether common management practices were adversely affecting S4 streams. Questions were immediately raised about whether the management strategies and outcomes in the central Interior were typical of the rest of the province. Under the British Columbia Forest and Range Evaluation Program (FREP), assessments have focussed on addressing this question and others related to the effectiveness of regulations and practices in maintaining forest values including water, fish, biodiversity, and soils (for more details, see www.for.gov.bc.ca/hfp/frep/). Results from province-wide field assessments between 2005 and 2008 (1441 streams managed under the FPC) revealed that about 11% of S4 streams and 19% of S6 streams were not in properly functioning condition because of various factors including roads, road crossings, and low levels of riparian retention (for more details, see "Riparian Assessments in British Columbia" below ).

### Site- and Watershed-level Approaches under the *Forest and Range Practices Act*

Results-based approaches are designed to provide for increased management flexibility, and are informed by existing watershed-scale information and (or) new data from integrated riparian assessments. By taking into account linkages between low-order headwater streams and high-order, valley-bottom channels, the goal is to implement riparian management on a more ecologically efficient and relevant basis than is possible when using rigid prescriptive regimes. Under the current FRPA, two options are available for riparian management:

1. the default prescriptive approach that mirrors the FPC (see "Forest Practices Code Approach to Riparian Management" above), and
2. an alternative approach set out in a forest stewardship plan, approved by government, which contains the results or strategies that show that a forest licensee is being consistent with government's objectives for riparian areas.

The first option is similar to the FPC approach in that it retains all FPC riparian classification systems for water bodies and a mixture of rules-based/results-based elements around riparian management zones. Tree retention requirements by basal area for these zones are not specified in regulation except for minor tenure holders (Table 15.4). The *Riparian Management Area Guidebook* (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a) is available for guidance regarding best management practices for retention in riparian management areas; however, this guidebook has no legal status under the current FRPA.

The second option provides freedom to manage. A proponent who wishes to vary from the prescriptive defaults must include results or strategies in a forest stewardship plan to address the objective set by government for water, fish, wildlife, and biodiversity within riparian areas, which is: "without unduly reducing the supply of timber from British Columbia's forests, to conserve, at the landscape level, the water quality, fish habitat, wildlife habitat and biodiversity associated with those riparian areas" (Forest Planning and Practices Regulation). Specifically, the plan must contain a result or strategy that addresses retention of trees in a riparian management area (Forest Planning and Practices Regulation). By giving licensees the option to implement the default prescriptive approach with fixed riparian reserve and management zones, the Act accommodates licensees who do not have the necessary expertise or resources to undertake and implement strategies for alternative riparian management schemes (e.g., complete assessments in support of these strategies), or who are otherwise unwilling to assume the costs and responsibilities of the results-based regime.

Regardless of the riparian management option chosen, other considerations may apply. For example, licensees may need to provide results or strategies to meet the requirements for government-designated, fisheries-sensitive watersheds where the intent is to prevent "the cumulative hydrological

TABLE 15.4 *Riparian management zone tree retention requirements by percent basal area for minor tenure holders under the* Forest and Range Practices Act *(Forest Planning and Practices Regulation)*

| Riparian class | Percent basal area to be retained within RMZ |
|---|---|
| S1 (A and B) streams | ≥ 20 |
| S2 streams | ≥ 20 |
| S3 streams | ≥ 20 |
| S4 streams | ≥ 10 |
| S5 streams | ≥ 10 |
| S6 streams | Not applicable |
| All classes of wetlands and lakes | ≥ 10 |

effects of primary forest activities in the fisheries sensitive watershed from resulting in a material adverse impact on the habitat of the fish species for which the fisheries sensitive watershed was established" (Forest Planning and Practices Regulation). Similarly, licensees are required to meet the objectives for water quality in community watersheds, and must not conduct activities in coastal areas that would cause the destabilization of alluvial fans (Forest Planning and Practices Regulation).

No guidance is explicitly provided within the Act to assist licensees with alternative riparian management approaches. The vision of this regime is that these approaches are proponent-implemented, inventory-based, and flexible. Plans and practices would be informed by existing knowledge for an area and (or) information collected at a watershed level that optimally would include the results of integrated riparian assessments. The intent is for alternative riparian retention schemes to be rationally informed from relevant knowledge, which integrates hillslope-stream channel linkages with stand-level requirements for riparian function. This information or process does not necessarily appear in a forest stewardship plan, but forms part of a licensee's non-legal background information as the rationale for the plan.

The Act depends extensively on "professional reliance" to deliver expected management outcomes. Generally, a team of qualified specialists on behalf of the proponent conducts planning and pre-harvest assessments. This team may consist of a geomorphologist and (or) hydrologist, forester, wildlife biologist, and fish-habitat biologist. The widths of riparian management areas and reserve zones are intended to be flexible to maintain riparian function, rather than be based on any arbitrary, fixed, and predetermined minima. Logically, this flexible approach is not necessarily anchored to stream classes, but rather to the riparian stand requirements of the stream, sediment and LWD transport potential, and hillslope-channel connections (i.e., to suit local watershed characteristics). When alternative riparian management approaches are implemented in this way, they are consistent with the current riparian management schemes associated with environmental certification (e.g., Forest Stewardship Council of Canada).

Post-harvest effectiveness evaluations are also a part of the FRPA management structure. Forest licensees may implement their own monitoring initiatives; however, the provincial government will monitor the effectiveness of its legislation, regulations, and licensee-implemented management practices province-wide for the purposes of adaptive management and continuous improvement.

A comprehensive watershed-based approach has the following advantages.

- Riparian protection is delivered on a more ecologically sound basis: retention (e.g., riparian reserves) is applied when and where it will provide maximum ecological benefits.
- A licensee-driven system of planning and implementation is within an adaptive management, results-based framework.
- Consistency is achieved with schemes currently proposed by environmental certification initiatives (e.g., the Forest Stewardship Council).

**Forest Stewardship Council**

The Forest Stewardship Council's main riparian standards for British Columbia reflect a more conservative management approach by using both riparian reserves and high-retention riparian management zones (Table 15.5). This scheme is somewhat similar to FRPA because it permits a prescriptive-like option with fixed-width reserve and management zones and an assessment-based, variable-width alternative. In addition, both management models incorporate the principles of post-harvest effectiveness monitoring within an adaptive management framework; however, the Council's alternative scheme is explicitly based on the requirement to conduct comprehensive riparian assessments and apply a minimum riparian retention budget as a part of the planning process at the watershed level or for other landscape-level ecological units of 5,000–50,000 ha.

The Council's riparian standards are generally based on the FPC/FRPA riparian classification framework. Therefore, direct comparisons to the FPC and default FRPA standards are possible if the Council's mandatory riparian retention budget is achieved with fixed-width reserve and management zones (Tables 15.5, 15.6, and 15.7). Such comparisons reveal substantial differences. For example, the Council subdivides class S5 and S6 non-fish-bearing streams to provide additional reserve-zone protection (20 m wide) for community watersheds, and for fish habitat that might be affected by operations occurring around the direct tributaries to fish-bearing streams (classes S5a and S6a).

By comparison, the Council's standards also provide:

TABLE 15.5 *Comparison of Forest Stewardship Council (FSC) riparian standards for streams with those of the FPC and FRPA*

| Riparian class | | Average channel width (m) | | Reserve zone width (m) | | Management zone width (m) | | Total RMA width (m) | | RMZ retention (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FSC | FPC/ FRPA | FSC | FPC/ FRPA | FSC | FPC/ FRPA | FSC | FPC/ FRPA | FSC | FPC/ FRPA | FSC | FPC only |
| S1a | S1 large/S1-A | > 100 | ≥ 100 | 30 | 0 | 40 | 100 | 70 | 100 | 65 | ≤ 70 |
| S1b | S1 / S1-B | > 20 | > 20 | 30 | 50 | 40 | 20 | 70 | 70 | 65 | 50 |
| S2 | S2 | > 5 to ≤ 20 | > 5 to ≤ 20 | 30 | 30 | 40 | 20 | 70 | 50 | 65 | 50 |
| S3 | S3 | 1.5 to ≤ 5 | 1.5 to ≤ 5 | 30 | 20 | 20 | 20 | 50 | 40 | 65 | 50 |
| S4 | S4 | < 1.5 | < 1.5 | 30 | 0 | 20 | 30 | 50 | 30 | 65 | 25 |
| S5a[a] | S5 | > 3 | > 3 | 20 | 0 | 20 | 30 | 40 | 30 | 65 | 25 |
| S5b[b] | S5 | > 3 | > 3 | 0 | 0 | 15 | 30 | 15 | 30 | 30/10 | 25 |
| S6a[c] | S6 | 0.5 to 3 | ≤ 3 | 20 | 0 | 20 | 20 | 40 | 20 | 65 | 5 |
| S6b[d] | S6 | ≤ 3 | ≤ 3 | 0 | 0 | 15 | 20 | 15 | 20 | 30/10 | 5 |

a S5a: No fish, not in a community watershed, >3 m wide, and (1) in a domestic watershed, and (or) (2) ≤ 500 m upstream from a fish-bearing stream, and (or) (3) >10 m wide.
b S5b: No fish, not in a community watershed, 3–10 m wide, not in a domestic watershed, and > 500 m upstream from a fish-bearing stream. RMZ retention is 30% except in Natural Disturbance Type 3 (NDT3 ecosystems with frequent stand-initiating events) where it is 10%.
c S6a: No fish, not in a community watershed, 0.5–3 m wide in the interior region (1–3 m in the coast) and (1) in a domestic watershed, and (or) (2) ≤ 250 m upstream from a fish-bearing stream.
d S6b: No fish, not in a community watershed, and (1) 0.5–3 m wide and not in a domestic watershed, and > 250 m upstream from a fish-bearing stream, or (2) < 0.5 m wide in the interior region (<1 m in the coast). RMZ retention is 30% except in NDT3 where it is 10%.

TABLE 15.6 *Comparison of Forest Stewardship Council (FSC) riparian standards for wetlands with those of the FPC and FRPA*

| Riparian class | | Wetland size (ha) | | Reserve zone width (m) | | Management zone width (m) | | Total RMA width (m) | | Retention in RMZ (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FSC | FPC/ FRPA | FSC | FPC/ FRPA | FSC | FPC/ FRPA | FSC | FPC/ FRPA | FSC | FPC/ FRPA | FSC | FPC only[a] |
| W1 | W1 | > 5 to < 1000 | > 5 to < 1000 | 20 | 10 | 15 | 40 | 35 | 50 | 30 | 25 |
| W2[b] | W2 | 1 to 5 | 1 to 5 | 20 | 10 | 15 | 20 | 35 | 30 | 30 | 25 |
| W3[b] | W3 | 1 to 5 | 1 to 5 | 20 | 0 | 15 | 30 | 35 | 30 | 30 | 25 |
| W4[c] | W4 | 0.25/0.5 to 1 | 0.25/0.5 to 1 | 20 | 0 | 15 | 30 | 35 | 30 | 30 | 25 |
| W5 | W5 | < 1000 | < 1000 | 20 | 10 | 15 | 40 | 35 | 50 | 30 | 25 |
| $\text{UNC}_{\text{fish}}$ | UNC | < W4 minima | < W4 minima | 20 | 0 | 15 | 0[e] | 35 | 0 | 30 | 0 |
| UNC[d] | UNC | < W4 minima | < W4 minima | 0 | 0 | 15 | 0[e] | 15 | 0 | 30 | 0 |

a Recommended maximum and averaged among cutblocks.
b Class W2 and W3 wetlands are distinguished by location in different biogeoclimatic zones.
c Minimum size of Class W4 wetlands depends on biogeoclimatic zone.
d $\text{UNC}_{\text{fish}}$ = unclassified wetland with fish. UNC = unclassified wetland without fish.
e Machine-free zone 5 m wide usually implemented for FPC.

