BUFFER STRIP FUNCTION AND DESIGN

An Annotated Bibliography

Compiled for the
Region III Forest Practices Riparian Management Committee
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SUMMARY

Natural forests adjacent to water bodies can contribute all of the ten habitat components listed in the FRPA, AS 41.17.115, which were discussed in the Introduction. The relative importance of each component to maintaining fish habitat and water quality varies with differences in the physical and other characteristics of the water body, such as stream width (or lake size), gradient, incision depth, bank characteristics, and average, seasonal, and peak flow.

Research has demonstrated the importance of maintaining forested conditions along water bodies that are naturally forested. In the 1990s, this research began to be incorporated into forest practices-related laws and regulations. In Alaska, the FRPA, Tongass Timber Reform Act, and Tongass Land Management Plan (TLMP) revision each prescribe mandatory buffers for certain types of fish-bearing (and, in the case of TLMP, some non-fish-bearing) water bodies. Buffer widths vary, based on different water body classifications, which are in turn based on different physical stream characteristics, and the presence of anadromous fish. The TLMP standards use the classification of Paustian (1992). These buffers were designed for the relatively small stream systems found in Southeast Alaska. Murphy (1995) provides a good summary of buffer-related research conducted in Alaska, and riparian management recommendations that have been applied in Southeast Alaska. The Tongass Land Management Plan (1997) and the FRPA revisions of 1999 update Murphy's summary of existing buffer standards. Some of the Southeast Alaska (and Pacific Northwest) research is applicable to streams and lakes in Interior Alaska that share similar physical characteristics.

There are five primary fish habitat-related functions of riparian forests. First, trees entering the stream through natural mortality due to senescence, wind throw, or bank erosion provide large woody debris (LWD) to the water body. LWD forms stream and fish habitat features, controls the movement of gravel and sediment, contributes energy to streams, and provides a substrate for the growth of organisms. Second, energy input to the stream is derived from leaf litter, macro-invertebrates, and other energy sources that fall from trees into the water body. Third, the forest acts to control water temperature, by shading in warm conditions, and by heat retention and wind reduction in cold conditions. Fourth, for streams and other water bodies having banks held in place by vegetation, trees provide stability to stream banks and floodplains. Fifth, riparian vegetation has been shown to function as a filter for sediment and pollutants from adjacent sites.

Buffers are, by definition, natural vegetation left along the banks of a water body in the course of conducting a land-disturbing activity. This definition implies that the buffer has a finite width, starting at the water body, and ending at some point where the activity occurs. The alteration of the vegetation beyond the edge of the buffer means that the buffer boundary is exposed to conditions different from those in the natural forest. The edge of the buffer receives more sunlight, and is exposed to prevailing winds. From a design standpoint, then, in addition to the buffer width that is appropriate for the site conditions, buffer stability is an issue. If the objective of leaving a buffer is to maintain a rate of LWD input plus bank or flood plain stability not significantly different from the natural rate or conditions, then any factors that lead to premature loss of the buffer are undesirable. Buffer blowdown (or windthrow), tree mortality from engraver beetles (*Ips* spp.) around harvest units, and rapid bank erosion along dynamic stream reaches can reduce the number of trees in a buffer, and decrease the recruitment pool for LWD. Reid and Hilton (1998), Steinblums, et al (1984) and others discuss this aspect of buffer design. The Tongass National Forest Land Management Plan (U.S. Forest Service, 1997) requires both a no-cut buffer and an additional area to be managed "to provide for a reasonable assurance of windfirmness."

The utility of buffers for protecting fisheries habitat on reaches of larger river systems where banks are not held in place by vegetation, such as reaches of the Tanana, Kuskokwim, Yukon, and Porcupine Rivers in northern Alaska has not been studied as thoroughly as have smaller systems, where banks are either held in place by vegetation or controlled by bedrock. Two reasons for this lack of knowledge are that: 1) the role of LWD in larger rivers is not as well understood, and 2) LWD recruitment processes in these river systems are different from and more variable in both space and time than those in smaller, more stable streams.

To date, literature found by the Stream Classification Committee (SCC) suggests that LWD concentrations, such as jams, in large rivers may play an important role in stream morphology. This role contrasts with smaller, less dynamic streams, where wood often plays an important role in the area of the stream immediately adjacent to the point of input. For example, island, bar, and slough formation, and bank protection in larger rivers can all be initiated or maintained by concentrations of LWD. Therefore, the primary reason for leaving a buffer on such a system or reach may primarily be to provide wood to the stream system in general, rather than for the site where the tree enters the stream. For more information on the role of buffers in providing LWD to large rivers, see the SCC Large Woody Debris literature review, including the article by Abbe and Montgomery (1996), and Bryant and Sedell (1995).

The role of riparian forests (and buffers) and LWD in providing nutrients and other fish habitat-forming functions in large, dynamic river systems is also not well known. The articles by France et al. (1996), Wipfli (1997) and Piccolo and Wipfli (in press) discuss allochthonous input of nutrients such as leaf litter, macroinvertebrates, and wood from forest stands adjacent to streams.

The role of buffers in regulating stream temperature is well documented. Buffers for this purpose are routinely left in the Pacific Northwest and other areas of the continental U.S. Several references discuss this aspect of buffer function, including O'Laughlin and Belt (1995) and Johnson and Ryba (1992). Stream temperature regulation has been identified as an issue in the Interior with regard to low-gradient, slow flowing water bodies, such as backwater sloughs. Buffer width for temperature regulation is primarily a function of tree height, sun angle, and stream width.

