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Riparian Zone Management in the Pacific Northwest: Who's Cutting What?

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ABSTRACT / In the Pacific Northwest (PNW) of North America, forestry practices during the last century have degraded the ecological linkages between riparian forests and streams. In an attempt to protect the integrity of lotic ecosystems and associated fisheries resources (primarily anadromous Pacific salmon, *Oncorhynchus* sp.), regional governments now restrict timber harvest in riparian forests. I summarize and assess the riparian zone management guidelines of the states of California, Oregon, and Washington (USA) and the province of British Columbia (Canada). Only Oregon and British Columbia protect fish-bearing streams with "no-harvest" zones, and only the wider (20–50 m) no-harvest zones for larger fish-bearing streams in British Columbia are likely to maintain near-natural linkages between riparian and stream ecosystems. All four jurisdictions protect most streams with "management zones" of variable width, in which timber harvest activities are restricted. All the management zone guidelines permit the harvest of the largest conifers from riparian forests and will, if applied over a series of timber harvest rotations (60–80 years), result in the continued removal of potential sources of large woody debris from the region's watersheds. All four jurisdictions require additional protection for streams and watersheds that are severely degraded or (in the United States) contain threatened or endangered species. The governments of the PNW have taken a "manage until degraded, then protect" approach to riparian forest management that is unlikely to maintain or restore the full suite of riparian-stream linkages necessary for lotic ecosystems to function naturally at the stream, watershed, basin, or regional scale.

Riparian forests encompass a range of chemical, biological, and physical processes and features unlike those represented within the larger forest matrix. Riparian zones contribute critically to the ecological character of forest ecosystems by containing high levels of floral and faunal diversity (Schoonmaker and McKee 1988, Pollock and others 1998), creating unique microclimates (Brosofske and others 1997), providing connectivity within increasingly fragmented landscapes (Noss 1987, Saunders and Hobbs 1991), and serving as chemical, biological, and physical boundaries between streams and rivers and the watersheds they drain (Gregory and others 1991, Naiman and others 1993). While riparian forests influence a broad range of ecological processes, ecologists, resource managers, and the public are increasingly occupied with how riparian zones and the disturbance thereof affect the structure and function of the aquatic ecosystems they border. This concern is particularly justified in the Pacific Northwest (PNW) of North America, where forest and aquatic resources (primarily anadromous Pacific salmon, *Oncorhynchus* sp.) are economically and culturally important and in recent decades have begun to show signs of ecological collapse after more than a century of exploitation and anthropogenic disturbance (Nehlsen and others 1991, Frissell 1993, Franklin 1993, Sedell and others 1993, Slaney and others 1996, National Research Council 1996). Appropriately, "riparian zone management" has emerged as a central theme of ecosystem management in the PNW (Swanson and Franklin 1992).

In response to the growing concern and corroborative evidence for the impairment of the region's forest and lotic ecosystems, the state and provincial governments of the PNW (California, Oregon, Washington [United States], and British Columbia [Canada]) have recently adjusted laws regulating timber harvest and associated activities. Included in these laws are more restrictive guidelines for forest practices within riparian zones, the aims of which (among others) are to maintain and enhance the structure and function of stream and river ecosystems and protect declining, and in many cases endangered, populations of resident and anadromous salmonids. Riparian forests affect nearly every ecological process and feature of lotic ecosystems in the PNW (Salo and Cundy 1987, Meehan 1991, Hicks and others 1991). Riparian forests can influence the temporal and physical properties of sediment fluxes into channels (Hicks and others 1991); regulate stream temperature (Beschta and others 1987); mediate autoch-

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thonous and allochthonous energy pathways by controlling the amount of incident solar radiation and the type and timing of organic matter entering and leaving channels (Newbold and others 1980, Bilby and Bisson 1992); and define channel structure and function by providing bank stability and sources of large and small woody debris (Bisson and others 1987, Bilby and Ward 1991, Ralph and others 1994). The affect of riparian timber harvest on different riparian-stream linkages and populations of resident and anadromous salmonids depends on the physical characteristics of the channel (Murphy and Hall 1981, Hawkins and others 1982, Beechie and Sibley 1997), the geoclimatic properties of the watershed (Murphy and others 1986, Hicks and others 1991), and the species of fishes considered (Bisson and Sedell 1984, Murphy and others 1986, Reeves and others 1993).

Here I review the riparian zone management guidelines established as part of the broader forest practice regulations enacted by the state and provincial governments of California, Oregon, Washington, and British Columbia. I focus my discussion on guidelines specifically affecting riparian zone timber harvest and refer to ''upslope'' and ''watershed'' guidelines when they directly influence riparian zone management guidelines. Except for California, all the jurisdictions have separate riparian zone management guidelines for interior forests, which are characterized by more continental climates, vegetation patterns, and hydrologic regimes. I consider the riparian management guidelines only for westside forests (the temperate coniferous forests west of the Cascade and Coast Mountains) falling under state (nonfederal lands in the United States) and provincial (Crown [federal] lands in British Columbia) jurisdiction. Finally, I will consider riparian management guidelines in relation to lotic ecosystems and the salmonid communities therein, not to ignore the many other equally important ecological functions of riparian forests (see, for example, Naiman and others 1993), but to limit the scope of the discussion and take advantage of the substantial body of research on fish–forestry interactions and watershed processes in temperate forests of the PNW.

I proceed with two primary goals. The first is to document and compare the management actions taken by PNW governments toward protecting lotic ecosystems through riparian zone management. The second is consider in the context of current scientific knowledge whether established management guidelines are likely to protect and restore natural riparian–stream linkages across ecologically relevant spatiotemporal scales. For each jurisdiction I present a table summarizing the key components of riparian zone management: stream classification; the presence / absence and width of ''no-harvest zones''; and the presence / absence, width of, and harvest restrictions within ''management zones.'' More general management guidelines and exceptions and alternatives to the riparian management guidelines presented in the tables are discussed in the text and table footnotes. I make no effort to formally rank the guidelines regarding potential efficacy, but instead aim to provide an ecological context to facilitate informed comparison and assessment. To this end, I present in the Discussion examples comparing how the riparian forests adjacent to three typical PNW streams would be managed in each of the four jurisdictions.