- reserves for more streams including 30 m wide riparian reserve zones for all fish-bearing classes including S4 streams and S1a large rivers;
- wider reserves, and more classes requiring reserves, for both wetlands and lakes;
- reserves that are narrower than or equal in width to FPC/FRPA stream classes S1 and S2, but have tree retention by basal area increased to 65% in riparian management zones;
- 65% tree retention levels by basal area in the riparian management zones of all streams except classes S5b and S6b; 30% retention in the management zones of all lakes and wetlands;
- wider riparian management zones for some

TABLE 15.7 *Comparison of Forest Stewardship Council (FSC) riparian standards for lakes with those of the FPC and FRPA*

| Riparian class | | Lake size (ha) | | Reserve zone width (m) | | Management zone width (m) | | Total RMA width (m) | | Retention in RMZ (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **FSC** | **FPC/ FRPA** | **FSC** | **FPC/ FRPA** | **FSC** | **FPC/ FRPA** | **FSC** | **FPC/ FRPA** | **FSC** | **FPC/ FRPA** | **FSC** | **FPC only**[a] |
| L1 | L1/L1-B | > 5 | > 5 to 1000 | 15 | 10 | 15 | 0[b] | 30 | 10 | 30 | 25 |
| L1 | L1 large/L1-A | > 5 | > 1000 | 15 | 0 | 15 | 0[b] | 30 | 0 | 30 | 25 |
| L2[c] | L2 | 1 to 5 | 1 to 5[c] | 15 | 10 | 15 | 20 | 30 | 30 | 30 | 25 |
| L3[c] | L3 | 1 to 5 | 1 to 5[c] | 15 | 0 | 15 | 30 | 30 | 30 | 30 | 25 |
| L4[d] | L4 | 0.25/0.5 to 1 | 0.25/0.5 to 1[d] | 15 | 0 | 15 | 30 | 30 | 30 | 30 | 25 |
| $UNC_{fish}$ | UNC | < L4 minima | < L4 minima[e] | 15 | 0 | 15 | 0 | 30 | 0 | 30 | 0 |
| UNC[e] | UNC | < L4 minima | < L4 minima[e] | 0 | N/A | 15 | N/A | 15 | N/A | 30 | N/A |

a Recommended maximum and averaged among cutblocks.
b L1 lakes have an additional lakeshore management zone established by the district manager. In the FPC, this was summarized within a regional lakeshore management guidebook, where these were available.
c Class L2 and L3 lakes are distinguished by location in different biogeoclimatic zones.
d Minimum size of Class L4 lakes depends on biogeoclimatic zone.
e $UNC_{fish}$ = unclassified lake with fish. UNC = unclassified lakes without fish.

streams including S1b (FRPA S1-B), S2, and S5a (FRPA S56): where management zones are narrower for fish-bearing streams, basal area retention is higher;

- narrower or equal-width management zones for non-fish-bearing streams but with basal area retention increased to 65% when they are in domestic watersheds or within specific distances from fish-bearing streams.

The Forest Stewardship Council riparian management approach represents a relatively low management-related risk to streams, lakes, wetlands, and the associated biota. The overall approach recognizes the broad principles of aquatic-riparian processes and riparian function and, for streams, addresses drainage network linkages by providing an elevated level of management attention to small headwater streams with sufficient hydraulic power to influence other parts of the drainage.

The Council's assessment-based management alternative allocates riparian tree retention on the basis of comprehensive, e.g., watershed-level, assessments that must integrate hillslope-stream channel linkages with stand-level requirements for hydroriparian function and wildlife values. However, the scope of management freedom faces some limitations because of the need to retain a minimum proportion of the total riparian area in an unharvested state (≥ 80% in reserves) within a defined operating area (a minimum-budget approach; Table 15.8).

In spite of implementation costs and other considerations, the assessment-based approach of the Forest Stewardship Council is conceivably one that a licensee might wish to propose under FRPA as an alternative to prescriptive defaults. However, regardless of whether this approach uses minimum-retention budgets or not, a full freedom-to-manage scheme has significant challenges. A watershed-based, flexible approach with integrated aquatic and terrestrial ecosystem requirements has not yet been implemented broadly in any jurisdiction, probably because of its inherent complexity, the need for extensive inventory data and technical expertise, and the costs associated with inventories, planning, and post-harvest monitoring.

A watershed-based, flexible approach is also more difficult to apply than default standards, and potentially prone to subjectivity in ranking different riparian values. Different riparian ecotypes have yet to be identified and defined for most parts of British Columbia. The appropriate level of riparian retention for such ecotypes remains a challenging choice although post-harvest effectiveness evaluations can contribute to learning and management adaptation.

Compliance and enforcement may also be more difficult to administer, and results (e.g., water temperature, suspended sediment, channel stability, etc.) may be difficult to audit and interpret in terms of the natural range of variability (see "Riparian Assessment in British Columbia" below). Co-ordinating activities with multiple licensees or tenures within a watershed area can also present challenges under this system.

TABLE 15.8 *Minimum budgets to be applied for the Forest Stewardship Council's (FSC) assessment-based riparian management option for streams (per length of stream channel) and by average equivalent riparian reserve and management zone widths*

| FSC riparian (stream) class | Application | Minimum reserve zone budget: By area (ha/km) | Minimum reserve zone budget: Reserve zone equivalent width (m) | Minimum management zone budget: By area (ha/km) | Minimum management zone budget: Management zone equivalent width (m) | Minimum management zone budget: RMZ basal area retention (%) |
|---|---|---|---|---|---|---|
| S1a, S1b, S2 | Streams with fish or in a community watershed and > 5 m wide | 6 | 30 | 8 | 40 | 65 |
| S3, S4 | Streams with fish or in a community watershed and < 5 m wide | 6 | 30 | 4 | 20 | 65 |
| S5a, S6a | Without fish, not in a community watershed: **(1)** >3m wide and (a) in a domestic watershed, and(or) (b) ≤ 500 m upstream from a fish-bearing stream, and(or) (c) >10 m wide; **or** **(2)** 0.5–3 m wide in the interior region, 1–3 m wide in the coast region, and (a) in a domestic watershed and(or) (b) ≤ 250 m upstream of a fish-bearing stream | 4 | 20 | 4 | 20 | 65 |
| S5b, S6b | Without fish, not in a community watershed: **(1)** >3 to 10 m wide, not in a domestic watershed, and >500 m upstream of a fish-bearing stream, **or** **(2)** 0.5–3 m wide, not in a domestic watershed, and >250 m upstream of a fish-bearing stream **or** **(3)** <0.5 m wide in the interior region, <1 m wide in the coast region | 0 | 0 | 3 | 15 | 30 (10 in NDT3) |

### Landscape-level Riparian Management Approaches

Riparian management approaches that are solely site-based do not address landscape-level issues and cumulative effects. The effectiveness of a particular riparian management area prescription may be strongly influenced by what is happening elsewhere in the landscape (e.g., landslides from upper watershed areas).

Landscape-level approaches for riparian management allow:

- a shift from the rigid buffer-width strategy to a more flexible one that is based on the characteristics of the stream and the historic array of disturbance conditions at the landscape level;
- the ability to achieve water temperature, suspended sediment, and LWD objectives by controlling the proportion of the landscape in various forested conditions; and
- greater flexibility in scheduling the extent and frequency of harvesting; that is, disturbances caused by harvesting can be concentrated in different sub-basins, which then are provided with long periods for watershed recovery.

Implicit within the landscape approach are results that include:

- mainstream channels with variable-width riparian reserves based on channel type and floodplain width;
- portions of the landscape having small streams, which are capable of transporting debris, protected by either reserves or high-retention management zones;
- portions of the landscape with no reserves and (or) minimal tree retention for small streams;
- an overall riparian forest condition more similar to pre-harvest levels than the most common current post-harvest outcome, which leaves relatively low levels of retention for small streams and, for larger ones, a network of older-age riparian strips within a landscape dominated by young, regenerating stands; and
- a retained riparian forest that can serve aquatic

protection objectives and integrate biodiversity objectives.

A hypothetical example of a landscape approach is given in Table 15.9. Alternative models can be contemplated, such as those focussed at more local scales and based on channel guilds identified on the basis of terrain, morphological type (including incised vs. unconstrained), sensitivity to disturbance, hillslope-channel connectivity, and channel-to-channel connectivity.

Landscape approaches are challenging to implement, not only technically but also socially. For example, an analysis of disturbance regimes and channel sensitivity may result in some streams actually receiving less protection from reserves or management zones than these streams presently do. These outcomes are potentially unpopular with the public, fisheries resource managers, and others concerned with fish stocks and other species already at risk because of various causes. For example, the Blue River Management Plan in Oregon originally envisioned a full landscape approach; however, the plan was ultimately modified to incorporate riparian reserves around all streams and other features because of concerns that the public would reject the plan (see Cissel et al. 1999). Landscape approaches remain problematic and may be best suited for implementation under a results-based pilot linked to a monitoring and evaluation program based on adaptive management principles. Despite the current challenges, landscape approaches linked to principles of ecosystem-based management are under development for parts of coastal British Columbia (see "Other Riparian Management Approaches," below).

**Other Riparian Management Approaches**

Since the late 1990s, other riparian management approaches in the Pacific Northwest have emerged in addition to those management regimes enacted by government legislation and implemented throughout a given jurisdiction. The management plan for the Plum Tree Timber Commitments in Washington, Idaho, and Montana employs a channel guild concept that groups streams within watersheds for specific management attention, identifies "channel-migration zones" as important features to buffer, and recognizes headwater streams and riparian-upland interfaces as key management factors. These elements are considered to augment existing state riparian standards to provide additional "riparian habitat area" protection for several resource values, but particularly for bull trout (*Salvelinus confluentus*) and other fish species as part of a native-fish habitat-conservation plan.

For streams with bull trout, riparian management is specifically targeted to maintain pre-harvest levels of stream shade to maintain water temperatures, and ensure an adequate LWD supply for the creation of fish habitat (Plum Tree Timber Company 1999a, 1999b). Depending on local circumstances, including sensitivity to disturbance, valley-bottom streams and wetlands may be bordered with no-harvest buffers 91 m wide. Fish-bearing streams may be provided with a 30 m wide riparian habitat area, which contains a 10-m no-harvest streamside buffer. Perennial, non-fish-bearing streams may receive a riparian habitat area 15 m wide, which contains a 9-m machine-free zone. Other areas are designated for "riparian leave trees," where trees are retained at a minimum density of 44 trees per acre (109 trees per hectare). Where streams have channel-migration zones deemed to be highly sensitive to disturbance, the entire width of the zone is restricted from harvesting. Harvest opportunities are permitted in less sensitive channel migration zones.

The concept of ecosystem-based management has emerged in recent years and in British Columbia has reached its most advanced state of development in the central and north coastal areas and on Haida Gwaii (the Queen Charlotte Islands) (Cortex Consultants 1995; Coast Information Team 2004). Key concepts within ecosystem-based management include planning and assessing at various scales from the landscape to the site, and considering the drainage network as a "hydroriparian ecosystem" with complex vertical and lateral linkages within watersheds. Within this system, the stream network is partitioned into three major zones according to dominant fluvial geomorphic processes: (1) a headwater "source zone," (2) an intermediate "transportation zone," and (3) a lower-elevation sediment "deposition zone."