Finally, the LWD recruitment processes along large rivers vary both spatially and temporally. Factors such as bank height, tree size, permafrost, channel complexity, seasonal flows, and natural rates of bank erosion make these processes both complex and dynamic. These factors make the proper prescription of buffers on larger, more dynamic stream systems more difficult, compared to smaller stream systems. The appropriate buffer prescription may vary over different reaches of a river, even though factors typically used for stream classification, such as width, depth, gradient, etc. may not change. Further, a prescription made at one point in time may only be appropriate for a limited period of time, as the stream or river characteristics often change.

In summary, while a "one size fits all" approach to buffers may work in many cases for smaller and more stable stream channel types, it is not likely that one riparian area management recommendation will be appropriate to all reaches of a larger, dynamic river system. Further, while there are some similarities, the reasons why buffers are appropriate on large river systems differ from those for smaller streams. In the short term, due to the lack of hard data on large rivers, these differences in buffer prescriptions will, to some extent, have to be inferred or deduced, based on what is known about natural processes on large, dynamic systems. The SCC has concluded that the most appropriate distinction to make in classifying stream systems for the purposes of applying buffers is whether the banks of the reach in question are held in place by vegetation and/or bedrock, or whether bank erosion by the stream is the dominant process. See the SCC Bank Stability literature review for more discussion of this point.

The following literature review includes references on the role and design of buffers on glacial and non-glacial, and large and small streams. However, most work that has been done on riverine systems has been on smaller non-glacial river systems, as the citations show. Bryant and Sedell (1995) provide additional references for work done on larger river systems.

The literature search used the following internet-based databases that are provided at no cost: Water Resources Abstracts, Fish & Fisheries Worldwide, and Arctic & Antarctic Regions. A few articles came from the ADF&G files in Juneau.

REFERENCES

Bren, L. J. 1993. Riparian zone, stream, and floodplain issues: a review. Journal of Hydrology 150:277-299.

In the last two decades, the effects of forest management on streams, riparian zones, and floodplains have become of much interest. In general, there is agreement that such areas should maintained in a state approximating naturalness, although it is recognised that definition of this state is usually difficult or impossible. A diversity of management effects has been recognised and , in some cases quantified. For upland catchments, issues particularly relate to direct disturbance of the zone, changes in the flow of woody debris into the stream, or disturbance to the environment by effects generated upstream or downstream. For many areas, a particularly important commercial aspect is the definition of a 'stream', as this can impose many expensive and severe restrictions on management of the land. For large rivers, a common issue is the effect of river management on flooding forests. In each case, the issues are complex, information is difficult to collect, and there are fundamental difficulties in going from anecdotal observation to data. Currently, most information appears to be at a relatively local level, and there is a very inadequate knowledge base to five a more holistic overview, although the concept of 'cumulative effects', with the effects accumulated over both space and time, has much potential value. There are many opportunities for work in this field.

Bren, L. J. 1998. The geometry of a constant buffer-loading design method for humid watersheds. Forest Ecology and Management 110:113-125.

Riparian buffer strips are used in forestry to protect streams from possible adverse effects of forest harvesting or other land uses. For any given stream reach, a buffer loading can be defined as the contributing watershed area per unit area of buffer. The study used a large (66 km^2) mountain watershed as a prototype. To allow accurate computation this was divided into facets by forming a flow net to the maximum accuracy of the 1:25,000 contour coverage. With fixed width buffers, the buffer loading was both highly variable and also independent of the Strahler order of the stream. Thus, the rationale of having larger buffers on larger streams does not seem justified. The study considered a buffer-strip design in which each element of stream buffer had exactly the same ration of upslope-to-buffer area, giving a constant buffer loading. Computation of the buffer for each facet used an iterative procedure to achieve a satisfactory shape and position of the buffer boundary within each facet. The method gave a much more substantial protection to (convergent) channel sources and less protection to divergent areas than a fixed-width buffer design. The buffers defined also were highly asymmetric and discontinuous. The buffers defined reflected the topography, and were strongly influenced by small facets close to the stream. In cases where flow lines run close to and approximately parallel to the streams, the buffers defined were also non-intuitive. The method is predicated on the subsurface hydrology flow paths being close to those given by surface flow lines and this is not always true. Of importance is the finding that, relative to the mean protection offered, fixed-width buffers tend to underprotect slope convergences at the heads of streams and overprotect divergent areas found along streams of increasing order.

Burckhardt, J. C., and B. L. Todd. 1998. Riparian forest effect on lateral stream channel migration in the glacial till plains. Journal of the American Water Resources Association 34:179-184.

Dendrochronology analyses of point bar complexes were used to quantify the effects of riparian forests on local lateral migration of bends in seven streams in the glacial till plains of north central Missouri. Stream bends were paired with similar bank height, midchannel radius of curvature, soil composition, and watershed size. In each pair, one concave bank was forested and one was unforested. Stream bends with unforested concave banks had an average local migration rate three times greater tan stream bends that had forested concave banks.

Davies, P. E., and M. Nelson. 1994. Relationships between riparian buffer widths and the effects of logging on stream habitat, invertebrate community composition and fish abundance. Australian Journal of Marine and Freshwater Research 45:1289-1305.

Impacts from the logging of Eucalyptus forest on stream habitat, macroinvertebrate abundance and diversity, and fish abundance were surveyed in Tasmania, Australia. Forty-five pairs of sites from 34 streams of greater than or equal to 2.5 km super (2) catchment area were each sampled once during summer in the period 1990-92. Each site pair consisted of an 'impacted' site downstream of a logging treatment and an upstream or closely matched 'paired control' site. Site pair treatments encompassed two logging methods (cable and conventional) with a range of riparian buffer strip widths (0-50 m) and included unlogged controls. Differences between site pair variables were used as test statistics for the detection of logging impacts. Logging significantly increased riffle sediment, length of open stream, periphytic algal cover, water temperature and snag volume. Logging also significantly decreased riffle macroinvertebrate abundance, particularly of stoneflies and leptophlebiid mayflies, and brown trout abundance. All effects of logging were dependent on buffer strip width and were not significantly affected by coupe slope, soil erodibility or time (over one to five years) since logging. All impacts of logging were significant only at buffer widths of <30 m. Minimum buffer widths for eliminating logging impacts on stream habitats and biota are discussed.