California

Article 6 of the California Forest Practice Rules (California Department of Forestry 1998) establishes guidelines for the management of Watercourse and Lake Protection Zones (WLPZs) in the state of California, including the temperate coniferous forests in the northwest portion of the state. California separates streams into four classes based on their beneficial uses. Here I consider only the first three, as Class IV watercourses are designated ''man-made'' and are not immediately relevant to the discussion. Class I watercourses are those with fish always or seasonally present; Class II water courses are those without permanent or seasonal fish use but within 330 m of Class I watercourses; Class III watercourses are channels with no fish use but showing evidence of sediment transport during high (winter) flow conditions (Table 1). WLPZs are designed to ''protect the beneficial uses of the water,'' including water temperature, large woody debris (LWD) loads, sediment filtration, upslope stability, bank and channel stability, and vegetation structure for fish and wildlife habitat.

None of the three stream classes is protected by a mandatory no-harvest zone adjacent to the active stream channel (Table 1). For Class I and II streams, WLPZ widths are determined from on-site inspections by the registered professional forester responsible for developing the timber harvest plan. The width of the WLPZ depends on the weighted average slope of the hills adjacent to the stream, with steeper slopes requiring wider WLPZs (Table 1). Class I WLPZs range from 23 to 45 m and prohibit the harvest of more than 50% of the overstory canopy and more than 75% of the overstory conifers (Table 1). Class II WLPZs range from 15 to 30 m and prohibit the harvest of more than 50% of the *total* (over- and understory) canopy and more than 75% of the existing overstory conifers. These harvest restrictions are based on total canopy closure. For example, if

Table 1. Stream classification and riparian zone management guidelines for California

Type	Class I			Class II			Class III		
Description	1. Domestic water supply on site or within 30 m downstream, and/or 2. Fish always or seasonally present			1. Fish always or seasonally present within 330 m downstream, and/or 2. Aquatic habitat for nonfish aquatic species			No aquatic life present, channel capable of sediment transport to Class I and II channels under high flow conditions		
Slope class (%)[a]	<30	30–50	>50	<30	30–50	>50	<30	30–50	>50
No-harvest zone	none	none	none	none	none	none	none	none	none
Management zone (m)	23	30	45[b]	15	23	30[c]		See below[d]	
Harvest restrictions	A, B	A, B	A, B	A, C	A, C	A, C	D	D	D

[a]Slope is determined from the edge of the active channel to a point 33 m upslope using a weighted average of observed values.

[b]Subtract 15 m for cable yarding.

[c]Subtract 7.5 m for cable yarding.

[d]The width of the Watercourse Lake Protection Zone (WLPZ) is determined on site by a registered professional forester (RPF). If no WLPZ is established, the RPF is to designate an equipment limitation zone (ELZ) to prevent soil disturbance near the channel (ELZ $\geq$7.5 m for slope class <30%, ELZ $\geq$15 m for slope class >30%).

A: Where <50% of the canopy exists in the WLPZ only ‘‘sanitation salvage’’ is allowed within the WLPZ. At least two living conifers $\geq$0.4 m diameter at breast height (DBH) and $\geq$15 m tall must be retained per acre within 15 m of all Class I and II channels (equal to approximately two such trees per 130 m of channel).

B: At least 50% of the overstory and 50% of the understory canopy shall be retained in ‘‘a well distributed multi-storied stand composed of a diversity of species similar to that found before the start of operations,’’ and ‘‘the residual overstory canopy shall be composed of at least 25% of the existing overstory conifers.’’

C: At least 50% of the *total* canopy shall be retained in ‘‘a well distributed multi-storied stand configuration composed of a diversity of species similar to that found before the start of operations,’’ and ‘‘the residual overstory canopy shall be composed of at least 25% of the existing overstory conifers.’’

D: ‘‘At least 50% of the understory canopy vegetation present before timber operations shall be left living and well distributed within the WLPZ to maintain soil stability.’’

initial canopy closure is 60% the operator may reduce that closure to 50, not 30%. The width of the WLPZ for both classes may be reduced by the RPF and the director (of Forestry and Fire Protection), but may in no case be less than 15 m. Timber harvest in Class I and II WLPZs is further limited by two general restrictions: (1) at least two living conifers with a diameter at breast height (DBH) $\geq$ 0.4 m and height $\geq$ 15 m must be retained within 15 m of the channel per 130 m of channel length, and (2) if prior to timber harvest less than 50% of the canopy exists in the WLPZ, only ‘‘sanitation salvage’’ is permitted. Timber harvest activities adjacent to Class III streams are not subject to WLPZ restrictions, but are required to protect soil stability via equipment limitation zones (ELZs) and/or the retention of at least 50% of the living understory vegetation (Table 1).

Departures from the standard WLPZ guidelines may be implemented in two ways. Alternative timber harvest plans require logistical and ecological justification and can be developed by the registered professional forester. The alternative timber harvest plan may be more or less restrictive than the standard guidelines, but must afford equal or greater protection of the beneficial uses listed earlier and must meet the two general restrictions for Class I and II streams described above. Riparian (and general) timber harvest may also be modified (to afford more protection) if the stream in question is within a watershed classified as ‘‘sensitive.’’ Sensitive watersheds are those where there is ‘‘substantial evidence that a condition, or conditions, exist(s) where further timber operations within the planning watershed will create a reasonable potential to cause, or contribute to ongoing, significant adverse cumulative effect(s) on the resources,’’ including but not limited to fish and aquatic and/or riparian habitat, and wildlife species (or their habitat) listed under state or federal law as rare, threatened, or endangered. Designating a watershed as sensitive involves a lengthy public and agency review process that must identify the contribution of timber harvest activities to those conditions limiting ecosystem function. If a watershed is classified as sensitive, mitigation actions that prevent further degradation to the identified resource(s) must be implemented if timber harvest is to occur.