The planning process for riparian management is based on comprehensive assessments and focussed on protecting hydroriparian functions and the full spectrum of aquatic and terrestrial ecosystem attributes and resource values. The *Hydroriparian Planning Guide* (Coast Information Team 2004) outlines the different steps in the planning process, which are to:

TABLE 15.9 *Hypothetical example of a landscape-level approach for riparian management based on a landscape unit of 4000 ha*

| Landscape unit | Historic landscape disturbance pattern | Landscape unit objectives | Prescriptions | | |
|---|---|---|---|---|---|
| | | | Riparian | Roads | Restoration |
| 1 | Frequent fire disturbance<br>Frequently burned small streams<br>No mass wasting | Even-aged management<br>Temperature-sensitive streams | 10- to 20-m reserves on streams for thermal management | Normal | Not high priority for hillslopes or streams |
| 2 | Frequent fire disturbance; north aspect<br>Frequently burned small streams<br>No mass wasting | Even-aged management: 70-year rotation<br>No temperature-sensitive streams | No reserves on streams | Normal | Riparian restoration for shading<br>No road deactivation |
| 3 | No fire disturbance<br>High mass wasting<br>Rain-on-snow zone | Retain large wood on unstable sites<br>Low Equivalent Clearcut Area<br>Reserves on all streams | Equivalent Clearcut Area limits below 25%<br>20- to 30-m reserves (based on stream size) on all streams | No harvest or roads on class IV and V slopes | Deactivation of high-risk roads |
| 4 | Avulsing floodplains and canyons<br>Low fire disturbance | Retain large trees in floodplains | Variable 20- to 150-m reserves based on stream channel type and floodplain width | No roads on floodplains | In-stream LWD restoration<br>Riparian restoration for large trees |

- identify hydroriparian ecosystem functions at several scales from landscape to site;
- identify indicators for hydroriparian functions at each scale;
- provide guidance for assessing hydroriparian ecosystems in specific locations;
- define risk to hydroriparian functions that may result from forest management activities;
- identify levels of risk for ecosystem-based management at each scale;
- provide a range of management approaches and prescriptions consistent with risk so that managers can implement decisions at different scales to maintain hydroriparian ecosystems; and
- provide a framework for adaptive management and monitoring.

The management approach and objectives are conservative in this planning guide. Protecting riparian biodiversity is included and integrated with protecting biodiversity at the watershed level. To this end, broad "hydroriparian zones" are delineated as the area extending from a given water body to the edge of the influence of water on land, which is defined by the local plant community (including high-bench or dry floodplain communities) and (or) landform (e.g., gullies) plus 1.5 site-specific tree heights (horizontal distance) beyond. If landform and plant communities delineate different areas, the feature extending farthest from water is adopted as the limit of the hydroriparian zone. In the transportation and deposition hydroriparian "process" zones, the entire valley flat, plus 1.5 tree heights, is considered the hydroriparian zone. These distances were chosen because some physical functions within the hydroriparian ecosystem were estimated to be influenced to some extent within at least 1 tree height (Young 2001), and biological functions at much greater distances (Price and McLennan 2002).

Under ecosystem-based management, riparian management within the hydroriparian ecosystem of a watershed is envisioned to include default linear reserves 1.5 site-potential tree heights around all streams (regardless of size) within the transportation and deposition process zones. Patches of reserves would be established in the headwater source zone around unstable terrain (Class IV and Class V; B.C. Ministry of Forests 1999) and around concentrations of small streams. Linear reserves in the source zone may also be established where streams are deemed susceptible to debris flows or contain distinctive habitats. Similar reserves are to be applied around all wetlands and broader areas designated as "active fluvial units."

A hypothetical hydroriparian ecosystem network might also include, for example, reserves around an endangered floodplain community, 50% retention on stable alluvial fans, and patch reserves for unique and (or) representative small, steep streams to maintain connectivity. The *Hydroriparian Planning Guide* also expects managers to define and identify high-value fish habitats in the future, and requires levels of riparian protection beyond that normally applied under ecosystem-based management.

Within a given watershed, some reserved areas are envisioned to remain as reserves in perpetuity (e.g., an area of high natural instability), whereas others may become available for harvest in the long term when recovery is well advanced in contemporary harvest areas (e.g., source zone patches for preservation of representative forest). It is expected that decisions about the permanence of reserves will be made in developing an ecosystem-based regional plan that will consider its component landscapes and watersheds.

**Comparison of British Columbia's Riparian Management Standards with Other Jurisdictions**

Freshwater classification and management systems vary greatly among jurisdictions in northwestern North America, making direct comparison with British Columbia's riparian standards difficult. Many systems do not account for stream size, and are based primarily on fish and domestic water use. Others use stream size based on discharge, not on channel width. In several jurisdictions, all fish-bearing streams, regardless of size, are managed by the same riparian prescription for tree retention (see Tables 15.10, and 15.11).

Regardless of differences in management systems and objectives, the fixed-width riparian reserves adjacent to larger-sized fish-bearing streams in British Columbia (FRPA classes S1-B, S2, and many S3s) are wider than those of any other jurisdiction in the Pacific Northwest, except for federally managed forest lands (e.g., U.S. Department of Agriculture Forest Service Region 6) where these reserves exceed 91 m wide for fish-bearing streams of any width (Blinn and Kilgore 2001a, 2001b; Cashore 2001). On the other hand, for the majority of smaller-sized streams (i.e., classes S4–S6), all jurisdictions from Alaska to California require higher levels of riparian retention than British Columbia (Tables 15.10, and 15.11).

In general, state riparian tree retention requirements in the United States tend to be highest in the northwest, intermediate in other northern states, and the least prescriptive or restrictive in the south. A common riparian prescription across several states for fish-bearing streams or streams used for domestic water supply is a 50 ft (15.2 m) wide management zone with requirements for 50–75% crown closure or 50–75 $ft^2$/acre (approximately 11.5–17 $m^2$/ha) basal area retention after harvesting (Blinn and Kilgore 2001a, 2001b). The riparian management zone width is sometimes increased when the adjacent hillslope gradients increase beyond 30–35% (e.g., in California and Montana). Some northwest states also use a no-harvest riparian reserve from 20 to 100 ft (6.1–30.5 m) wide in addition to a management zone for the majority of small fish-bearing streams (Blinn and Kilgore 2001a, 2001b).

The wide reserves on federally managed forest lands in the Pacific Northwest were intended to deliver full protection for stream channels and aquatic habitats in response to the *Endangered Species Act* and other legislation. The width of riparian buffers required for this purpose was estimated from analyses that examined the effectiveness of riparian processes as a function of distance from the stream bank (Forest Ecosystem Management Assessment Team 1993). The distances where 100% protection was assigned for functions such as shade, organic litter fall, root strength (bank stability), riparian LWD supply, and microclimate were estimated from limited empirical data together with professional opinion and extrapolation from studies performed in non-riparian areas. In spite of criticism around the subjectivity and other limitations of the analysis,[2] the process undoubtedly satisfied the needs for a protectionist management regime for all streams, large or small.

Since the late 1990s, there has been increased information and awareness that small streams in both valley flats and headwaters are important for various watershed processes and functions (Gomi et al. 2002; Moore and Richardson 2003; Richardson 2003). Several jurisdictions already recognize

2 CH2MHill and Western Watershed Analysts. 1999. FEMAT riparian process effectiveness curves: what is science-based and what is subjective judgement? Report prepared for the Oregon Forest Industries Council, Salem, Oregon.

TABLE 15.10 *Summary of riparian standards and management practices in northwestern United States for small streams with fish and (or) used for domestic water supply (equivalent to FPC/FRPA class S4 streams, and some class S3 streams) (reserve and management zone widths are converted from measurements in feet and usually rounded to the nearest metre)*

| Jurisdiction | Riparian reserve width (m) | Management zone(s) width (m) | Management zone(s) retention | Comments |
|---|---|---|---|---|
| **U.S. Department of Agriculture Forest Service Region 6** (Pacific Northwest) | Widest of:<br>1. 100-year floodplain<br>2. Streambank to far edge of riparian vegetation<br>3. 2 times stand tree height (up to 91 m) | None | N/A | Example of site-potential tree height applies to the coast forest |
| **U.S. Department of Agriculture Forest Service Region 10** (Alaska) | 1. 30.5 m wide for anadromous streams<br>2. Others variable width (based on professional site assessment and judgement) | None | N/A | Variances to reserves common; may harvest after a Streamcourse Protection Plan is developed |
| **Alaska** State lands | 1. 30.5 m for anadromous streams<br>2. 30.5 m for some others | 1. None for anadromous<br>2. Most other streams with fish: 30.5 m | Non-merchantable trees for non-anadromous streams | Alaska standards vary by region; example given for Coastal Spruce–Hemlock Region |
| **Alaska** Other public lands | 1. 30.5 m for anadromous streams<br>2. None for other streams | 1. None for anadromous<br>2. Non-anadromous-fish streams: 30.5 m | 1. N/A<br>2. Non-merchantable trees for non-anadromous streams | Alaska standards vary by region; example given for Coastal Spruce–Hemlock Region |
| **Alaska** Private lands | 1. 20 m for high-value (low-gradient) anadromous<br>2. Other anadromous: the lesser of 20 m or distance to slope break<br>3. None for other streams | 1. None for anadromous<br>2. None for anadromous<br>3. Other streams: greater of 8 m or to limit of riparian vegetation (to maximum of 15 or 30 m depending on 12% gradient break) | Non-merchantable trees "where prudent" only for larger non-anadromous-fish streams<br>No retention specified for non-anadromous S4 equivalents | Alaska standards vary by region; example given for Coastal Spruce–Hemlock Region |
| **Oregon** State and private lands | 6 m | 9 m | Retain enough conifers for basal area of 3.7 $m^2$ per approx. 305 m of fish stream length; modified by region-specific targets | Retention varies by region; retain non-merchantable trees (only) for the smallest domestic-use streams |

TABLE 15.10 *Continued*

| Jurisdiction | Riparian reserve width (m) | Management zone(s) width (m) | Management zone(s) retention | Comments |
|---|---|---|---|---|
| **Washington –West** State and private lands | 15 m (core zone) | Inner zone: 3–26 m<br><br>Outer zone: 9–20 m | Inner zone: varies by stand class and management option, up to approx. 70% retention<br>Outer zone: 49 dominant and co-dominant trees per hectare | Inner zone may be a reserve if stand is below basal area target for site class; first 9 m of inner zone is reserved for management option to leave trees nearest to the water |
| **Washington – East** State and private lands | 9 m (core zone) | Inner zone: 14 m<br><br>Outer zone: 5–17 m | Inner zone: varies by stand class and management option, up to approx. 70% retention<br>Outer zone: 25–49 dominant and co-dominant trees per hectare based on forest type | Example inner zone retention for ponderosa pine timber type: leave 124 trees per hectare to achieve at least 13.8 $m^2$/ha basal area |
| **California** State and private lands | None | 23 m, 30 m, or 46 m for adjacent hillslope gradients of < 30%, 30–50%, and > 50%, respectively | Retain ≥ 50% of canopy overstorey and understorey; retain ≥ 25% of overstorey conifers | |
| **Idaho** State and private lands | None | 23 m | Retain (1) 75% of the existing shade over the stream, (2) all non-merchantable trees, and (3) 91 trees per hectare for streams < 3 m wide | These are streams with domestic water use or important for fish habitat<br><br>Entire management zone is machine-free |
| **Montana** State and private lands | None | 1. 15 m where adjacent hillslope gradient is < 35%<br>2. 30 m in steeper-sloped areas | 1. Retain 217 trees per hectare of ≥ 20.3 cm dbh<br>2. Retain 50% of trees > 20.3 cm dbh | No clearcutting within 15 m of any stream, lake, or wetland<br><br>Entire management zone is machine-free |