Dwyer, J. P., D. Wallace, and D. R. Larsen. 1997. Value of woody river corridors in levee protection along the Missouri River in 1993. Journal of the American Water Resources Association 33:481-489.

Following the Midwest flood of 1993, a study was initiated along a 39-mile segment of the Missouri River to determine if there was an association between woody corridors and levee stability. A systematic sample of levee failures revealed that primary levees which did not fail had a significantly wider woody corridor than failed levees. Analysis of the total inventory of failed levees revealed that as the width of the woody corridor decreased, the length of the levee failure increased. Number of levee failures and their severity of damage could be reduced if woody corridors were at least 300 feet wide.

Fennessy, M. S., and J. K. Cronk. 1997. The effectiveness and restoration potential of riparian ecotones for the management of nonpoint source pollution, particularly nitrate. Critical Reviews in Environmental Science and Technology 27:285-317.

The interface found where rivers meet terrestrial systems is an ecotone that has a profound influence on the movement of water and waterborne contaminants. Maintaining or restoring ecotone functions and characteristics such as natural near stream vegetation and channel morphology are important means to safeguard water quality in agricultural landscapes. A riparian buffer zone of 20 to 30 m width can remove up to 100% of incoming nitrate. Denitrification is the major pathway of removal and rates depend on nitrate loadings, carbon availability, and hydrology. Denitrification occurs throughout the year as long as subsurface hydrology is intact, whereas plant uptake of nitrogen is limited to seasonal removal. Nitrate removal is favored in forested areas with subsurface flow and is less in grassed areas with surface flow. The balance between surface and subsurface flows and the redox conditions that result are critical to nitrate removal in riparian ecotones. Surface retention of nutrients and sediment is a function of slope length and gradient, vegetation density, and flow rates. Plant communities play a major role in nitrogen cycling by acting as a source of carbon for denitrifying bacteria, direct uptake of nutrients, and creating oxidized rhizospheres where nitrification can occur. Restoration of riparian zones requires knowledge of the area's hydrology and ecology, as well as clear goals for the project. Restoration of riparian zones for water quality improvement may provide higher economic benefits than allocating the same land to crops. While it is possible to restore the functions of natural floodplain systems, existing restoration techniques are in their infancy and success cannot be guaranteed, especially given the extent of hydrological modification that has occurred in most developed countries.

France, R. L. 1997. Potential for soil erosion from decreased litterfall due to riparian clearcutting: Implications for boreal forestry and warm- and cool-water fisheries. Journal of Soil and Water Conservation 52:452-455.

One of the most overt consequences of catchment clearcutting is increased soil erosion, which can seriously affect fish stocks. Riparian stands around 10 northwestern Ontario lakes, clearcut 4 to 10 years previously, were found to produce only 60% of the litterfall of nearby uncut riparian forests. As a result of this decrease in protective ground surface cover, the retention of organic duff within deployed mesh-bags, was significantly reduced in clearcut riparian zones. A rainfall simulation experiment further suggested that the erosion of sandy loam can be twice as great under litterfall conditions representative of clearcut, compared to forested shorelines. Due to the potential for increased soil erosion from clearcutting, Ontario should consider a return to its pre-1985 policy of preventing timber harvesting around "warm-" and "cool-water" lakes that contain percid and esocid sportfish and often support a lucrative commercial cyprinid baitfishery.

France, R., H. Culbert, and R. Peters. 1996. Decreased carbon and nutrient input to boreal lakes from particulate organic matter following riparian clear-cutting. Environmental Management 20:579-583.

The plankton communities of oligotrophic Canadian Shield lakes are strongly regulated by the allochthonous supply of total phosphorus (TP) and dissolved organic carbon (DOC), a proportion of both of which originate from particulate organic matter. Although decreased inputs of allochthonous leaf litter have been documented for small streams whose riparian forests have been removed, no such data exist for boreal lakes. Through estimates of airborne litter input from forested and clear-cut shorelines and laboratory measurements of concentrations released from leaf leachate, we determined that riparian deforestation resulted in reductions of DOC from 17.8 to 0.4 g/m shoreline/yr and of TP from 2.9 to 0.3g/m shoreline/yr. Previous predictive models indicate that such reductions may be substantial enough to decrease basic metabolic processes of lake plankton communities by as much as 9% in primary production and 17% in respiration.

France, R., R. Peters, and L. McCabe. 1998. Spatial relationships among boreal riparian trees, litterfall and soil erosion potential with reference to buffer strip management and coldwater fisheries. Annales Botanici Fennici 35:1-9.

Litter cover is known to protect ground surfaces from raindrop impact and therefore reduces soil erosion. Significant differences were found to exist in the abundance, composition and size of trees, in their litter production rates, and in the resulting potential for soil erosion of the foreshore (0-20 m from shorelines) compared with the backshore (20-50 m upslope) regions of riparian zones around four boreal lakes located in northwestern Ontario, Canada. These findings support a global pattern wherein litter production adjacent to waterbodies is often considerably reduced compared with that characteristic of upland forests. This study therefore raises questions of the presumed effectiveness of existing forestry guidelines concerning widths of protective buffer strips around boreal, coldwater lakes in Ontario, which are presently based on an erroneous assumption of uniform tree cover and litterfall throughout riparian zones.

Frissell C. A., W. J. Liss, C. E. Warren, and M. D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10:199-214.