Oregon

Chapter 629, Division 635 of the Oregon Forest Practice Administration Rules (FPAR) (Oregon Department of Forestry 1995) establishes the guidelines for riparian zone management for state and private lands in

Table 2. Stream classification and riparian zone management guidelines for western Oregon

Type	Type F			Type D and N		
Description	Streams with fish use,[a] including those with domestic water use			D: Streams with domestic water use, but not fish use N: Streams not classified as F or D		
Size[b]	Small	Medium	Large	Small	Medium	Large
No-harvest zone (m)						
Understory	3	3	3	none[c]	3	3
Trees	6	6	6	none[c]	6	6
Management zone (m)	15	21	30	none[c]	15	21
Harvest restrictions[d]						
Retention requirements[e] (live conifers / 300 m)	see below	30 ≥ 0.20 m DBH	40 ≥ 0.27 m DBH	none[c]	10 ≥ 0.20 m DBH	30 ≥ 0.27 m DBH
Standard Target[f] (ST) (m^2/300 m)						
Clear-cut	4	10–13	20–24	none[c]	5[g]	8–10
Partial Cut	5	13–16	26–32	none[c]	5.4[g]	11–14
Retention (trees ≥ / 300 m)						
Initial Basal Area (IBA) > ST	To meet ST	To meet ST	To meet ST	NA[c]	To meet ST	To meet ST
0.5 ST < BA < ST	≤70[h]	≤100[h]	≤150[h]	NA[c]	≤70	≤100
IBA <0.5 ST	A	A	A	NA[c]	B	B

[a]A stream is ‘‘considered to have fish use if inhabited at any time of the year by anadromous or game fish species or fish that are listed as threatened or endangered species under the federal or state endangered species acts.’’

[b]Small streams have watersheds less than 40 ha or a mean annual flow less than 0.03 m^3/s. Medium streams have mean annual flows between 0.03 and 0.3 m^3/s. Large streams have mean annual flows greater than 0.3 m^3/s.

[c]For small Type N streams no retention is required for streams in the Coast Range and western Cascades. Elsewhere in western Oregon, 3-m no-harvest zones for understory vegetation and nonmerchantable trees (<0.15 m DBH) are required for those portions of perennial small streams draining areas greater than 64 (South Coast), 133 (Interior valleys), and 234 (Siskiyou province) ha.

[d]Harvest restrictions are those required to meet standard target goals (basal area retention in m^2/300 m) in RMAs. Operators must retain *all* live and dead conifers (and certain hardwoods ≥6 m from the channel) (≥0.15 m DBH), up to the limit given, per 300 m on *each* side of the channel; standard targets are determined by upslope harvest practices (clear-cut or partial cut); harvest levels are determined by the standard target and the basal area existing in the RMA at the time of harvest. The ranges encompass the standard target values for different regions of western Oregon.

[e]Trees in the no-harvest zone are included in meeting the RMA retention requirement.

[f]The range in standard target values is based on site productivity estimates and is higher for more productive geographic regions. If enhancement projects are conducted by the operator in Type F streams these standard target values are reduced to ‘‘active management target values’’ by the following percentages: for clear-cuts: large, 75%, medium, 78%, small, 50%; partial-cut: large, 90%, medium, 87%, small, 60%.

[g]Hardwoods may count for up to 60% of this target value.

[h]‘‘Operators shall retain all live conifer trees 0.15 m DBH or larger in the riparian management area up to a maximum of’’ the number in the table. Any trees remaining after meeting this condition may be harvested.

A: Operators may apply an approved alternative vegetation retention prescription (see text) *or* retain all conifers in the RMA and hardwoods within 15 m of the high water level for large streams, 9 m for medium streams, and 6 m for small streams.

B: Operators may apply an approved alternative vegetation retention prescription (see text) *or* retain all conifers in the RMA and hardwoods within 9 m of the high water level for large streams, and 6 m for medium streams.

Oregon. Oregon divides the state into seven biogeoclimatic regions where different riparian management guidelines apply; I discuss the guidelines for the five regions west of the Cascade crest. Oregon classifies streams into three types: Type F streams have fish use and possibly domestic water use; Type D streams have domestic water use but no fish use; Type N streams are all those not classified as F or D (see Table 2 for the definition of ‘‘fish use’’). I will discuss only Type F and N streams, though Type D streams are in most cases managed similarly to Type N streams. Stream Types are further divided into small, medium, or large based on a measure or estimate of mean annual flow (Table 2).

Except for small Type N streams, all streams in western Oregon are protected by a 6-m no-harvest zone for trees, a 3-m no-harvest zone for understory vegetation, and the mandatory retention of any tree leaning over the active channel; small Type N streams may receive 3-m buffers of brush and nonmerchantable trees to protect water quality (Table 2). The no-harvest zone is contained within a larger Riparian Management Area (RMA) where timber harvest activities are restricted. The width of the RMA depends on the type and size of the stream. Harvest restrictions in the RMA depend on (1) the initial basal area (IBA) (square meters of stems at breast height) of conifer trees in the

RMA per 300 m of channel relative to a target basal area (TBA), and (2) the harvest method (clear-cut or partial cut) upslope of the RMA. RMAs range from 15 to 30 m for Type F streams. All medium and large streams, regardless of type, have mandatory retention requirements within the RMA (Table 2). Beyond these requirements, harvest levels are determined by the IBA and the TBA. If the IBA is greater than the TBA, trees in RMA may be harvested until the TBA is reached. If the IBA is less than the total TBA but greater than one-half the TBA, a variable number of live conifers greater than 0.15 m DBH must be retained in the RMA. If the IBA is less than one-half the TBA, the operator has two options: one is to leave all live conifers and hardwoods within approximately one-half the width of the RMA, the other is to apply an alternative vegetation retention prescription (Table 2). Alternative prescriptions are intended for situations where the RMA contains too few conifers due to catastrophic events or past management practices and include thinning and restocking the RMA with conifers.

The riparian management guidelines of Oregon are unique in that they include an ''active management'' option that uses a basal area credit system for live tree retention in the RMAs of Type F streams. If the operator conducts habitat enhancement projects (placement of logs or rootwads, bank stabilization, creation of off-channels habitat, grazing exclosures, etc.), the TBA is reduced to allow more harvest in the RMA (see Table 2). For each log placed in a large or medium Type F stream, the basal area credit is twice that of the log placed in the stream. For small Type F streams the basal area credit is equal to that of the log placed in the stream. The credit for other restoration or enhancement projects is negotiated between the operator, the Oregon Department of Forestry, and the Oregon Department of Fish and Wildlife. The enhancement projects need not be within the RMA in question, so long as the project is in the ''same immediate vicinity.'' The credit system allows operators to increase harvest levels in the RMA to meet a modified active management TBA retention value, which ranges from 50 to 90% of the standard TBA depending on stream size and upslope harvest method (Table 2). Finally, the RMA guidelines summarized above are subordinate to restrictions imposed for watersheds that are water quality limited or contain aquatic species listed as threatened or endangered under state or federal law.