TABLE 15.11 *Summary of riparian standards and management practices in northwestern United States for small streams without fish and (or) not used for domestic water supply (FPC/FRPA equivalent class S6 streams, and some class S5 streams) (reserve and management zone widths are converted from measurements in feet and usually rounded to the nearest metre)*

| Jurisdiction | Riparian reserve width (m) | Management zone(s) width (m) | Management zone(s) retention | Comments |
|---|---|---|---|---|
| **U.S. Department of Agriculture Forest Service Region 6** (Pacific Northwest) | Perennial: 45 m up to 2 times stand tree height<br>Non-perennial: Greater of 30.5 m or 1 times stand tree height | None | N/A | Perennial: Some harvesting permitted beyond 45 m from stream where 2 times tree height implemented |
| **U.S. Department of Agriculture Forest Service Region 10** (Alaska) | 1. Variable width for streams with downstream impact potential<br>2. None for streams with low downstream impact potential for fish habitat | 1. None<br>2. No specified management zone | Unspecified | 1. Buffers based on professional site assessment and judgement<br>2. Applies to perennial and non-perennial streams; recommendations and practice rules similar to FPC |
| **Alaska** State lands | None | 30.5 m | Non-merchantable trees | Alaska standards vary by region; example given for Coastal Spruce–Hemlock Region |
| **Alaska** Other public lands | None | 30.5 m | Non-merchantable trees | Alaska standards vary by region; example given for Coastal Spruce–Hemlock Region |
| **Alaska** Private lands | None | Minimum of 8 m up to riparian vegetation limit; maximum of 15 or 30.5 m depending on 12% gradient break | Non-merchantable trees for larger streams only (unconfined streams > 4 m wide; incised streams > 2.4 m wide) | Alaska standards vary by region; example given for Coastal Spruce–Hemlock Region |
| **Washington – West** State and private lands | 1. Perennial: 15 m for lowermost 152.4 m (500 ft) and at tributary junctions<br>2. 17 m at headwater springs<br>3. 15 m at groundwater seeps<br>4. Non-perennial: None | No additional management zone | N/A | 1. No clearcutting > 50% of stream length<br><br>No harvest on alluvial fans<br><br>All streams have a machine-free zone 9.1 m wide |
| **Washington – East** State and private lands | None | 1. Perennial; springs; seeps; tributary junctions: 15 m<br>2. Non-perennial: no management zone specified | 1. Retain a basal area of ≥ 13.8 $m^2$/ha<br>2. 9.1-m machine-free zone only | No clearcutting alluvial fans<br>Retain a basal area of ≥ 13.8 $m^2$/ha<br>All streams have 9.1-m machine-free zone |

TABLE 15.11 *Continued*

| Jurisdiction | Riparian reserve width (m) | Management zone(s) width (m) | Management zone(s) retention | Comments |
|---|---|---|---|---|
| **Oregon** State and private lands | 1. 6 m for streams > 0.056 $m^3/s$ discharge 2. None for smaller streams | 1. 9 m for streams > 0.056 $m^3/s$ discharge 2. None for smaller streams | 1. Retain 10 or more conifers ≥ 20.3 cm dbh plus non-merchantable trees per 305 m of stream 2. Retain non-merchantable vegetation within 3.1 m of the channel in some regions | 1. Relates to FPC class S5 streams and larger class S6 streams 2. Relates to small FPC class S6 streams including non-perennial streams; no retention required in Coast Range and West Cascades regions; no RMA or retention required for small ephemeral channels without fish |
| **California** State and private lands | None | 1. Within 305 m of fish habitat or with other aquatic habitat: 15–30.5 m 2. Streams that can transport sediment/debris: RPF determines management zone 3. Other streams: None | 1. Retain ≥ 50% total forest cover including ≥ 25% of overstorey conifers 2. Retain 50% of understorey 3. No specified retention | 1. Management zone widths based on adjacent hillslope gradient 2. Machine-free zones 8–15 m wide depending on adjacent hillslope gradients |
| **Idaho** State and private lands | None | 1. Connected to domestic-use or fish streams: 9 m 2. Locally designated streams of concern: 15 m 3. Minor, disconnected streams: 1.5 m | Retain all hardwood shrubs, non-merchantable conifers, grasses Entire management zone is machine-free | These streams may contain marginal fish habitats and "a few fish" |
| **Montana** State and private lands | None | 1. Flow more than 6 months per year and direct tributaries to fish streams: 15–30 m depending on hillslope gradient break of 35% 2. Flow less than 6 months per year and connected to other waters, or more than 6 months and disconnected: 15–30 m (as above) 3. Flow less than 6 months per year and disconnected: 15 m | 1. Retention as for fish streams 2. Prescription as for fish streams but retain one-half the number of trees = 109 per hectare 3. Retain non-merchantable trees and shrubs | Entire management zone is machine-free for all streams |

the significance of some features of the drainage network, such as tributary junctions and perennial reaches flowing directly into fish-bearing waters. For example, Washington has opted to protect such sites in the western region of the state with riparian reserves, whereas management zones with basal area tree retention targets protect perennial streams east of the Cascade Mountains (Tables 15.10, and 15.11). Other jurisdictions, such as Alaska, California, and Montana, recognize terrain slope and channel-hillslope connectivity as important management factors and provide riparian buffers or increase the width of management zones accordingly. For example, Montana doubles the width of its riparian management zones from 15 to 30 m when the steepness of adjacent side slopes exceeds 35%. California requires management zones 23, 30, or 46 m wide where adjacent hillslope gradients are less than 30, 30–50, and greater than 50%, respectively (Tables 15.10, and 15.11).

California, Montana, and Idaho do not employ no-harvest reserves around streams; instead, management zones with retention requirements are in place. These zones include requirements for stream shade. For example, Idaho requires that 75% of the original shade is retained after harvesting adjacent to "important" fish-bearing streams or streams used for domestic water supply. California requires 50% of streamside canopy retention, including 25% of the shade provided by conifers, regardless of fish-bearing status or stream size (Tables 15.10, and 15.11).

For non-fish-bearing streams, management zone widths and tree retention in California and Montana also vary according to the ability of streams to transport sediment and debris. In California, this is determined by a professional forester.

Identifying small streams capable of affecting reaches downstream from those with little potential to do so involves some subjectivity; however, in Montana, this potential is decided according to discharge thresholds, whether the streams are perennial or seasonal, and whether they are connected directly to the drainage network further downslope (Tables 15.10, and 15.11).

Because the management zones and retention requirements for California, Montana, and Idaho are not specifically tied to stream size, the associated riparian tree retention requirements are higher than those specified in regulation for class 4–6 streams in British Columbia.

Increased knowledge of the importance of small streams, plus efforts to address declining salmon populations and restore riparian forest stands, has resulted in increasingly complex riparian management rules in Washington and Oregon (Cashore 2001). With the introduction of the *Forest Practices Rules* in 2001, Washington currently has the most conservative riparian tree retention requirements for smaller streams among all state jurisdictions. These rules require riparian reserves for all fish-bearing and domestic-water streams more than 2 ft (approx. 0.7 m) wide, and require a core, no-harvest reserve zone immediately adjacent to the stream irrespective of stream size; therefore, regulation requirements in Washington well exceed those for the smallest fish-bearing streams (class S4) and for non-fish-bearing streams (classes S5 and S6) in British Columbia; however, streams less than 0.7 m wide are not covered under the Washington rules.

Washington's complex riparian management system has three classes of water bodies. These are: (1) class S or "shorelines of the state," which includes large rivers, lakes, and marine shores; (2) class F, which covers fish-bearing streams or domestic-water-use streams; and (3) class N, which includes all other streams and is subdivided into streams that flow perennially (Np) and those that flow seasonally (Ns). All classified streams have three separate riparian zones: (1) a bank-side core reserve either 9 or 15 m wide, depending on whether the stream is in the eastern or western regions of the state, respectively; (2) an inner zone next to the core with tree retention targets; and (3) an outer management zone with yet different rules.

Each stream class may be further subdivided into as many as five site classes depending on the makeup of the riparian forest. The widths, tree retention requirements, and other practices in the inner and outer management zones also vary according to site class. Site classes have been defined to maintain the structure and species composition of natural riparian stands or to rehabilitate affected sites to historic conditions. For example, where the existing forest of the core zone plus the inner zone falls below the target basal area objectives associated with the site class, the inner zone also becomes a no-harvest riparian reserve. This is called the "no management option" for the inner zone. Together with a 15 m wide core zone, this could add, for forest Site Class I in western Washington, an additional 25 m wide reserve for streams 3 m or less wide, and 30 m of reserve for streams 3 m or more wide. Where existing riparian stands meet target basal area objectives, other management options exist for the inner and outer zones. For example, one option where the smaller trees of a stand can be felled is called "thinning from below."

Although Washington's riparian management rules offer relatively high levels of stream protection, the American Fisheries Society (2000) has criticized them as being too complicated and difficult to implement. In Oregon, riparian management rules are not quite as complex, but are still wide-ranging and vary according to region of harvest (Tables 15.10 and 15.11).

The wide range of approaches for riparian management in the Pacific Northwest appears to reflect outcomes influenced by local landscapes, the history of land use management and its effects on the current condition of riparian forests and streams, varying habitat protection priorities and prerogatives in balance with social and economic values, and different solutions to the challenges of administration and implementation. Ideally, riparian management should be simple to implement, operationally flexible, applied on the basis of local assessments with attention to watershed-scale physical and biological linkages, and guided by conditions in watersheds that are unaffected by forest management. For riparian management to be ecologically sustainable, some reviewers have stressed that it must also be ecologically precautionary (Young 2001); however, what is considered precautionary versus too risky is subject to interpretation. In spite of this variation, all management systems attempt to reduce the well-known potential effects of forest practices on the condition of streams and other water bodies.

## FORESTRY-RELATED EFFECTS ON RIPARIAN AREAS

Nearly 50 years of research information is available on the effects of forest harvesting—particularly riparian harvesting—on streams and stream-riparian functions from both short-term and long-term studies (see Chapman 1962; Murphy et al. 1986; Hall et al. 1987; Salo and Cundy [editors] 1987; Hartman and Scrivener 1990; Bisson et al. 1992; Hogan et al. 1998; Young 2001; Broadmeadow and Nisbet 2004; Tschaplinski et al. 2004). Collectively, many studies have generated information on: forestry-related alterations to water temperature regimes; introduction of fine sediments; channel bedload dynamics; LWD sources, dynamics, and functions; channel bank stability and erosion; inputs of fine organic matter, nutrients, and pollutants; primary productivity; macroinvertebrate abundance and community composition; and fish populations and habitats (see Gregory et al. 1987; Hartman and Scrivener 1990; Naiman et al. 1992, Hartman et al. 1996; Hogan et al. 1998; 2000, 2002; Young 2001).

Related to this body of research, numerous studies and reviews have addressed the issue of riparian buffer width and aquatic ecosystem protection (Forest Ecosystem Management Assessment Team 1993; Castelle et al. 1994; Young 2001; Broadmeadow and Nisbet 2004). No definitive width of riparian reserve or buffer will protect streams and other water bodies from every possible impact in all situations. Different physical and biological attributes of streams and other aquatic ecosystems respond differently to riparian forestry according to the influence of climate, geology, natural disturbance regimes, channel type, aquatic communities, and channel interconnections within basins (Vannote et al. 1980; Gregory et al. 1987; Poff and Ward 1990).

Forest harvesting, roads, and other related activities can result in both direct and cumulative effects to streams and riparian areas that affect the overall integrity of these systems and, ultimately, form and function. Because streams and their riparian areas integrate much of the upslope impacts that forestry operations and natural processes may cause, discussions about the effects of forestry operations on streams and the associated riparian areas are much broader than the focus of this chapter. As such, many, if not most, other chapters in this compendium provide details of how various watershed-level effects influence riparian areas. Specifically, forestry effects on LWD supply, landslides, sediment, and channel bank strength are detailed in Chapters 8 ("Hillslope Processes"), 9 ("Forest Management Effects on Hillslope Processes"), and 10 ("Channel Geomorphology: Fluvial Forms, Processes, and Forest Management Effects"). Background on sediment (turbidity and total suspended solids) and temperature as water quality parameters is given in Chapter 12 ("Water Quality and Forest Management"). Measurement techniques for some of these parameters are covered in Chapter 17 ("Watershed Measurement Methods and Data Limitations"). These chapters and others provide detailed discussion of how forestry affects various watershed elements.