Classification of streams and stream habitats is useful for research involving establishment of monitoring stations, determination of local impacts of land-use practices, generalization from site-specific data, and assessment of basin-wide, cumulative impacts of human activities on streams and their biota. This article presents a framework for a hierarchical classification system, entailing an organized view of spatial and temporal variation among and within stream systems. Stream habitat systems, defined and classified on several spatiotemporal scales, are associated with watershed geomorphic features and events. Variables selected for classification define relative long-term capacities of systems, not simply short-term states. Streams and their watershed environments are classified within the context of a regional biogeoclimatic landscape classification. The framework is a perspective that should allow more systematic interpretation and description of watershed-stream relationships.

Gilliam, J. W. 1994. Riparian wetlands and water quality. Journal of Environmental Quality 23:896-900.

Because of wet soils adjacent to the streams, riparian buffers are frequently present between farming and urban activities on the uplands and small streams. These riparian areas have been shown to be very valuable for the removal of nonpoint-source pollution from drainage water. Several researchers have measured > 90% reductions in sediment and nitrate concentrations in water flowing through the riparian areas. The riparian buffers are less effective for P removal but may retain 50% of the surface-water P entering them. I consider riparian buffers to be the most important factor influencing nonpoint-source pollutants entering surface water in many areas of the USA and the most important wetlands for surface water quality protection.

Johnson, A.W. and D. M. Ryba. 1992. A literature review of recommended buffer widths to maintain various functions of stream riparian areas. Prepared for King County Surface Water Management Division. Aquatic Resource Consultants, Renton, WA. 29pp.

This paper examines available scientific literature on the function of riparian areas along streams. Specifically, we reviewed literature containing recommendations for buffer widths to maintain those functions, and various methodologies for setting buffer widths.

Some commonly recognized functions of stream riparian zones include:

1. stabilizing streambanks and preventing erosion;
2. filtering suspended solids, nutrients, and harmful or toxic substances;
3. moderating the microclimate of a riparian system; and
4. supporting and protecting fish and wildlife species and providing migration corridors.

In small and intermediate-sized streams in then Pacific Northwest, riparian vegetation directly influences the physical conditions of the stream environment. The roots of riparian vegetation stabilize streambanks, retard erosion, and create overhanging cover for fish. The above-ground portions of plants dissipate the energy of storm flows, obstruct the movement of sediment and detritus, and provide large organic debris to streams.

The effects of land uses on riparian areas can be multiple and varied. The effect depends on the type of land use, degree of disturbance to streamside vegetation, size of stream, physical setting, and succession after disturbance. While land use may vary, the resulting environmental alterations generally affect riparian systems in similar ways.

Buffer widths for stream and wetland habitats may be established using two general methods. These are fixed width to protect specific functions, or a variable width that considers specific site conditions. Fixed- or variable-width buffers each have advantages and drawbacks. An agency's available resources and constraints will figure strongly in the final choice of how buffers will be set.

Widths for vegetated buffers recommended by various investigators vary widely depending on the specific resource or function to be maintained. Buffer widths recommended by 38 separate investigators to maintain seven major riparian functions ranged from 3 to 200 meters (m). From our review, it appears buffers less than 10 m provide little if any maintenance of various riparian functions. Buffers of 15 to 30 m provide minimal maintenance for most functions; buffers greater than 30 m appear adequate for most functions. Despite whether a fixed or variable width buffer is to be established, we recommend a *minimum* buffer distance of 15 to 30 m. This distance will vary depending on the riparian function to be maintained.

Lisle, T. E., and M. B. Napolitano. 1998. Effects of recent logging on the main channel of North Fork Caspar Creek. Pages 81-86 *in* Ziemer, R.R., editor. Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story. USDA Forest Service, Pacific Southwest Research Station, PSW-GTR-168.

The response of the mainstem channel of North Fork Caspar Creek to recent logging is examined by time trends in bed load yield, scour and fill at resurveyed cross sections, and the volume and fine-sediment content of pools. Companion papers report that recent logging has increased streamflow during the summer and moderate winter rainfall events, and blowdowns from buffer strips have contributed more large woody debris. Changes in bed load yield were not detected despite a strong correlation between total scour and fill and annual effective discharge, perhaps because changes in stormflows were modest. The strongest responses are an increase in sediment storage and pool volume, particularly in the downstream portion of the channel along a buffer zone, where large woody debris (LWD) inputs are high. The association of high sediment storage and pool volume with large inputs of LWD is consistent with previous experiments in other watersheds. This suggests that improved habitat conditions after recent blowdowns will be followed in future decades by less favorable conditions as present LWD decays and input rates from depleted riparian sources in adjacent clearcuts and buffer zones decline.

Lowrance, R., L. S. Altier, J. D, Newbold, R. R. Schnabel, P. M. Groffman, J. M. Denver, D. L. Correll, J. W. Gilliam, J. L. Robinson, R. B. Brinsfield, K. W. Staver, W. Lucas, and A. H. Todd. 1997. Water quality functions of riparian forest buffers in Chesapeake Bay watersheds. Environmental Management 21:687-712.

Maryland, Virginia, and Pennsylvania, USA, have agreed to reduce nutrient loadings to Chesapeake Bay by 40% by the year 2000. This requires control of nonpoint sources of nutrients, much of which comes from agriculture. Riparian forest buffer systems (RFBS) provide effective control of nonpoint source (NPS) pollution in some types of agricultural watersheds. Control of NPS pollution is dependent on the type of pollutant and the hydrologic connection between pollution sources, the RFBS, and the stream. Water quality improvements are most likely in areas of where most of the excess precipitation moves across, in, or near the root zone of the RFBS. In areas such as the Inner Coastal Plain and Piedmont watersheds with thin soils, RFBS should retain 50%-90% of the total loading of nitrate in shallow groundwater, sediment in surface runoff, and total N in both surface runoff and groundwater. Retention of phosphorus is generally much less. In regions with deeper soils and /or greater regional groundwater recharge (such as parts of the Piedmont and the Valley and Ridge), RFBS water quality improvements are probably much less. The expected levels of pollutant control by RFBS are identified for each of nine physiographic provinces of the Chesapeake Bay Watershed. Issues related to establishment, sustainability, and management are also discussed.