Washington

Riparian zone management guidelines for Washington state are established in Chapter 222-30 of the Washington Forest Practice Rules (Washington Department of Natural Resources 1995) and summarized in *Forest Practices Illustrated* (WDNR 1997). Washington has established different Riparian Management Zone (RMZ) guidelines for the portions of the state west and east of the Cascade crest. Washington divides streams into five types, which, along with average channel width and substrate characteristics, determine the width of and harvest restrictions within RMZs (Table 3). Type 1 streams are official ''shorelines of the state,'' generally large rivers with fish use. Type 2 streams have average channel widths greater than 6 m and fish and domestic use. Type 3 streams have channels widths less than 6 m and fish use. Type 4 (channel width $>$0.6 m) and Type 5 streams (channel width $<$0.6 m) have no fish use.

None of the five stream types are protected by a no-harvest zone adjacent to the channel (Table 3). Type 4 and 5 streams are not protected by RMZs or other harvest restrictions adjacent to the channel, except where downstream public water resources require protection, in which case some retention may be required. Type 1, 2, and 3 streams are each divided into two classes based on channel width, and all have a minimum RMZ width of 7.5 m and a maximum RMZ width ranging from 7.5 m (for small Type 3 streams) to 30 m (for large Type 1 and 2 streams) (Table 3). RMZs begin at the edge of the active channel, including flood plains and off-channel habitat. Within all RMZs operators must ''leave an average of five of the largest trees per acre undisturbed, with a ratio of one conifer to one deciduous, at least two of which must be alive.'' The width of the RMZ depends on the area needed to meet the retention requirements, which are given as the number of ''representative'' tress retained on each side of the stream for every 300 m of linear channel length. Additional retention requirements within the RMZ depend on channel width and the dominant substrate, with wide and large-substrate streams requiring less retention. The size and conifer:deciduous ratio of retained trees depend on the stream type and size (Table 3). In addition to the mandatory and variable retention requirements, operators must retain a percentage of the trees providing shade to the wetted channel. The minimum acceptable canopy closure varies with the elevation of the stream and whether its ''water quality stream temperature classification'' is 16 or 18°C (see Table 3 for examples). If the initial stand has a canopy closure below the minimum value, all trees within the maximum RMZ that provide shade to the stream must be retained. There are no requirements for the size or conifer:deciduous ratio of the retained shade trees, so long as the general and variable retention

Table 3. Stream classification and riparian zone management guidelines for western Washington

Type	Type 1		Type 2		Type 3		Type 4	Type 5
Description	Large, fish use[a] streams classified as ''shorelines of the state''		Substantial fish, wildlife, and human use		Moderate to slight fish, wildlife, or human use		No fish use	No fish use
Channel width (m)	≥23	<23	≥23	<23	≥1.5	<1.5	≥0.6	<0.6
No-harvest zone (m)	none	none	none	none	none	none	none	none
Management zone[b] (m)	7.5–30	7.5–23	7.5–30	7.5–23	7.5–15	7.5	none[c]	none[c]
Harvest restrictions								
Retention[d] / 300 m	25, 50[e]	50, 100[e]	25, 50[e]	50, 100[e]	25, 75[f]	25[g]	none[c]	none[c]
Shade tree retention[h]	A	A	A	A	A	A	none[c]	none[c]

[a]Fish use includes permanent or seasonal use by anadromous salmonids or other game fish. Stream segments are assumed to have significant anadromous or resident game fish use if: the active channel is greater than 0.6 m and the gradient ≤16% *unless* naturally occurring water quality parameters prevent fish use, short (seasonal snow melt) flow regimes prevent fish use, sufficient biogeographic information indicates there is no fish use, or an acceptable survey establishes the absence of fish use.

[b]All Type 1, 2, and 3 waters have a minimum 7.5 m RMZ. The maximum RMZ depends on the width of the channel and the area necessary to meet ''leave tree'' requirements (see harvest restrictions). If retention requirements cannot be met within the maximum RMZ width, the RMZ need not be extended. Permits are required to operate machinery within the maximum RMZ.

[c]Type 4 and 5 streams do not require RMZs but may be protected by ''riparian leave tree areas'' when public water resources are located downstream.

[d]Retention levels are for each side of the stream for every 300 m of channel. Within the RMZ the operator *must* retain an average of five of the largest trees per acre with a ratio of one conifer to one deciduous, two of which must be alive.

[e]The sizes and conifer:deciduous ratio of the leave trees must be representative of the original stand. The low and high values are for streams with boulder / bedrock, or gravel / cobble dominated substrate, respectively.

[f]The leave trees must have a 2:1 conifer:deciduous ratio and be a minimum of 0.3 m DBH or the next largest trees available. The low and high values are as above.

[g]The leave trees must have a 1:1 conifer:deciduous ratio and be a minimum of 0.15 m DBH or the next largest trees available.

[h]Shade trees are those that provide shade to the wetted channel. The presence of a tree's crown in the field of a forest densiometer held at elbow height in the middle of the channel identifies a tree as a shade tree.

A: The level of shade tree retention required for Type 1, 2, and 3 streams depends on the elevation of the stream and whether the stream's ''water quality stream temperature classification'' is 16 or 18°C. Canopy cover requirements decrease with elevation and are higher for 16°C streams. Examples (elevation, 16°C minimum canopy cover, 18°C minimum canopy cover): sea level, 100%, 85%; 150 m, 87%, 68%; 300 m, 73%, 50%; 450 m, 60%, 30%. If more than 25% of the canopy cover is to be removed, a computer model must predict a temperature increase of not more than 2.8°C; the amount of canopy removed must be reduced until this upper limit is predicted. If the stream does not meet minimum shade requirements before harvest all shade trees within the maximum RMZ must be retained. The conifer-deciduous composition of the retained shade trees is not specified and may vary as long as general leave tree retention requirements within the RMZ are met (see above).

requirements have been met in the larger RMZ (Table 3). It is important to note that the shade retention requirement allows the harvest of trees whose shade is redundant. That is, if a large conifer provides shade to channel but is behind a small deciduous tree providing the same shade, the large conifer may be harvested.