In this section, we focus on how forest management directly affects streams and riparian areas with an emphasis on information generated within British Columbia. Three broad and interrelated categories of forestry-related effects on riparian areas include: (1) physical habitat structure alterations, (2) trophic responses, and (3) temperature-related shifts. These categories, separately and in combination, can have different effects on fish, depending on species, life stage, and distribution in freshwater (Hartman and Scrivener 1990). Population and habitat responses to harvest practices are complex. In addition, not all outcomes for some fish species, particularly anadromous salmon, which spend a part of their life cycle in marine environments, can be interpreted solely from processes occurring in freshwater and the effects of forestry on these processes. Long-term trends in fish abundance, especially for anadromous salmon, may be confounded by changes in climate, ocean conditions, and fisheries management strategies (Tschaplinski et al. 2004) and are therefore often difficult to interpret in terms of land use management.

**Physical Habitat Alterations**

Riparian forest practices can result in increased input of fine sediments (sand and pea-sized gravel) into streams through increases in streambank erosion as a consequence of loss of root strength following tree harvest. Between 2 and 5 years after harvest, streambank erosion increased along nearly 2 km of Carnation Creek that was subjected to clearcut riparian harvesting, compared to erosion observed within a variable-width riparian buffer (2–70 m wide) 1.3 km long (Hartman and Scrivener 1990; Tschaplinski 2000; Tschaplinski et al. 2004). Within 5 years after clearcut riparian harvesting, erodible streambanks collapsed as roots from harvested trees decayed (Hartman et al. 1987). Sediments eroded and were transported downstream by floods, with deposition occurring in the lowermost stream areas and upper estuary used by chum salmon (*Oncorhynchus keta*) (Hartman et al. 1987; Scrivener and Hartman 1990). Accumulation of these fines in the streambed was associated with the decline in the survival of chum salmon eggs from 20 to 11% in the depositional areas (Scrivener and Brownlee 1989).

Problems associated with fine sediments can also result from riparian harvesting through exposure of bare soil by machinery operation, from roads and stream crossings, and from the mineral soil exposed to rain at the base of retained riparian trees overturned by windthrow (Chatwin et al. 2001; Tripp et al. 2009). For example, suspended sediment levels downstream of logged areas were 5–10 times higher than levels in unharvested reaches during peak spring flows in Centennial, Donna, and upper Slim Creeks in the Slim-Tumuch study in central British Columbia (Brownlee et al. 1988).[3] Fine sediments were mobilized from the cut-and-fill slopes of forestry roads, and from skidder trails located near streams (Brownlee et al. 1988).[4]

Channel disturbances also result from cross-stream falling and yarding (Hartman et al. 1987; Brownlee et al. 1988; Hartman and Scrivener 1990). This non-directional falling and near-stream skidding caused the greatest channel disturbances observed in the Slim-Tumuch study. These disturbances were progressively reduced by directional falling and skidding, selective riparian harvest (partial retention buffers), and riparian reserves (Brownlee et al. 1988).

Increased amounts of fine sediments in streambeds can affect benthic macroinvertebrate abundance (Culp et al. 1986). Sediment deposition in areas downstream of logged reaches in the Slim-Tumuch study was strongly associated with reductions in benthic invertebrate densities, particularly in riffles (Brownlee et al. 1988).[5] In one stream, invertebrate drift (originating from the benthos) was also lower in the logged reach than in control reaches.

Channel bank erosion as a consequence of riparian harvesting (Figure 15.9) can also destabilize LWD and result in streambed mobilization and increased rates of channel scour and deposition, which ultimately affect fish populations. In-stream LWD at Carnation Creek, primarily of riparian origin, was mobilized as a result of streambank erosion and collapse, which contributed to changes in channel configuration within 5 years after harvesting was initiated (Toews and Moore 1982). Increased streambed mobility was associated with a nearly 50% post-harvest decline in the survival of coho salmon

3 Slaney, P.A. 1975. Impacts of forest harvesting on streams in the Slim Creek watershed in the central interior of British Columbia. B.C. Min. Environ., Fish Wildl. Br., Victoria, B.C. Presented at Forest Soils and Stream Ecology, a program (FP 2453, May 1975) sponsored by Assoc. B.C. Prof. For. and Univ. British Columbia Fac. For. and Cent. Contin. Ed. Unpubl. report.

4 Ibid.

5 Ibid.

FIGURE 15.9 *Near-stream practices: harvest of streambank tree. (Photo: R.G. Pike)*

(*O. kisutch*) eggs in the clearcut riparian treatments (Holtby and Scrivener 1989).

Watershed-level forestry can also affect channel structure and aquatic habitats irrespective of site-level riparian practices. The magnitude of these effects may have long-term implications. Debris flows originating in steep, logged gullies greater than 1.5 km upstream from anadromous salmon habitats at Carnation Creek occurred shortly after forest harvesting and caused the most pronounced changes to the stream channel and aquatic habitats (Hartman and Scrivener 1990; Hogan et al. 1998).

These storm-triggered debris flows deposited large volumes of logging-associated woody debris and inorganic sediments into the stream channel where the materials were carried rapidly downstream into the riparian clearcut treatments inhabited by anadromous fish. Large logjams and associated sediments deposited by the debris flows moved progressively downstream, passed through the riparian buffer treatment, and eventually reached the stream mouth nearly two decades after the mass wasting events occurred (Tschaplinski et al. 2004). These processes overwhelmed the effects of the riparian management treatments. Major physical changes resulted and are continuing to occur, such as channel widening by two- to threefold, further accelerated scour and deposition processes, loss of stable LWD, and in-filled pools (Hogan and Bird 1998; Hogan et al. 1998;).

Outcomes associated with mass wasting at Carnation Creek and elsewhere represent longer-term, basin-wide processes that point to critical linkages between steep hillslopes and the stream channel network. These linkages are more important in areas of steep terrain where the channel network is closely coupled to the hillslopes. Although the volume of landslide material increased by 12-fold after logging at Carnation Creek (Hartman et al. 1996), much of this material did not enter the channel network. By contrast, in steep and unstable terrain on Haida Gwaii, many small streams have narrow floodplains; therefore, hillslope processes and the stream channel network are closely linked.

Fish-Forestry Interaction Program research on Haida Gwaii quantified large increases in hillslope instability and landslide rates caused by forestry operations in steep terrain. Mass wasting rates increased by 15-fold in areas with forestry operations when compared to areas without forestry-related activity (Schwab 1998). Compared with unharvested sites, the area affected by landslides alone increased by 43 times because of clearcutting, and by 17 times because of problems associated with forestry roads. Correspondingly, the volume of mass-wasted materials attributed to clearcuts and roads increased by 46 and 41 times, respectively (Schwab 1998). About 39 and 47% of the total volume of sediment and woody debris generated by landslides on Haida Gwaii entered streams in unlogged and logged terrain, respectively (Rood 1984). Forestry operations in steep, sensitive terrain where annual precipitation is high clearly require attention.

Recognition of watershed-scale linkages has resulted in increased research and management attention regarding natural processes and management practices in headwater catchments. For example, a multi-agency study of the outcomes of the Prince George District Manager policy for riparian management of class S4 streams was carried out. This B.C. Ministry of Forests and Range policy required the implementation of a 5 m wide machine-free zone adjacent to the stream, retaining all non-merchantable vegetation plus 10 merchantable conifers per 100 m of channel length, and maintaining 50–70% of the pre-harvest levels of riparian shade (www.for.gov.bc.ca/hre/ffip/PGSSP.htm). To achieve management objectives, most of the tree retention occurred within 10 m of the channel. The streams studied were small, first-order watercourses (less than 1.5 m wide), with gradients less than 12% and channel morphologies consisting primarily of riffle-and-pool sequences. A paired, before-versus-after treatment, control-versus-impact experimental design was used to determine the temporal, geographic, and among-stream differences across three geographically distinct areas.

The biological and physical variables measured over time and space included: summer and autumn water temperatures, channel substrate textures, morphometrics and in-stream wood, sources of erosion, riparian litter fall, stream shade and solar radiation exposure, benthic invertebrates, invertebrate drift, periphyton accrual, water chemistry, nutrients, downstream delivery of organic material, and fish community response.

Short-term findings of the Prince George study indicated that fine-sediment generation was effectively managed by riparian practices, although fines from roads and skid trails entered the channel network at stream crossings. Concerns were also low regarding the future outcomes for inorganic nutrients, periphyton, and dissolved organic matter. However, moderate-level concerns were noted for long-term channel morphology integrity and benthic invertebrates, and high concern was noted regarding long-term LWD supply, stream shade, and litter fall, given the level of riparian retention applied (B.C. Ministry of Forests and Range et al. 2007).

**Trophic Changes**

Stream communities and the associated food webs are driven by primary production (autotrophic production by algae) based on the direct incorporation of solar energy, and by decomposition of organic materials including leaf litter from riparian vegetation (Cummins 1974; see Chapter 13, "Stream and Riparian Ecology" and Chapter 14, "Salmonids and the Hydrologic and Geomorphic Features of Their Spawning Streams in British Columbia" for related information). Of these two major trophic pathways, the one that predominates depends on the availability of direct solar radiation, water chemistry, type and availability of organic material of riparian origin, and several other factors. These variations will determine the community composition of aquatic invertebrates and the relative abundance of those species that feed directly on benthic algae, those that depend on leaf litter and other organic materials decomposed by aquatic microbes, those that use both food sources, and the predators of all of these types (Hawkins and MacMahon 1989; Merritt and Cummins 1996). Although fish species in northwestern North America are generalist predators on aquatic and riparian invertebrates (Hyatt 1979; Tschaplinski 1987, 1988), forestry practices that influence the abundance and availability of these prey are important for determining fish abundance, distribution, growth, and survival.

Riparian harvesting can increase aquatic primary productivity and benthic macroinvertebrate biomass (Newbold et al. 1980; Kiffney and Bull 2000) as well as change the composition of the benthic community (Richardson et al. 2002, 2005); however, research results have varied substantially. For example, Culp and Davies (1983) concluded that benthic macroinvertebrate populations were reduced in Carnation Creek in areas where riparian clearcutting had recently occurred. The reductions were attributed to reduced leaf litter input and retention, and increased erosion, transport, and deposition of sand in the benthos. Culp and Davies (1983) also reported that post-harvest changes in periphyton were small because of phosphorus limitation. In contrast, Richardson et al. (2002) found up to fourfold increases in algal biomass relative to controls (in some seasons) at sites subjected to different riparian management treatments, some of which included riparian reserves 30 m wide. The highest amounts of algae were found in streams with reserves only 10 m wide and those that were clearcut to the banks. Richardson et al. (2002) reported that, when compared with unharvested controls, the densities of midge larvae (Chironomidae) in their experimental treatments in southwestern British Columbia increased in parallel with increased amounts of algae associated with riparian clearcuts and 10 m wide reserves. Also, with decreasing amounts of streamside protection, shifts occurred within the benthic invertebrate community toward more generalist taxa, such as the mayflies *Baetis* and *Ameletus*. Litter input rates were maintained from 10 m wide and 30 m wide riparian reserves at levels similar to controls. At the same time, organic litter input rates declined to about 10% in clearcut sites, when compared with streams having some forest cover.