Mann, D. H., C. L. Fastie, E. L. Rowland, and N. H. Bigelow. 1995. Spruce succession, disturbance, and geomorphology on the Tanana River floodplain, Alaska. Ecoscience 2:184-199.

A long-standing paradigm in the ecology of the Alaskan taiga states that black spruce (*Picea mariana* [Mill.] BSP) replaces white spruce (*Picea glauca* [Moench] Voss) after several centuries of primary succession on flooodplains. According to this Drury Hypothesis, autogenic thickening of organic horizons and shrinking of the active layer interact with the species' different physiological tolerances to cause black spruce dominance. We test the Drury Hypothesis on >200-year-old portions of the Tanana River floodplain near Fairbanks, Alaska, and reject it. In the meander belt portion of the study area, white spruce mixed with black spruce persists on geomorphic surfaces approximately 3,000 years old. Predictions of the Drury Hypothesis regarding active-layer and organize-horizon thicknesses are not substantiated. Neither of these variables correlates with the abundances of the different spruce species. Forest communities in the study area are distributed along geologically based environmental gradients and are shaped by secondary succession following fires and probably floods. Black spruce dominates in the poorly drained, permafrost-rich, and fire-prone backswamp and white spruce in the oppositely characterized meander belt. Although geological chrono sequences can be identified along avulsion-prone rivers like the study reach of the Tanana River, superposition of a meander belt-backswamp plan and frequent fire and flood disturbances may negate any vegetation chronosequences older than several centuries.

Martin, D. J., M. E. Robinson, and R. A. Grotefendt. 1998. The effectiveness of riparian buffer zones for protection of salmonid habitat in Alaska Coastal Stream. Prepared for Sealaska Corporation, Juneau AK, and Alaska Forest Association, Ketchikan AK.

For this study, low-elevation aerial photographs were used to delineate potential LWD sources and these date were used to determine the effects of buffer zones on the short- and long-term supply of LWD. We used annual channel survey data from a four-year period (1994-197) to monitor changes in LWD recruitment and to examine the interaction between LWD, channel morphology, and fish habitat. The findings of this study concur with previous research and add new knowledge concerning the relative sensitivity of fish habitat to changes in LWD in different geomorphic channel types. The results show that LWD is most important for the formation of pools and contributes to the retention of gravel that forms spawning habitat. Increases in LWD loading can increase the frequency of small to medium pools, which improves the quantity and quality of salmonid rearing habitat. The relative effectiveness of LWD to form habitat is a function of channel type and the amount of LWD in the stream.

The analysis of 38 riparian zones and more than 11,000 trees indicates that nearly all (mean 94%) of the recruitable size trees in the riparian zone (i.e., tall enough to become LWS) occur within 20 m of the stream. Selective timber harvest in the standard buffer zones removed from 1% to 12% of the original stand. This harvest, in addition to windthrow following logging, did not significantly diminish the potential supply of LWD from the 0-10 m zone. The study shows that a 20-m buffer zone is more effective for providing LWD than a wide buffer (>20 m) or an unlogged area. Examination of tree densities at 15 standard 20-m buffer zones four to six years after logging indicated that the capacity of these buffers to maintain a future supply of LWD was directly related to the pre-harvest recruitable tree density.

The results of this study indicate that implementation of the current buffer regulation should include evaluation of stand composition for buffer zones adjacent to alluvial channels (Type A waters). The results also show that windthrow may reduce the potential long-term supply of LWD in a small percentage of the buffer zones. Planning buffer zones to increase the probability of LWD recruitment could improve the quantity and quality of fish habitat in streams that have a naturally low supply of LWD (e.g., channels formed in a mixture of alluvial and cobble/boulder bed materials, Type A and some Type B waters). In these channels LWD recruitment rates are minimized by the low frequency of bank erosion, landslides, and windthrow. Therefore, formation of fish habitat is limited by the ED recruitment rate, which will not improve without some type of buffer disturbance. Buffers wider than 20 m will maintain the natural recruitment rate, but a narrower buffer (e.g., 20-m wide) could increase the probability of LWD recruitment. In this case, designating buffers to take advantage of natural disturbances may provide more long-term benefits to fish habitat than might otherwise occur under natural conditions.

Mason, O. K., and J. E. Begét. 1991. Late Holocene flood history of the Tanana River, Alaska, U.S.A. Arctic and Alpine Research 23:392-403.

The Tanana River basin in central Alaska drains both the north slope of the Alaska Range and the south slope of the Yukon-Tanana upland. A sequence of historic and prehistoric flood deposits of the Tanana River is preserved in a small bedrock-sheltered slough near Fairbanks. Examination of these deposits using a suite of radiometric dates, microstratigraphic observation, and granulometric statistics suggests that large changes in flood frequency occurred during the late Holocene. Three major lithostratigraphic units are observed: (1) thick cross-bedded, pedogenically unaltered alluvial silty sands which were deposited between 3000 and 2000 yr BP, recording an interval of large floods; (2) a series of this silty beds and paleosols forms after 23000 yr BP during an interval when large floods were uncommon; and (3) a sequence of sand units recording large floods during the last several hundred years. Flood frequencies appear to have changed in response to regional climatic changes, with more frequent flooding occurring during times of widespread alpine glaciation and increase storminess.