The riparian management guidelines established by the state of Washington are unique in two ways. First, the width of the RMZs for like stream types can vary depending on the number of trees present in the initial stand. (Oregon addresses variable stand conditions by adjusting the harvest restrictions within a constant management zone width.) Maximum widths are established to prevent landowners ''from having to go to extreme distances to meet minimum tree counts.'' Second, Washington considers the fluvial geomorphology of the channel when determining retention levels within the RMZ. Channels with larger substrate, which generally have higher gradients and more stable banks, have lower tree retention requirements than channels with smaller substrate. As in other states, if a watershed analysis indicates unique conditions or the presence of species listed as threatened or endangered by state or federal agencies, the RMZ guidelines outlined above need to be appropriately modified.

British Columbia

Riparian zone management guidelines for coastal British Columbia are established by the Forest Practices Code of British Columbia Act and described in the Riparian Management Area Guidebook (Ministry of Forests 1995). In British Columbia streams are divided into six classes. Classes S1–4 have fish use and / or are in a community watershed, and are classified based on average channel width. Classes S5 (channel width >3 m) and S6 (≤3 m) have no fish use and are not in

Table 4. Stream classification and riparian zone management guidelines for western British Columbia

Type	S1[a]	S2	S3	S4	S5	S6
Description	Fish use[b] and / or part of a community watershed				No fish use and not part of a community watershed	
Channel width (m)	>20	>5 ≤ 20	1.5 ≤ 5	<1.5	>3	≤3
No-harvest zone (m)	50	30	20	none	none	none
Management zone[c] (m)	20	20	20	30	30	20
Harvest restrictions[d]	A	A	A	B	C	D

[a]British Columbia also designates a Type ''S1 large rivers'' for which there is no RZ and a 100-m MZ (see below).

[b]Fish use includes any life stage of species of anadromous salmonids, sport fish, fish identified as threatened or endangered, or fish deemed by the Ministry of Environment to be regionally important. Unless found otherwise by an approved fish inventory, streams are considered to have fish use if the channel gradient is less than 20% *and* flow directly into a fish stream, the Pacific Ocean, or a lake known to contain fish. Streams with a gradient over 20% may be classified as S5 or S6 until fish use is established by an approved fish survey.

[c]The riparian management zone (MZ) width is in addition to the width of the no-harvest zone (riparian reserve zone [RZ]), if present. Thus the riparian management area (RMA) for an S1 river is 70 m, and for a S4 stream it is 30 m. All widths are slope distances measured from the edge of the active channel.

[d]British Columbia does not impose categorical harvest restrictions in MZs (equal to the RMA if no RZ is required). Instead, ''best management practices'' are recommended to protect riparian area values (see text and summaries below).

A: *Maximum* recommended overall basal area retention (BAR): 50%. Manage the RMA to reduce risk of windthrow within the RZ: realign RMA boundary to windfirm edges (rock bluffs, nonmerchantable timber, deep soils), ''feather'' edges of RMA, remove ''unsound trees,'' retain windfirm trees (short and thick trees, small-crown trees, trees with good root anchorage). Retain ''wildlife trees'' within the RZ and the MZ: large, dead trees, or trees with known eagle (subfamily *Accipitrinae*), osprey (*Pandion haliaetus*), or great blue heron (*Ardea herodias*) nests should be retained unless deemed to pose high risk to workers. If a tree is deemed high risk and wildlife tree requirements have been met elsewhere, the tree may be harvested, preferably felled at 3 m to create ''stubs.''

B: *Maximum* recommended overall BAR: 25%. Reduce the risk of windthrow and retain wildlife trees (see above). ''Retain all windfirm trees with roots embedded in the bank. . . . Remove dominant conifers and retain 50% of the remaining trees within 10 m of the channel.'' Retain nonmerchantable trees and understory vegetation within 5 m of the channel. Fall and yard away from the channel. Reduce risk of windthrow in the MZ (equal to the RMA in this case). ''In streams dependent on woody debris to maintain channel process, retain all conifer stems <30 cm DBH.''

C: *Maximum* recommended overall BAR: 25%. RMAs of S5 streams are managed to protect downstream values, wildlife habitat, bank stability, and provide shade for temperature limited streams. For valley bottom streams: reduce the risk of windthrow and retain wildlife trees (see above), ''retain 50% of dominant and codominant stems,'' retain nonmerchantable trees and understory vegetation within 10 m of the channel ''to the fullest extent possible,'' and fall and yard away from the channel. For nonvalley bottom streams: reduce the risk of windthrow and retain wildlife trees (see above), retain conifer stems <30 cm and understory vegetation within 5 m of the channel, retain trees leaning over the channel within 10 m of the channel. For streams not dependent on woody debris the best management practices include ''stream clean-out'' to remove debris introduced during logging.

D: *Maximum* recommended overall BAR: 5%. RMAs of S6 streams are managed to maintain bank stability and provide shade for temperature-sensitive streams tributary to S1–S4 streams. Fall and yard away. Retain at least 10 trees <30 cm DBH per 100 m of streambank. Retain nonmerchantable conifer trees and understory vegetation within 5 m of the channel ''to the fullest extent possible.'' Perform ''stream clean-out'' when necessary. Retain wildlife trees within the RMA (see above).

community watersheds (Table 4). Harvest restrictions are imposed within a Riparian Management Area (RMA) which consists of a Management Zone (MZ) where timber harvest is restricted, and, in some cases, a Reserve Zone (RZ) where timber harvest is prohibited.

Class S4, S5, and S6 streams are not protected by a mandatory no-harvest zone (RZ) adjacent to the channel, but do require varying degrees of tree retention within the RMA (Table 4). S4 streams, which are the smallest fish-bearing streams, are protected by a 30-m MZ, the retention of windfirm trees rooted in the bank, and some vegetation within 10 m of the channel. Similarly, S5 and S6 streams are protected by 30-m and 20-m MZs and harvest restrictions within 10 m of the channel, as well as other restrictions (Table 4). Class S1, S2, and S3 streams are protected by 50-m, 30-m, and 20-m RZs, respectively. Each class (S1–3) also has an additional 20-m MZ for total RMAs of 70 m, 50 m, and 40 m, respectively (Table 4). British Columbia does not impose categorical harvest restrictions within MZs, instead recommending ''best management practices'' aimed at reducing wind-throw within the RZ (if present) and retaining wildlife trees within the MZ. The *maximum* recommended basal area retention in the MZs of S1–3 streams is 50% and in the MZs of S4–6 streams 25%, 25%, and 5%, respectively. Additional measures are taken to reduce the chance of wind-throw and retain trees considered valuable to wildlife (Table 4). Timber harvest activities are more generally limited by the presence of sensitive species and the results of mandatory watershed analyses, which aim to identify processes or features limiting ecosystem function and restrict harvest activities accordingly.