The consequences of these changes for fish populations and riparian management options remain unclear. Fish biomass and salmon smolt abundance may increase following riparian harvest (Connolly and Hall 1999; Tschaplinski 2000; Tschaplinski et al. 2004); however, the duration of these increases has yet to be determined unequivocally. Juvenile coho salmon growth and smolt production increased immediately after logging at Carnation Creek, but these shifts appeared strongly related to increases in water temperature rather than the consequences of increased food abundance. Elevated temperatures caused substantial shifts in the ecology of coho salmon at Carnation Creek. Warmer conditions (approximately 1°C overwinter) increased coho salmon egg incubation rates, resulting in earlier emergence in spring, a longer season of summer growth, larger-sized fry entering the first winter (11 mm longer on average), and higher overwinter survival attributed to larger size. Consequently, higher levels of smolt production have been sustained in Carnation Creek for nearly three decades (Tschaplinski et al. 2004). The ecological implications for fish of even modest forestry-related temperature changes remain unclear. The same water temperature increases at Carnation Creek have allowed more juvenile coho to transform into smolts after just 1 year of growth in freshwater compared with the pre-harvest situation, where about 50% of the population required an additional year to grow to smolt size. The shift to a majority of 1-year-olds may have implications for poor cohort survival in marine environments in years when ocean conditions are unfavourable (Tschaplinski 2000). Furthermore, any short-term or medium-term responses by fish to trophic regime shifts in Carnation Creek must be viewed in the context of other factors influencing ecosystem features and functions; for example, physical habitat alterations associated with forest practices in riparian areas and on hillslopes. For further information on the cumulative effects of these factors among a number of fish-forestry interactions studies, see www.for.gov.bc.ca/hre/ffip/index.htm.

**Riparian Management and Stream Temperature**

Water temperature controls chemical and biological processes that importantly influence aquatic ecosystems. Several authors have reviewed how stream temperature varies in both space and time and they should be consulted for a more detailed description of the environmental variables that control water temperatures (e.g., see Chapter 12, "Water Quality and Forest Management," Chapter 17, "Watershed Measurement Methods and Data Limitations," and Chapter 19, "Climate Change Effects on Watershed Processes in British Columbia"; Beschta et al. 1987; Moore et al. 2005). In brief, stream temperature varies daily, monthly, and seasonally because of changes in the sources of energy available to heat water. These energy sources include: longwave and shortwave radiation; sensible and latent heat from the atmosphere; conduction from the streambed; and advective inputs from groundwater, hyporheic, and tributary inflows (see Figure 1 in Moore et al. 2005). Channel size and shape influence the sensitivity of streams to these heat fluxes, with wide, shallow streams being more sensitive to heating than deep, narrow streams of a similar discharge. Generally, stream temperatures increase with decreasing elevation (i.e., further distance from headwaters), although there are exceptions in systems with lakes and wetlands where cooling can occur downstream of these tributary water sources.

Forest management affects stream temperature directly through the removal of shading vegetation and alteration of riparian microclimate (Figure

15.10), and indirectly through channel widening as a consequence of channel destabilization caused by altered streamflow, LWD, and sediment regimes. Riparian harvesting increases solar radiation exposure, wind speed, and exposure to air advected from openings, causing increased air, soil, and water temperatures (Moore et al. 2005). The overall effect of riparian harvesting is increased stream temperatures in all seasons, with the greatest increases occurring in the summer (Table 15.12). Removing shading canopy cover, or a proportion of it, may also decrease nighttime minimum temperatures by allowing greater radiation heat loss. In the northern hemisphere, changes in stream temperature are likely larger in the summer, as the intensity and duration of solar radiation is greatest at this time of year.

Direct comparisons between studies in the literature are difficult because of differing treatments (clearcut, partial cut, prescribed burning, buffers), varying watershed characteristics, and most importantly, differing measures of temperature increases in time (e.g., daily maximum, average monthly maximum, annual maximum). In general, the absolute magnitude of stream temperature increase (Figure 15.11) is directly related to the proportion of surface area newly exposed (Gibbons and Salo 1973) or to the amount of shade reduction (Beschta et al. 1987).

FIGURE 15.10 *Class S4 stream with clearcut riparian management area; virtually all trees removed (Chatwin et al. 2001).*

The duration of elevated stream temperatures after timber harvesting depends on local watershed factors and rate of riparian revegetation. Elevated temperatures are reported to persist anywhere from 2–30 years. In the Bull Run Watershed in Oregon, Harr and Fredriksen (1988) observed that elevated annual maximum stream temperatures returned to pre-logged values within 3 years. At the University of British Columbia Research Forest, Feller (1981) observed increases in stream temperature in summer that lasted 7 years as a result of clearcutting, whereas streams subjected to clearcutting and slash burning showed no signs of returning to pre-treatment temperatures during the same period of time. At the H.J. Andrews Experimental Forest in Oregon, Johnson and Jones (2000) found that stream temperatures gradually returned to normal levels 15 years after harvest.

In some streams, recovery may be slowed or unattainable if the channel has widened to the point where shade is no longer the primary determinant of recovering processes (Tschaplinski et al. 2004). Trees of the recovering riparian forest may need to be taller than the original stands to provide effective shade for channels that have widened because of natural and human-caused disturbances.

Riparian management focussed on maintaining water temperature regimes may become ever more important in the future for British Columbia and elsewhere, given the expected global increases in atmospheric temperatures and associated changes in precipitation regimes (Tyedmers and Ward 2001; Pike et al. 2008a, 2008b, 2008c; Spittlehouse 2008; see Chapter 19, "Climate Change Effects on Watershed Processes in British Columbia"). Current predictions indicate that the province may experience substantial increases in mean annual air temperatures (Spittlehouse 2008; see Chapter 19). Mitigating the extent of water temperature increases resulting from forestry operations in riparian areas will likely become an increasing priority, especially in areas where fish and other aquatic species are already near the limits of thermal tolerance and preference.

TABLE 15.12 *Effect of timber harvesting on water temperature increases*

| Location | Temperature increase | Measure | Treatment[a] | Reference |
|---|---|---|---|---|
| H.J. Andrews, Oregon | 7°C, summer<br>2–8°C | Max.<br>Diurnal fluctuation | CC/BB/PC (25% with debris flow) | Johnson and Jones (2000) |
| West Olympic Peninsula | 3.5°C, summer | Avg. max. | Two partially harvested watersheds (7%, 33%) | Murray et al. (2000) |
| Coyote Creek, Cascades | 8°C | Max. | CC | Adams and Stack (1989) |
| Salmon Creek Watershed | 6°C<br>2°C | Avg. daily max.<br>Avg. daily min. | | Beschta and Taylor (1988) |
| Bull Run Watershed | 2–3°C | Annual max. | CC/BB | Harr and Fredriksen (1988) |
| Alsea, Newport, Oregon | 14°F (7.9°C)<br>28°F (15.5°C) | Avg. month max.<br>Annual max. | CC/BB | Brown and Krygier (1970) |
| Slim Creek | 2–3°C<br>Doubling<br>4–9°C | Mean temp.<br>Diurnal fluctuation<br>Summer max. | CC | Brownlee et al. (1988) |
| Carnation Creek | 0.7°C, winter<br>0.75°C, spring<br>3.2°C, summer | Mean monthly | CC (41%) with 1.8 km riparian CC | Holtby (1988), Hartman and Scrivener (1990), Hartman et al. (1996) |
| Carnation Creek | 0.7°C, summer<br>2.7°C, 1st summer<br>1.4°C, 2nd summer | Mean daily<br>Daily max.<br>Daily max. | Herbicide | Holtby (1989) |

a CC=Clearcut, BB=Burned, PC=Partially cut

FIGURE 15.11 *The absolute magnitude of change in stream temperature is related to the amount of shade reduction. Shown is a class S4 stream with "clearcut" riparian prescription; non-merchantable and deciduous trees were retained within 5 m of the stream (Chatwin et al. 2001).*

The wide variation in riparian management regimes in the Pacific Northwest and throughout North America has resulted in several summary papers that compare systems among jurisdictions (Blinn and Kilgore 2001a, 2001b; Cashore 2001; Decker 2003; Lee at al. 2004).[6] Comments are often made about which regimes are more environmentally conservative; that is, which ones offer the best levels of streamside protection for aquatic ecosystems. However, the relative effectiveness of the different management systems is difficult to assess because data are not available on the post-harvest environmental outcomes of the standards and practices applied in the different jurisdictions. Similarly, much discussion has occurred on the design of riparian buffers for the protection of different riparian, stream, and aquatic ecosystem components and functions (e.g., Forest Ecosystem Management Assessment Team 1993; Belt and O'Laughlin 1994),[7] but this discussion similarly lacks supporting empirical evidence from field assessments of buffer effectiveness. The Province of British Columbia established the Forest and Range Evaluation Program (FREP) in 2003 to obtain this type of information on post-harvest management outcomes.

Evaluating the effectiveness of forestry practices in British Columbia has become a priority with the implementation of the results-based FRPA, under which a wide spectrum of forestry management practices may be applied, including those pertaining to riparian and watershed management. Since 2005, province-wide assessments of riparian management effectiveness have been conducted on streams managed under the FPC (www.for.gov.bc.ca/hfp/frep/values/fish.htm). These assessments are annual and ongoing. They now incorporate streams managed under the FRPA.

The key questions asked around riparian management and linked management systems are:

- Are riparian forestry and range practices effective in maintaining the structural integrity and functions of stream ecosystems and other aquatic resource features over both short and long terms?
- Are forest road stream crossings or other forestry practices maintaining connectivity of fish habitats?
- Are forestry practices, including those for road systems, preserving aquatic habitats by maintaining hillslope sediment supply and the sediment regimes of streams and other aquatic ecosystems?

Riparian management assessments are focussed on the first two questions and related effectiveness monitoring programs (for soils and water quality) address the third. Effectiveness evaluations are conducted annually in the field on a large sample of streams selected randomly in each British Columbia Ministry of Forests and Range district. Streams must have experienced at least 2 years (winters) post-harvest to allow for climatic and other disturbances to potentially occur. Each site is surveyed by employing an assessment protocol that includes a set of 15 principal riparian, stream channel, and aquatic habitat indicators (Tripp et al. 2009; Table 15.13). This assessment system, called a "Routine Effectiveness Evaluation," is a simplified version of a relatively intensive sampling protocol developed by an inter-agency/university FREP technical team. It is based on information from the scientific literature, a large base of empirical data that included details about 88 harvested and control streams in 10 forested biogeoclimatic zones, and expert opinion to cover gaps (Tripp and Bird 2006).[8] The indicators have built-in thresholds to assess departure from expected conditions in undisturbed, mature forest stands. This approach was adopted for the provincial-scale monitoring program because of practical problems (e.g., logistics, cost, stream inventory limitations)

6 Zielke, K. and B. Bancroft. 2001. A comparison of riparian protection approaches in the Pacific N.W. and British Columbia. Symmetree Consulting Group, Victoria, B.C. Unpubl. report.

7 CH2MHill and Western Watershed Analysts, 1999.

8 Tripp, D. 2005. On testing the repeatability of a routine riparian effectiveness evaluation methodology. B.C. Min. For. Range, Res. Br., Fish-Forestry Interact. and Watershed Res. Program, Victoria, B.C. Unpubl. report.
Tripp, D. 2007. Development and testing of extensive-level indicators and methods for determining if current forestry practices are sustainably managing riparian, aquatic ecosystem, and fish-habitat values. B.C. Min. For. Range, Res. Br., Fish-Forestry Interact. and Watershed Res. Program, Victoria, B.C. Unpubl. report.
Tripp, D. and S. Bird. 2004. Riparian effectiveness evaluations. B.C. Min. For. Range, Res. Br., Fish-Forestry Interact. and Watershed Res. Program, Victoria, B.C. Unpubl. report. www.for.gov.bc.ca/hfd/library/FIA/2004/FSP_R04-036a.pdf (Accessed May 2010).

TABLE 15.13 *Riparian, stream, and aquatic habitat indicators used for the routine-level assessment of riparian management effectiveness evaluations in British Columbia (see Tripp et al. 2009)*

| **Riparian, stream, and aquatic habitat indicators** | |
|---|---|
| Channel bed disturbance | Aquatic invertebrate diversity |
| Channel bank disturbance | Windthrow frequency |
| LWD characteristics | Riparian soil disturbance/bare ground |
| Channel morphology | LWD supply/root network |
| Aquatic connectivity | Shade and microclimate |
| Fish cover diversity | Disturbance increaser plants/noxious weeds/invasive plants |
| Moss abundance and condition | Vegetation form, vigour, and structure |
| Fine sediments | |

in identifying suitable control sites for reference purposes across all of the administrative classes and geomorphic stream types within each watershed or other defined area (e.g., physiographic region, specified landscape, biogeoclimatic zone, or portion of a defined watershed).