Murphy, M. L. 1995. Forestry impacts on freshwater habitat of anadromous salmonids in the Pacific Northwest and Alaska--requirements for protection and restoration. NOAA Coastal Ocean Program Decision Analysis Series No. 7. NOAA Coastal Ocean Office, Silver Springs, MD.

This synthesis presents a science overview of the major forest management issues involved in the recovery of anadromous salmonids affected by timber harvest in the Pacific Northwest and Alaska. The issues involve the components of ecosystem-based watershed management and how best to implement them, including how to: Design buffer zones to protect fish habitat while enabling economic timber production; Implement effective Best Management Practices (BMPs) to prevent nonpoint-source pollution; Develop watershed-level procedures across property boundaries to prevent cumulative impacts; Develop restoration procedures to contribute to recovery of ecosystem processes; and Enlist support of private landowners in watershed planning, protection, and restoration. Buffer zones, BMPs, cumulative impact prevention, and restoration are essential elements of what must be a comprehensive approach to habitat protection and restoration applied at the watershed level within a larger context of resource concerns in the river basin, species status under the Endangered Species Act (ESA), and regional environmental and economic issues. This synthesis 1) reviews salmonid habitat requirements and potential effects of logging; 2) describes the technical foundation of forest practices and restoration; 3) analyzes current federal and non-federal forest practices; and 4) recommends required elements of comprehensive watershed management for recovery of anadromous salmonids.

Murphy, M. L., J. Heifetz, S. W. Johnson, K V. Koski, and J. F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaskan streams. Canadian Journal of Fisheries and Aquatic Science 43:1521-1533.

This research paper reports the results of field studies conducted in southeastern Alaska that were designed to assess the short-term effects of logging on the density and habitat use of streams by juvenile coho salmon, steelhead, cutthroat trout, and Dolly Varden in old growth forest and in clearcuts with and without stream buffers. All streams were apparently nonglacial. Winter and summer habitat use was examined. Old growth forest contained Sitka spruce and western hemlock. Clearcuts were 1 to 12 years old with trees cut to both streambanks. Buffered reaches were on 3 to 10 year old clearcuts: one bank had a strip of uncut streamside trees 15 to 130 m wide; the other side had undisturbed forest.

Clearcut stream reaches had less undercut bank, canopy density, pool volume, and debris and more periphyton than old growth reaches. Clearcut reaches were less stable than old growth reaches, having significantly greater point bar formation, sediment packing, and scour and deposition. Buffered reaches had more debris than old growth reaches but did not differ consistently from old growth reaches in any other habitat variable. Most pools were formed by debris, and pool volume and debris volume were positively related. Periphyton biomass and benthos density were positively related.

Summer density of coho fry averaged more than two times greater in both buffered and clearcut reaches than in old growth reaches. Summer fry density was directly related to periphyton biomass and benthos. The more periphyton a reach had, the more fry it had, and the clearcut and buffered reaches with open canopy and abundant periphyton had the most fry. In winter, density of coho salmon fry was still greater in buffered than in old growth reaches. Clearcut reaches no longer had significantly more fry than old growth reaches. Both summer food abundance and debris appeared to influence winter density of coho fry. The more periphyton a reach had in summer and the more debris, the more fry it had in winter. Summer food abundance limited summer fry densities and quality of winter habitat (i.e., debris) determined winter survival.

Coho salmon parr were equally abundant in old growth, buffered, and clearcut reaches in summer, but significantly less abundant in clearcut than in old growth reaches in winter. If debris was left in clearcut reaches, or added in buffered reaches, coho salmon parr were abundant (10 to 22/100 m^2) in winter. If debris had been removed from clearcut reaches, parr were scarce (<2/100 m^2) in winter.

Nakamoto, R. J. 1998. Effects of timber harvest on aquatic vertebrates and habitat in the North Fork Caspar Creek. Pages 87-96 *in* Ziemer, R. R., editor. Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story. USDA Forest Service, Pacific Southwest Research Station, PSW-GTR-168.

[The author] examined the relationships between timber harvest, creek habitat, and vertebrate populations in the North and South forks of Caspar Creek. Habitat inventories suggested pool availability increased after the onset of timber harvest activities. Increased large woody debris in the channel was associated with an increase in the frequency of blowdown in the riparian buffer zone. This increase in large woody debris volume increased the availability of pools. No dramatic changes in the abundance of young-of-the-year steelhead, yearling steelhead, coho, or Pacific giant salamanders were directly related to logging. High interannual variation in the abundance of aquatic vertebrates made it difficult to contrast changes in abundance between pre-logging and post-logging periods. Changes in channel morphology associated with increased volume of large woody debris in the channel suggest that yearling steelhead, coho, and Pacific giant salamanders may benefit from logging in the short-term because of increased living space. However, over a longer time scale these conditions will probably not persist (Lisle and Napolitano, these proceedings).

O'Laughlin, J., and G. H. Belt. 1995. Functional approaches to riparian buffer strip design. Journal of Forestry 93(3):29-32.

The term buffer strip include functional descriptions such as filter, stabilization, or leave strips, and administrative designations such as Idaho's Stream Protection Zone, Oregon's Riparian Management Area, Washington's Riparian Management Zone, and the USDA Forest Service's Streamside Management Zone. This article summarizes the functions of buffer strips and describes three approaches to their design. These are FPA, the Forest Practices Act regulations for implementing the Clean Water Act in northwestern states; FEMAT/PACFISH, the closely related federal agency approaches for managing threatened and endangered species habitat; and CSE, the "bankfull channel width" buffer option developed by the Center for the Study of the Environment to manage salmon habitat in the Pacific Northwest.

Osborne, L. L., and D. A. Kovacic. 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. Freshwater Biology 29:243-258.