The riparian management guidelines of British Co-

Table 5. Comparison of riparian zone management practices for three stream types[a]

Description	5 m bank full width, salmon fish use, low gradient, low elevation	5 m bank full width, above barrier, no fish use, low gradient, low elevation	2 m bank full width, no fish use, aquatic habitat, high gradient, low elevation
No-harvest zone			
California	none	none	none
Oregon	6 m	6 m	none
Washington	none	none	none
British Columbia	20 m	none	none
Management zone (width, stream type)			
California	23 m, Class I, <30%	15 m, Class II, <30%	23 m, Class II, 30–50%
Oregon	21 m, Type F, medium	15 m, Type N, medium	none, Type N, small
Washington	7.5–23 m, Type 2, <23 m	none, Type 4	none, Type 4
British Columbia	20 m, S3	30, S5	20, S6

[a]The streams are assumed to have closed canopies and fully stocked riparian zones at the time of harvest. See Tables 1–4 for restrictions within the management zone for each stream type.

lumbia represent a different approach than that taken by the other governments in the PNW. Most striking is the protection afforded to large and medium-sized fish-bearing streams of coastal British Columbia. British Columbia's no-harvest zones are in many cases wider than other jurisdictions' management zones for similar watercourses (Tables 1–4). In turn, harvest restrictions within the MZs are relatively flexible (Table 4).

Discussion

The state and provincial governments responsible for managing natural resources (on certain lands) in the temperate coniferous forests of the PNW of North America attempt to protect stream and river ecosystems by restricting timber harvest activities within riparian zones. Beyond establishing riparian zone management guidelines and acknowledging the importance of riparian forests in maintaining the integrity of lotic ecosystems, there is little commonality among the four approaches. All the jurisdictions similarly distinguish streams with and without fish use, though ''fishes'' are generally limited to salmonids, those judged to have some value to humans, or to be already threatened or endangered. Streams are separated further based on width (British Columbia and Washington), mean annual flow (Oregon), the slope of adjacent hillsides (California), and fluvial geomorphology (Washington). Where timber harvest is allowed but restricted, the primary ''currency'' that is regulated differs between jurisdictions (canopy cover [CA], basal area [OR, BC], number of trees [WA]), though most governments require additional, specific retention requirements in their riparian management guidelines. Despite these differences (Tables 1–4), it is possible to compare the different riparian management guidelines and consider how likely they are to protect the ecological integrity of the region's lotic ecosystems.

The most obvious difference between the four riparian zone management guidelines is the presence or absence of mandatory no-harvest zones within the larger management zones. Oregon protects all fish-bearing streams and larger fishless streams with a 6-m no-harvest zone. British Columbia protects all but the smallest fish-bearing streams with 20–50-m no-harvest zones. California and Washington do not protect any streams with no-harvest zones. Table 5 illustrates these differences by comparing the riparian zone management practices of the four jurisdictions for three stream types found in the PNW. Considered along with management zone harvest restrictions outlined in Tables 1–4, these comparisons reveal two unsettling facts. First, despite over a century of habitat degradation, and substantial scientific evidence documenting the importance of riparian forests in maintaining the structure and function of lotic ecosystems, many streams in the PNW remain unprotected by riparian no-harvest zones. Second, where management zones are required, harvest restrictions allow, and in some cases even promote, the removal of the largest conifers from riparian forests (Tables 1–4, see below).

What width of no-harvest zone is necessary to maintain at natural levels the full complex of ecological linkages between riparian forests and streams? Different riparian–stream linkages operate at different spatiotemporal scales and in concert determine the dynamic chemical, biological, and physical environment in which salmonids and broader aquatic communities are embedded (Murphy and others 1986, Gregory and others 1987, Thedinga and others 1989, Bilby and Bisson 1992). The most comprehensive management approach would be to determine for individual stream channels which riparian–stream linkage extends furthest from the channel and establish a no-harvest zone of that width. Channel stability is influenced primarily by the root strength of trees bordering the active channel (references in Sedell and others 1993). Insuring natural levels of channel incident LWD (and SWD) requires no-harvest zones of one site potential tree height (SPTH) in width, though the majority of LWD originates from trees within one half this distance (Murphy and Koski 1989, McDade and others 1990, Van Sickle and Gregory 1990). Much less is known about the source distance of litter fall and small organic inputs, but no-harvest zones that to protect LWD and SWD sources will probably do the same for litter inputs (Sedell and others 1993). A no-harvest width of one SPTH is required to maintain natural levels of incident solar radiation, though again the majority (≈80%) of shade is provided by trees within 30 m of the channel (Steinblums and others 1984, Brosofske and others 1997). Chen and others (1995) found decreases in soil moisture and relative humidity up to 100 m from clear-cut edges in old-growth Douglas fir forests. Brosofske and others (1997) studied the influence of riparian buffer width on stream microclimate and found relative humidity levels were maintained at natural levels by buffer widths of approximately 80 m. Based on additional microclimatic gradients, they suggested no-harvest zones of 45 m were required to maintain natural microclimatic patterns near small streams in western Washington. It is important to appreciate that these various physical relationships may not scale directly or even similarly to measurable biological indicators of ecosystem function. Still, when considered along with the height of mature conifers in the temperate forests of the PNW (up to 100 m; Franklin and Dyrness 1988), these physical relationships suggest that maintaining the full complex of natural riparian–stream linkages may require no-harvest zones from 70 to 90 m, depending on site-specific conditions. In its report to the U.S. federal government in 1993, the Aquatic/Watershed Group recognized this ‘‘one tree height’’ approach as that most likely to maintain lotic ecosystem function and ensure the regional distribution (i.e., prevent extinction) of anadromous and nonanadromous salmonids (Sedell and others 1993).