The routine-level assessment was required to cover a large sample of streams economically each year. Before implementation, the assessment was tested experimentally and operationally to ensure that the results were repeatable and consistent with the more quantitative method from which it was derived (Tripp 2007).[9] The evaluation approach assesses biological and physical attributes of stream reaches and the adjacent riparian areas by using a checklist of 15 questions covering the 15 primary indicators (Tripp et al. 2009; Table 15.14).

Each question is answered either "yes" or "no" to represent a pass or fail for the indicator. Before each question can be answered, several additional questions ("sub-indicators") must be addressed. For example, to answer indicator question five ("Are all aspects of the aquatic habitat sufficiently connected to allow for normal, unimpeded movements of fish, organic debris, and sediments?"), observations must determine whether:

1. there are temporary blockages to fish, debris, or sediment movement caused by instream accumulations of debris or sediment;
2. fluvial downcutting in the main channel isolates the floodplain from normal flooding or blocks access to tributary streams or "off-channel" areas;
3. sediment or debris accumulations occur within or immediately upstream of any crossing structure;
4. downcutting below any crossing structure blocks fish movements upstream by any size fish at any time of year;
5. all crossing structures on fish-bearing streams are open-bottomed ones (versus closed-bottom culverts);
6. dewatering over the entire channel width has occurred because of excessive new accumulations of sediment;
7. off-channel or overland flow areas have been isolated or cut off by roads or levees; and
8. water in the stream has not been withdrawn of diverted elsewhere (Tripp et al. 2009).

For indicator question 5, if a problem is identified with any one of these eight sub-indicators, then the main question is answered "no." For other indicators, a "yes" answer may still occur if one or more of the sub-indicators fail (see Tripp et al. 2009).

A total of 53 different observations and measurements must be made before the 15 main questions can be completed. Each site is classified into one of four possible outcomes by the roll-up score of answers out of 15:

1. Properly functioning condition (PFC): 0–2 "No" answers
2. Properly functioning condition, limited impacts (PFC-L): 3–4 "No" answers
3. Properly functioning condition with impacts (PFC-I): 5–6 "No" answers
4. Not properly functioning (NPF): more than 6 "No" answers

Some main questions may not apply (NA) to some

9 Tripp, D., 2007.

TABLE 15.14 *Fifteen main assessment questions that correspond to the 15 indicators of stream riparian function as given in Table 15.13. These questions, ordered in a checklist, are answered "Yes" or "No" or "Not Applicable" (NA). Before each of these questions can be answered, assessors must answer several additional questions ("sub-indicators") that are associated with the main questions (see Tripp et al. 2009 for full checklist and assessment protocol).*

| | **Indicator main question** | **Yes** | **No** | **NA** |
|---|---|---|---|---|
| Question 1 | Is the channel bed undisturbed? | ☐ | ☐ | |
| Question 2 | Are the channel banks intact? | ☐ | ☐ | |
| Question 3 | Are channel LWD processes intact? | ☐ | ☐ | |
| Question 4 | Is the channel morphology intact? | ☐ | ☐ | ☐ |
| Question 5 | Are all aspects of the aquatic habitat sufficiently connected to allow for normal, unimpeded movements of fish, organic debris, and sediments? | ☐ | ☐ | |
| Question 6 | Does the stream support a good diversity of fish cover attributes? | ☐ | ☐ | ☐ |
| Question 7 | Does the amount of moss on the substrates indicate a stable and productive system? | ☐ | ☐ | ☐ |
| Question 8 | Has the introduction of fine sediments been minimized? | ☐ | ☐ | ☐ |
| Question 9 | Does the stream support a diversity of aquatic invertebrates? | ☐ | ☐ | ☐ |
| Question 10 | Has the vegetation retained in the RMA been sufficiently protected from windthrow? | ☐ | ☐ | |
| Question 11 | Has the amount of bare, erodible ground or soil disturbance in the riparian area been minimized? | ☐ | ☐ | |
| Question 12 | Has sufficient vegetation been retained to maintain an adequate root network or LWD supply? | ☐ | ☐ | |
| Question 13 | Has sufficient vegetation been retained to provide shade and reduce bank microclimate change? | ☐ | ☐ | |
| Question 14 | Have the number of disturbance-increaser plants, noxious weeds, and (or) invasive plant species been limited to a satisfactory level? | ☐ | ☐ | |
| Question 15 | Is the riparian vegetation within the first 10 m from the edge of the stream generally characteristic of what the healthy, unmanaged riparian plant community would normally be along the reach? | ☐ | ☐ | |

streams. For example, question 4 on channel morphology does not apply to a stream whose form is not created by water (non-alluvial streams). Similarly, fish cover attributes (question 6) are not assessed in non-fish-bearing streams.

Research from the Malcolm Knapp Research Forest has shown measurable, forestry-associated alterations to some of the biological and physical attributes of streams and riparian areas, even when riparian reserves 30 m wide are used (Richardson et al. 2002). Therefore, assessments under FREP are not focussed on whether managed streams are left in pristine condition. Instead, assessments of ecosystem function are employed where "properly functioning condition" is defined as the ability of a stream (Figure 15.12) and its riparian area to:

- withstand normal peak flood events without experiencing accelerated soil loss, channel movement, or bank movement;
- filter runoff;
- store and safely release water;
- maintain the connectivity of fish habitats in streams and riparian areas so that these habitats are not lost or isolated as a result of management activity;
- maintain an adequate riparian root network or LWD supply; and
- provide shade and reduce bank microclimate change.

Therefore, it is assumed that natural ecological functions of the habitat will be maintained if changes that are attributable to forestry practices are within an identified range of natural variability over most of the habitat.

By the end of 2008, a total of 1441 streams from randomly selected cutblocks was assessed province-wide, including 690 class S6 (48% of the total), 93 class S5 (6%), 269 class S4 (19%), 300 class S3 (21%), 84 class S2 (6%), and 5 class S1 (< 1%) streams. Although the sample does not include equal representation across the six riparian stream classes, it is considered to well represent the distribution of the different classes of streams on the landscape, as well as the distribution encountered in forestry operations.

FIGURE 15.12 *Stream in properly functioning condition with all riparian vegetation intact. (Photo: R.G. Pike)*

Most harvesting since 1995 in British Columbia has occurred in areas upslope from large, valley-bottom S1 streams. Sixty-seven percent of the sample consists of class S4 and S6 streams. These stream classes have been the focus of most of the debate and discussion on whether British Columbia's riparian management standards provide sufficient streamside protection to small watercourses, which do not receive riparian reserves in regulation.

Results overall showed that 87% of all streams assessed were in one of the three properly functioning condition (PFC) categories, whereas less than 13% were in the not PFC (NPF) category (Figure 15.13). Thirty-eight percent of all streams were found to be properly functioning without caveats, 29% were in PFC with limited impacts, and 20% were in PFC with impacts (Figure 15.14). Most of the 182 NPF streams were in the non-fish-bearing class S6 (131 streams), whereas most of the remainder were in the small, fish-bearing class S4 (Figures 15.14, and 15.15); however, a small number of NPF streams were class S3, and the impacts were frequently associated with catastrophic windthrow in the riparian reserve.

Results summarized by individual indicators show that most indicators passed ("yes" answers) by a substantial margin with the one exception being fine sediments (Figure 15.16). Fine sediments at levels above the identified assessment thresholds affected more than 63% of all streams that could be assessed for this indicator, including all riparian classes, and regardless of the presence of riparian reserves. Fine sediments affected all stream classes partly because a major source of these materials was from roads and stream crossings. These sediments, and those from riparian management-related sources (e.g., windthrow, exposed soil) affected the performance of some of the other indicators such as benthic invertebrates. However, for other indicators (e.g., vegetation form, vigour, and structure) with relatively high frequencies of "no" answers for the small S4 and S6 streams, responses were attributed to low levels of riparian tree retention and high levels of near-stream harvesting activity within the management area (e.g., cross-stream felling and yarding for S6 streams). For streams that scored NPF or were in one of the two intermediate categories, low riparian

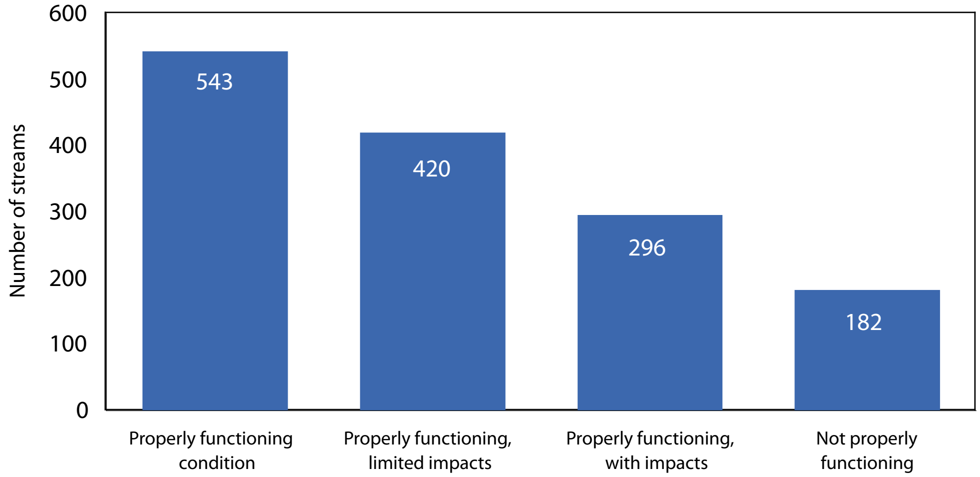


FIGURE 15.13 *Overall outcomes of riparian management effectiveness evaluations under the Forest and Range Evaluation Program for 1441 streams assessed between 2005 and 2008.*

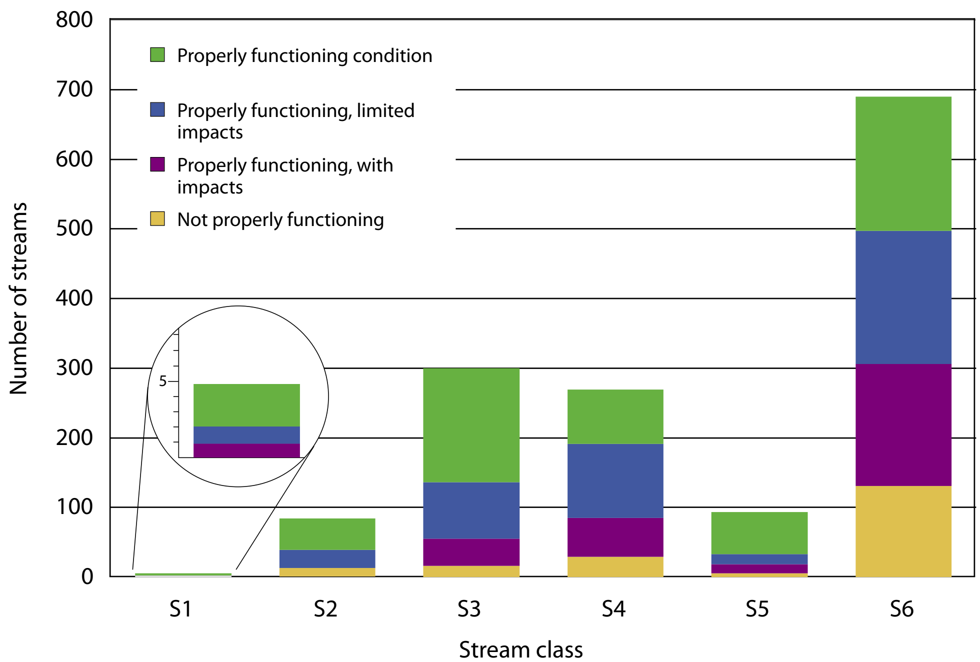


FIGURE 15.14 *Overall outcomes of riparian management effectiveness evaluations by riparian stream class for the 1441 streams assessed under the Forest and Range Evaluation Program between 2005 and 2008.*