A review is presented of the literature on riparian vegetated buffer strips (VBS) for use in stream-water-quality restoration and limitations associated with their use are discussed. The results are also presented of recent investigations on the effectiveness of a forested and a grass vegetated buffer strip for reducing shallow subsurface inputs of nutrients from agriculture to a stream in central Illinois, U.S.A. Both the forested and grass VBS reduced nitrate-N concentrations in shallow groundwater (up to 90% reduction). On an annual basis the forested VBS was more effective at reducing concentrations of nitrate-N than was the grass VBS, but was less efficient at retaining total and dissolved P. During the dormant season, both grass and forested buffer strips released dissolved and total P to the groundwater. The VBS apparently acted as a nutrient sink for much of the year, but also released accumulated nutrients during the remaining portion of the year.

Paustian, S. J., editor. 1992. A channel type users guide for the Tongass National Forest, southeast Alaska. USDA Forest Service, Alaska Region. R10 Technical Paper 26.

This User Guide is intended for forest resource planners, fisheries biologists, hydrologists, ecologists, or anyone involved with water resource management on the Tongass National Forest. It describes a stream classification system based on mapped stream reaches called channel types. Channel type mapping is a principal tool for managing aquatic and riparian resources of the Tongass National Forest. The purpose of this User Guide is to provide users with sufficient information to understand the characteristics of each channel type and to know what should considered when planning activities that may affect water and fisheries resources associated with each one.

Components of the Alaska Region Channel Type Classification System are defined within the context of nine basic fluvial process groups. These process groups describe the interrelationship between watershed runoff, landform relief, geology, and glacial or tidal influences on fluvial erosion and deposition processes. Individual channel type classification units within each process group are defined by physical attributes, such as channel gradient, channel pattern, stream bank incision and containment, and riparian plant community composition. Channel types are a means of distinguishing the various parts of a stream system. They allow us to define the characteristics of the channel and to predict, with a high degree of accuracy, probable responses to natural and human influence. However, channel types cannot be managed as isolated segments. Stream reach in one part of a watershed can be affected by activities taking place in a different part of the watershed, either upstream, downstream, or on adjacent land areas. Channel types help define the parts of a drainage basin and, as such, are tools intended to complement a holistic watershed management approach.

The Channel Type Classification System was developed with water resource management needs in mind. Propagation of anadromous fisheries is the major beneficial use of water resources in Southeast Alaska. Channel type inventories provide key information of fish habitat utilization, fish habitat capability, and fisheries enhancement options in survey area watersheds. Channel types also provide information on suitable stream crossing locations and design criteria for road drainage structures. Channel types are used to evaluate potential sediment delivery and retention for cumulative watershed effect analysis. Information of sport fishing potential and boat access is also included in the channel type descriptions.

This User Guide contains brief information for each of the 38 channel types currently mapped on the Tongass National Forest. There is a separate section, consisting of thee parts (Title, Physical Characteristics, and Management Considerations), for each channel type. Data used to describe the channel structure, riparian vegetation, and aquatic habitat have been obtained from channel typing verification and stream inventories conducted on watershed throughout Southeast Alaska.

Piccolo, Jack J. and Mark S. Wipfli. In press. Does alder (Alnus sp.) in upland riparian forests elevate macroinvertebrate and detritus export from headwater streams to downstream habitats in Southeast Alaska?

ABSTRACT: We assessed the effects of past timber management on macroinvertebrates and detritus export from headwater streams to downstream habitats in the Tongass National Forest, Southeast Alaska. Twenty-four fishless headwater streams (mean discharge = 3.5L / s, mean gradient 22%) were sampled across four riparian canopy types: old growth, clearcut (<5 years post-cut), young growth (35-40 years post-cut) alder, and young growth conifer. Export of each of six replicate streams per canopy type was sampled with a 250 µm net for 96 h intervals, monthly from April-August 1998. Young-growth alder sites exported significantly more macroinvertebrates (mean = 10.9 vs. 2.6 individuals / m^3 water and mean = 3.5 vs. 1.0 mg dry mass / m^3 water) and detritus (mean = 46.8 vs. 10.1 mg dry mass / m^3) than did young-growth conifer sites. No significant differences were observed between other canopy types. Approximately 70% of the export was made up of aquatic macroinvertebrates; the remainder was terrestrial or unidentified. These results suggest that alder riparian canopies elevate macroinvertebrate and detritus export from headwater streams. We attribute elevated export to greater in-stream productivity associated with higher quality and quantity of allochthonous input. Maintaining an alder component in upland forests following timber harvest should increase the productivity of headwater streams, benefiting downstream, salmonid-bearing food webs that receive prey and detritus from these upland habitats.

Reid, L. M., and S. Hilton. 1998. Buffering the buffer. Pages 71-80 *in* Ziemer, R. R., editor. Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story; held May 6, 1998, in Ukiah, California. USDA Forest Service, Pacific Southwest Research Station, General Technical Report PSW-GTR-168.

Riparian buffer strips are a widely accepted tool for helping to sustain aquatic ecosystems and to protect downstream resources and values in forested areas, but controversy persists over how wide a buffer strip is necessary. The physical integrity of stream channels is expected to be sustained if the characteristics and rates of tree fall along buffered reaches are similar to those in undisturbed forests. Although most tree-fall-related sediment and woody debris inputs to Caspar Creek are generated by trees falling from within a tree's height of the channel, about 30% of those tree falls are triggered by trees falling from upslope of the contributing tree, suggesting that the core zone over which natural rates of tree fall would need to be sustain is wider than the one-tree-height's-width previously assumed. Furthermore, an additional width of "fringe" buffer is necessary to sustain appropriate tree-fall rates within the core buffer. Analysis of the distribution of tree falls in buffer strips and un-reentered streamside forests along the North Fork of Caspar reek suggests that rates of tree fall are abnormally high for a distance of al least 200 m from a clearcut edge, a distance equivalent to nearly four times the current canopy height. The appropriate width of fringe buffer needed to protect the core zone will need to be determined using an analysis of the long-term effects and significance of accelerated tree-fall rates after logging.