Claiming this ecologically justified level of protection would remove an economically unacceptable amount of land from the harvestable timber base, the states and province have compromised this solution to varying degrees. The no-harvest zones established by Oregon (Table 2) likely maintain (especially for smaller, hillslope-constrained channels) near natural riparian–stream linkages for bank stability, while doing less to maintain linkages associated with temperature, incident solar radiation, microclimate, and SWD and LWD inputs. British Columbia requires 20–50 m no-harvest zones for all fish-bearing streams over 1.5 m wide. These widths protect approximately 50–80% of potential SWD and LWD sources, provide similar percentages of natural shade, but may fail to protect ecological linkages associated with microclimatic gradients. The riparian management guidelines of California and Washington are unlikely to maintain at natural levels any of the functional linkages between riparian and stream ecosystems. Beyond the general management zone restrictions, California requires that only two living conifers over 0.4 m DBH and over 15 m tall be retained within 15 m of fish-bearing streams for every (approximately) 130 m of channel (Table 1). The near channel restrictions in Washington are based on maintaining a variable percentage of canopy closure with no specific requirements for the size or type (conifer or deciduous) of trees retained (Table 3). In both cases the largest, most valuable conifers bordering the channel can be legally harvested, leaving smaller trees to provide bank stability and serve as potential sources of LWD.

Not all LWD affects stream channels the same way. It is large, ‘‘key pieces’’ of LWD that define channel structure by: scouring pools; retaining sediment, organic debris, and smaller LWD; providing cover for juvenile and adult fish; and sorting gravel for spawning (Bisson and others 1987, Bilby and Ward 1989). The wider the stream channel, the larger the LWD required to create and maintain these channel features (Bilby and Ward 1989, 1991), meaning that in many cases trees hundreds of years old must enter the channel to replace LWD displaced during floods or removed from watersheds during present and historic management practices (Murphy and Koski 1989). Many of the other riparian–stream linkages recover from riparian harvest sooner than does channel structure associated with LWD (e.g., incident solar radiation and temperature, energy pathways, bank stability, sediment input), but in closed-canopy forests it is habitat complexity associated with LWD that limits salmonid production (Murphy and others 1986, Bilby and Bisson 1987). Thus, retention of the largest available conifers with the potential to enter channels should be the foundation of any riparian zone management strategy purporting to protect the diversity of ecological processes dependent on natural riparian forests (Bisson and others 1987, Sedell and others 1993).

All four riparian management guidelines reduce the width of and restrictions within the management zones of smaller streams and streams without fish (Tables 1–5). Only Oregon protects fishless streams with mandatory no-harvest zones, and only those designated as medium and large. Riparian zones of fishless streams are generally managed to protect the water quality of fish-bearing streams lower in the watershed by controlling temperature and sediment transport. Harvest restrictions are accordingly aimed at maintaining shade over the channel and preventing hillslope and bank erosion. Though established guidelines will fail to maintain natural solar radiation levels for small streams, the intent is appropriate and recognizes the importance of temperature increases and sediment input / transport at the watershed scale. Present guidelines will also fail to maintain natural levels of LWD in small and / or fishless streams. This is often viewed as an acceptable condition, as there are no fish to utilize what habitat exists and small channels are normally unable to transport key pieces of LWD to larger, fish-bearing streams below (Lienkaemper and Swanson 1987); the wood be ''wasted.'' But LWD in small headwater streams can affect ecological processes throughout the watershed in a number of ways. First, by creating debris jams and dam pools, LWD promotes the retention of organic (SWD, detritus, coarse and fine particulate organic matter, etc.) and inorganic (silt, sand, etc.) sediment (Bilby and Likens 1980, Bilby 1981, Bilby and Ward 1991). Retention of allochthonous carbon and other nutrients in small streams influences macroinvertebrate community composition and sets the template for energy flow throughout the watershed (Vannote and others 1980, Naiman and Sedell 1980, Triska and others 1984). Second, the ability of small channels to transport LWD is not determined by normal or even flood conditions but by rare events, such as landslides, debris torrents, and dam-break floods, which may occur hundreds of years apart (Lienkaemper and Swanson 1987, Reeves and others 1995). The presence or absence of LWD during such events can influence whether the effects on larger streams lower in the watershed are beneficial or detrimental to salmonid habitat (Lamberti and others 1991, Reeves and others 1995). By failing to protect LWD sources for small streams, none of the four riparian management guidelines will maintain natural ecological processes associated with the input and transport of LWD at the stream reach or watershed scale. Requiring no-harvest zones and retaining even some of the largest conifers near small, steep, and fishless streams would also maintain the broader suite of riparian–stream linkages operating at the stream to watershed scale.

The governments of the PNW restrict timber harvest differently within riparian management zones (Tables 1–4). California manages percent canopy cover; Oregon and British Columbia manage basal area; Washington manages the number of trees. In addition to the harvest restrictions on their chosen currency, all four jurisdictions have retention requirements aimed at maintaining stand structure and wildlife habitat. None of the governments explicitly manage the species and age–class distributions necessary to maintain natural conditions in riparian forests. For example, California requires that retained trees represent the ''diversity of species similar to that found before the start of operations,'' but allows 75% of conifers to be harvested. For larger fish-bearing streams, Washington requires that retained trees in the management zone be ''representative'' of the original stand, but provides no such restriction on shade trees retained near the active channel. Explicit retention requirements in all three jurisdictions of the United States have minimum DBHs of 0.15 to 0.4 m (Tables 1–3), which represent relatively small trees. For streams not protected by no-harvest zones, British Columbia recommends a *maximum* DBH for retained trees of 0.3 m, and a *maximum* basal area retention of 5–25% (Table 4).

The difficulty in preserving forest structure in general, and larger conifers in particular, in management zones is that many riparian forests have been previously clear-cut and are presently single age stands less than 100 years old (particularly in the United States). Recognizing this dilemma, Oregon's basal area retention strategy aims to ''retain vegetation so that, over time, average conditions across the landscape become similar to those of mature streamside stands,'' which the state defines as occurring at approximately 120 years, an age discordant with the life span of Northwest conifers (500–1000 years) and the frequency of stand-setting fires in coastal forests (approximately 300 years) (Benda 1994 as referenced in Reeves and others 1995). If present management zone guidelines were applied over a series of harvest rotations (60–80 years), streams (and thus entire watersheds and basins) not protected by no-harvest zones will be depleted of the larger pieces of LWD that critically affect channel structure and function (Ralph and others 1994). The scenario is worse yet considering the legacy of LWD removal from the channels and hillslopes of most nonfederal watersheds in the United States (Bisson and others 1987).