FIGURE 15.15 *Class S4 stream with full retention from the streambank up to the top of the gorge (Chatwin et al. 2001).*

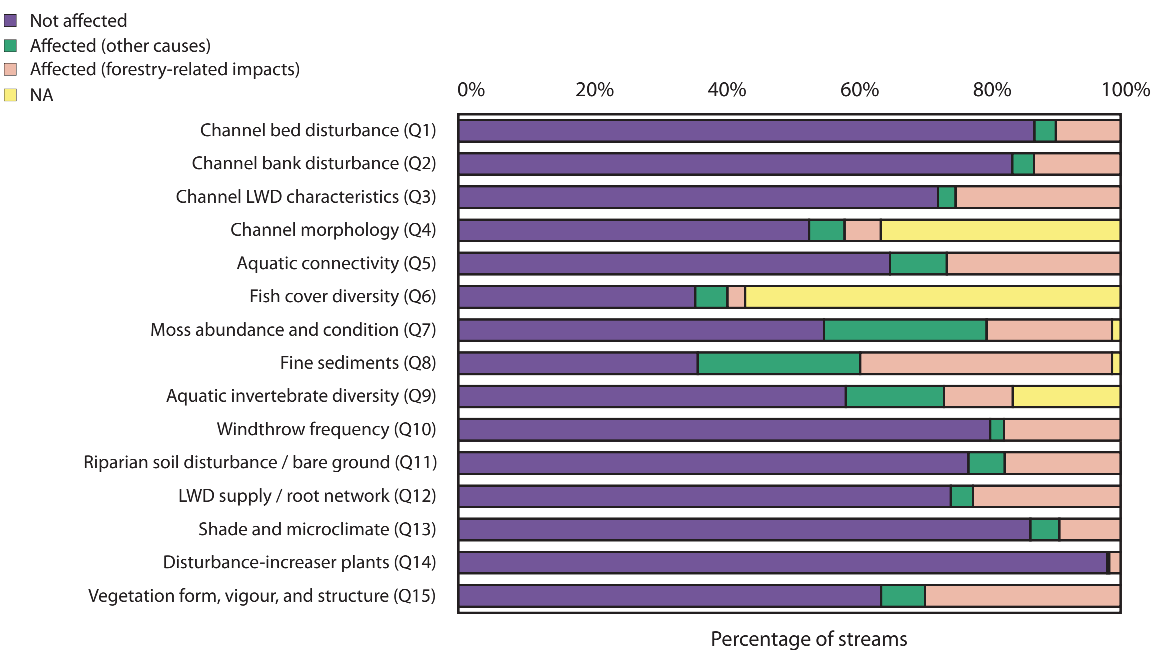


FIGURE 15.16 *Overall outcomes of riparian management effectiveness evaluations by individual indicator for all streams assessed under the Forest and Range Evaluation Program between 2005 and 2008 combined. Yes = purple; No (tan) = indicator failure attributed to site-level forestry causes; No (green) = indicator failure attributed to other causes; Yellow bars are where either an indicator was not applicable (e.g., fish habitat diversity in non-fish-bearing streams), or where the indicator could not be scored.*

tree retention was identified as a main or contributing causal factor for indicator failure 48% of the time, whereas road-related factors affected 35% of the indicator failures as the main agent, and 68% of all failures as either the main or contributing factor. Other important impact causes included windthrow (32% main plus contributing), cross-stream felling and yarding (30% main plus contributing), and livestock-related activities (9% of the main causes).

Not all of the indicator failures were attributed to site-level, forestry-related causes. Impacts delivered from sources upstream contributed to about 21% of the indicator failures. Other indicator failures were related to antecedent conditions outside the range of variation built into the indicators, or to non-forestry-related activities. For example, fine sediments appeared to be naturally abundant in some small, low-gradient S6 streams, particularly in central Interior locations where glaciolacustrine sediments are widespread. Nearly 40% of all "no" answers for the fine sediments indicator were attributed to causes other than site-level forestry (Figure 15.16); however, averaged over all sites provincially, the mean number of indicator failures due to non-forestry-related factors was only 1.1 per stream (Table 15.15).

On average, when forestry-related factors are included, the mean number of indicator failures ("no" answers) was 3.6 per stream, leaving a mean forestry-related increment of 2.5 per stream. The largest increments attributed to forestry occurred in class S4 and S6 headwater streams where 2.5 and 3.4 "no" answers were added for the two classes, respectively. The predominant broad causal factors of low riparian tree retention, road-delivered fine sediments, and cross-stream falling and yarding (S6s) appear to explain the outcomes for these smallest streams, whereas road-delivered fine sediments and windthrow-related impacts were common sources of problems for larger fish-bearing streams with riparian reserves (classes S1–S3) and for the large non-fish-bearing class S5 streams (Table 15.15). Larger streams appear to be relatively well managed. On average, forestry added only 0.9–1.0 "no" answers for the largest streams (classes S1 and S2), and 1.4 and 1.6 "no" answers for classes S3 and S5, respectively.

These results, together with the identified causal factors, have initiated discussions on how the environmental outcomes of riparian management in British Columbia might be further improved. Anticipated problems with some class S6 and S4 streams and the associated frequencies of occurrence have been systematically identified and statistically assessed. However, the FREP assessments also demonstrate that many S6 and S4 streams scored well when certain practices were applied. Preliminary observations indicate that the number of "no" answers related to riparian management can be substantially reduced if the following three practices are followed, particularly within the riparian management zones of small streams.

1. Limit introduction of logging debris and riparian management area–related sediments into channels.
2. Limit physical contact with streambanks and streambeds when falling and yarding around class S6 streams; fall and yard trees away from the channel wherever possible.
3. Retain more vegetation more frequently around class S4 streams and important S6 streams.

For example, problems were frequently encountered when non-merchantable trees and understorey vegetation (at a minimum) had not been retained in riparian areas. Fine sediment generation from roads and crossings was also frequently encountered.

TABLE 15.15 *Mean number of indicator failures ("no" answers) per riparian class of stream attributable to forestry-related and non-forestry-related causes*

| Stream class | No. streams | Total "no" answers | No. non-forestry "no" answers | Unhealthy (NPF) without forestry (%) | Unhealthy (NPF) with forestry (%) | Mean non-forestry condition (no. "no") | Mean condition with forestry added (no. "no") | Mean impact increment with forestry (no. "no") |
|---|---|---|---|---|---|---|---|---|
| S1 | 5 | 14 | 9 | 0 | 0 | 1.8 | 2.8 | 1.0 |
| S2 | 84 | 217 | 142 | 0 | 1.2 | 1.7 | 2.6 | 0.9 |
| S3 | 300 | 803 | 397 | 0 | 5.3 | 1.3 | 2.7 | 1.4 |
| S4 | 269 | 1011 | 352 | 0 | 10.8 | 1.3 | 3.8 | 2.5 |
| S5 | 93 | 228 | 81 | 0 | 5.4 | 0.9 | 2.5 | 1.6 |
| S6 | 690 | 2904 | 555 | 0 | 19.0 | 0.8 | 4.2 | 3.4 |
| All | 1441 | 5177 | 1536 | 0 | 12.6 | 1.1 | 3.6 | 2.5 |

However, these problems can be addressed using well-known streamside retention and sediment management practices. The more frequent implementation of these techniques will likely improve outcomes for small streams.

The discussion of best management practices versus those associated with problems should continue and expand beyond the broadly identified issues of riparian retention, road-related sediment, and harvesting or range activities within riparian management areas. To identify which practices are the most suitable for specific situations, several site-specific options need to be discussed with forestry and range practitioners.

Among the many challenges is adapting management to the diversity of streams within the numerically dominant class S6. These streams dominate the lengths of drainage networks and can be relatively large (2.5–3 m wide), perennially flowing watercourses with sufficient hydraulic energy to influence streams, aquatic habitats, and fish downslope. At the other end of the spectrum are the narrow, ephemeral class S6 streams, which may scarcely be 100 m long with barely discernable channel beds, and may not be connected to the rest of the drainage network by surface flow. Identifying appropriate riparian management activities across this broad spectrum of channels will continue to be one of the most challenging aspects of land use management.

Riparian assessments in British Columbia under the FREP are still at a relatively early stage despite the large sample of sites already evaluated. The 1441 sites assessed between 2005 and 2008 form a substantial sample representative of the outcomes achieved under the prescriptive FPC regime, and provide a performance baseline for comparison with streams managed under the results-based FRPA regime.

## SUMMARY

Monitoring the responses of streams and riparian areas under FREP will continue and will contribute to incremental improvements to riparian management outcomes in British Columbia. In the immediate future, the effectiveness of riparian management implemented under the FRPA will be the main subject of post-harvest assessments of stream and riparian conditions. Existing riparian and stream channel monitoring in British Columbia provides information in the form of one-time "snapshots" of functional condition 2–12 years after harvesting. These data represent relatively short-term forest harvest effects (Figure 15.17). Research has shown that forestry-related impacts on streams and aquatic habitats may not be fully developed until two decades or more have elapsed, especially in cases where impacts are related to mass wasting in headwater areas and are propagated over time down the stream channel network (Tschaplinski et al. 2004). Therefore, continuous monitoring will have to be conducted over the long term to allow adequate adjudication of the potential long-term effects of forestry activities and thus inform strategies proposed for riparian and watershed management in British Columbia. This long-term perspective is particularly important in a results-based forest management regime where several strategies may be proposed for these purposes.

The debate on how to best manage streams, particularly small streams, will likely continue. Although the implementation of ecologically sound riparian management practices is desirable, actually accomplishing this will pose significant challenges. Several questions will have to be addressed. For example, if some small streams are managed more conservatively by increasing the levels of streamside tree retention to maintain attributes and functions on-site and to provide for aquatic habitats downslope, can this be done on an ecologically sound basis at the watershed level, while also providing some forestry opportunities? Can some forestry opportunities be achieved by re-allocating riparian retention from the riparian reserve zones of some larger streams? Will doing so have undesirable consequences for stream reaches where fish actually live?

Many sound reasons exist for managing within a watershed context. However, we are still learning about how physical processes operate, how these processes are interrelated at larger spatial scales, and how these physical processes interact with biological processes at the watershed level. On the other side of this issue, one notion is that good practices exercised at the site level will likely go a long way towards providing functions at the watershed level. For example, if we provide for shade and sources of instream

FIGURE 15.17 *Clearcut riparian management area with second-growth vegetation. (Photo: R.G. Pike)*

wood, limit ground disturbance in and near riparian management areas, manage roads to minimize sediment introductions to streams, and maintain fish passage, will these site-level actions be sufficient to maintain the integrity of the channel network and its aquatic ecosystems from the rim of the basin to the outlet of the principal stream? Is our knowledge of watershed functions sufficient to provide us with the confidence to achieve desirable outcomes?

Significant research gaps persist about the interactions of forestry practices in regard to LWD dynamics, sediment budgets and routing, water temperature impacts, groundwater–channel interactions, and riparian reserve and management zone design to maintain these functions effectively at the site level. These and other research needs will be accentuated in the future given the mid- and long-term effects of global climate change and its implications for precipitation and temperature regimes, forests, aquatic ecosystems, and watershed management. At the same time as post-harvest effectiveness monitoring continues to provide the important data necessary for adaptive management, additional research information in key gap areas can only benefit operational designs for riparian and watershed stewardship.

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