I have focussed on the riparian–stream linkages associated with the physical role of LWD in defining the structure and function of stream channels for two reasons. First, the riparian–stream linkages associated with LWD generally operate over the longest time scale (Gregory and others 1987, Murphy and Koski 1989). Second, and of more practical relevance, it is LWD in the form of harvested conifers—not sediment, water temperature, macroinvertebrate communities, energy pathways, or litter fall—that is harvested from PNW forests. Nevertheless, it is important to appreciate how different riparian–stream linkages interact to affect resident and anadromous salmonid populations. The removal of riparian vegetation often results in a short-term increase in the density or growth of salmonids, due to an increase in autochthonous energy production (Murphy and Hall 1981, Bilby and Bisson 1987, 1991) and/or improved feeding efficiencies of juvenile fish in less shaded environments (Wilzbach and others 1986). Alternatively, canopy removal may result in fish mortality or emigration if temperatures exceed thermal tolerances (Hall and others 1987, Beschta and others 1987) or alter the timing of critical life history events, such as fry emergence or smolt migration, if the temperature perturbation is less severe (Heming 1982, Beschta and others 1987, Holtby 1988, Murray and others 1990). These types of disturbances, ''good'' or ''bad,'' are generally short-lived because temperature and solar energy levels return to preharvest levels as the canopy begins to close and provide shade to the channel (Gregory and others 1987). Bank erosion can increase the amount of sediment entering channels, the effect on salmonids depending on the type introduced and the ability of the channel to sort and transport fines and bedload (processes affected by LWD). More lasting effects of bank instability include loss of cover provided by undercut banks and rootwads, increasing channel width, and decreased water depth (Hicks and others 1991). These and other riparian–stream linkages may operate at decadal to centurial time scales, while processes governing the production, input, and movement of LWD through channels and watersheds operate at centurial time scales and will require similar times to recover from disturbance. Managing riparian forests to provide near-natural inputs of LWD at the stream, watershed, and basin scale should protect de facto other riparian–stream linkages operating at lesser spatiotemporal scales.

Conclusion

How then to manage riparian forests in the PNW? First, there is an important distinction between the private and state timberlands of the three U.S. states and the forests managed under British Columbia's riparian management zone guidelines. Many of the nonfederal watersheds in the United States have been previously clear-cut two and even three times in the last 150 years, often without any riparian zone protection. In many parts of British Columbia timber harvest occurs in areas previously unharvested (old-growth) or harvested only once. Thus, British Columbia's challenge is often to protect existing riparian-stream linkages, while in the United States the goal of riparian zone management should be to protect, restore, *and* compensate for previous degradation. The only ecologically and scientifically justified action would be to establish mandatory no-harvest zones for all channels capable of transporting organic or inorganic material, the width of which can vary with channel size, hillslope, and natural vegetation. This approach is especially appropriate in the United States, where its likely efficacy has been recognized in federally sponsored studies (e.g., Sedell and others 1993, Sierra Nevada Ecosystem Project 1996), yet has gone unheeded by the region's governments. This approach would simplify management zone restrictions and has been implemented to different degrees in Oregon and British Columbia (Tables 2 and 4). Short of establishing no-harvest zones for all streams, management zone guidelines should require the retention of all or most of the largest conifers with the potential to affect channel structure and function at the reach, watershed, and basin scale. Again, this is especially true in the United States, where entire basins have LWD loads far below natural levels and potential inputs from lotic and terrestrial sources are already depleted (Bisson and others 1987).

Management zone guidelines based on currencies other than forest structure will continue to allow the largest conifers to be removed from riparian zones and represent a modified continuation of historical management practices, which have failed to protect riparian–stream linkages and associated ecosystem functions. Credit systems like that established in Oregon for habitat enhancement promote the removal of large conifers from riparian zones, sacrifice natural watershed processes under the guise of in-stream restoration, and represent small-scale, short-term solutions to large-scale, long-term problems (Frissell and Nawa 1992, Frissell and others 1993). A more enlightened and effective approach would be to promote the retention of the largest conifers by providing tax credits (via a similar formula) for large conifers *not* harvested from riparian management zones. The principal goal of riparian zone management (and forest and ecosystem management in general) should be to maintain and promote the establishment of conditions representative of natural disturbance regimes and ecological processes over all relevant spatial and temporal scales (Sedell and others 1990, Gregory and others 1991, Swanson and Franklin 1992, Doppelt and others 1993, Frissell and others 1993, Reeves and others 1995, Chapin and others 1996). The present practice in all four jurisdictions of providing enhanced protection in cases where a watershed is deemed ''sensitive,'' ''water quality limited,'' or contains already threatened or endangered species or Evolutionarily Significant Units represents a ''manage until degraded, then protect'' approach that is unlikely to maintain or restore functional riparian–stream linkages at the stream, watershed, basin, or regional scale.

The streams and rivers of the PNW provide habitat for over half a dozen species of salmon and trout and are in a state of ecological impairment. Beyond their inherent value to biodiversity and broader ecosystem functions (Willson and Halupka 1995), resident and anadromous salmonids provide economic value and cultural identity to the region. Forest managers presently face the challenge of maximizing profits from timber harvest while protecting already degraded stream and river ecosystems. Riparian management guidelines that attempt to protect lotic ecosystems have and will continue to reduce timber harvest rates and associated profits, a fact that fuels economic arguments against ecologically responsible riparian zone management. The sophistic and divisive call of ''jobs versus the environment'' is sounded here as loud as anywhere, underscoring the fact that riparian zone management is as much a political and economic as ecological issue. Often lost in the economic equation is the value of salmon, whose persistence depends at once on the ecological integrity of both aquatic and terrestrial ecosystems. What would be the effect on the economy, culture, and communities of the PNW if the region's forest and lotic ecosystems produced naturally only *half* the number of salmon as 100 years ago? Answering this question will require the governments of the PNW to confront one of far broader ecological, economic, and cultural importance, one that, withstanding the present discussion, transcends the conventional fish/forestry approach to riparian zone management. How naturally will the linkages between forest and lotic ecosystems operate 100 years hence? Considering present management guidelines in the context of available scientific information, their collective answer appears to be a qualified though unequivocal ''not very.''

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