Steinblums, I. J., H. A. Froelich, and J. K. Lyons. 1984. Designing stable buffer strips for stream protection. Journal of Forestry 82(1):49-52.

On 40 streamside buffer strips in the Cascade Mountains of western Oregon, stability was a function of one vegetation and six topographic variables, and shading was related to three characteristics of buffer strips and one of adjacent clearcuts. Prediction equations were developed from these relationships to aid assessment of stream protection in proposed harvest designs and to aid rapid evaluation of design modification. Options can be quantified so that the most suitable design may be chosen.

Timoney, K. P., G. Peterson, and R. Wein. 1997. Vegetation development of riparian plan communities after flooding, fire, and logging, Peace River, Canada. Forest Ecology and Management 93:101-120.

In this study, we compare and contrast vegetation development following natural and logging disturbances in a major boreal river valley. Permanent sample plots and releves were establish and sampled for vegetation and landscape attributes in June and July of 1993 and 1994 in the Peace River Lowlands, Wood Buffalo National Park, Canada. In the Peace River Lowlands, primary succession is a flood-origin process. Secondary succession may be either autogenic through gap dynamics mediated by nursery logs, buried wood, and suckering, or allogenic, following fire or logging. Flood origin accounts for 72% and fire origin for 29% of the undisturbed forests. From 19561-1995, 24% of the forest land burned, yielding a fire return interval of 186 years. Forest successional trajectories are set soon after flood, logging, or fire, with little evidence of gradual replacement of one forest type by another. Vegetation

composition and relative species abundance are strongly correlated with living moss depth, moss-lichen total cover, total tree cover, herb cover, and canopy height. Species with high indicator value are *Hylocomium splendens*, *Picea glauca*, *Pyrola chlorantha*, *Equisetum pratense*, and *Epilobium angustifolium*. Strong correlations exist between white spruce tree density and canopy height, total tree cover and canopy height, total tree cover and basal area per hectare, basal area and canopy height, and between canopy height and surface area. Clearcuts are initially dominated by rose-raspberry followed by balsam poplar (with lesser amounts of Alaska birch and aspen). After logging, temporal changes in composition and dominance occur more rapidly than during natural succession. There is no evidence of post-logging convergence toward the original white spruce and mixedwood forests; a long-term deciduous disclimax is predicted. Vegetation associations, successional pathways, landscape relationships, ad ecological benchmarks are identified.

U.S. Forest Service. 1997. Land and resource management plan, Tongass National Forest. USDA Forest Service. Alaska Region. R10-MB-338dd.

ABSTRACT: The Riparian forest-wide standards and guidelines discuss the management objectives and set the standards for buffers and other riparian management techniques for water bodies within the Tongass National Forest. The standards and guidelines for fish-bearing waters in the flood plain (FP) and glacial outwash (GO) channel type process groups state, in part: "No programmed commercial timber harvest in the Riparian Management Area (greatest of flood plain, riparian vegetation or soils, riparian associated wetland fens, or 130 feet (the height f one site-potential tree)). Manage an appropriate distance beyond the no-harvest zone to provide for a reasonable assurance of windfirmness of the Riparian Management Area (pay special attention to the area within one site-potential tree height of the Riparian Management Area)."

U.S. Forest Service. 1995. Report to Congress, synthesis: anadromous fish habitat assessment. USDA Forest Service. Alaska Region and Pacific Northwest Research Station. R10-MB-279.

ABSTRACT: The document, generally known as AFHA, includes a summary of the riparian management standards, including buffers, that were in place on the Tongass National Forest at the time of publication. The assessment includes three sections: a literature review, an evaluation of existing standards by a panel of experts, and a summary of three watershed analyses conducted on Game, Kadake, and Old Franks creeks. A synthesis of the three sections by an oversight team concluded that the existing riparian management standards, which included mandatory 100-foot no-cut buffers on anadromous fish streams and on resident fish streams that flow into anadromous streams, did not provide adequate long-term protection for salmon and steelhead habitats.

Welsch, D. J. 1991. Riparian forest buffers: function and design for protection and enhancement of water resources. USDA Forest Service, Northeast Area State and Private Forestry. NA-PR-07-91.

This relatively short publication is primarily directed at establishing riparian forest buffers for nonpoint source pollution control in agricultural and livestock grazing settings. As such, it

provides a good primer on functional values of buffers other than the more usual shading, large woody debris, etc. Welsch provides a functional definition for riparian buffers, then a set of specifications for designing effective buffers to mitigate effects of upslope, upstream, and subsurface changes brought about the land management activities and uses. He notes in particular the need to control hillside erosion at the source for a riparian zone to effectively buffer fine sediment transport. Welsch describes a three-zone buffer prescription, with Zone 1 beginning at the water body's edge to create a stable ecosystem adjacent to the water's edge, Zone 2 mid-buffer to provide contact time and buffering processes for sheet flow toward the water body, and Zone 3 away from the water body to provide sediment filtering, nutrient uptake, and the space necessary to convert flows concentrated by land use activities into uniform shallow sheet flow. Zonal and total buffer width recommendations vary by local hydrology, soil capability, and the size of adjacent drainage areas and land use areas.

Wipfli, M.S. 1997. Terrestrial invertebrates as salmonid prey and nitrogen sources in streams: contrasting old-growth and young-growth riparian forests in southeastern Alaska, U.S.A. Can J. Fish. Aquat. Sci. 54: 1259-1269.

ABSTRACT: Terrestrial-derived invertebrate (TI) inputs into streams and predation on them by salmonids (40-180 mm fork length) were measured in six coastal Alaska stream reaches from April through October 1993-1994; riparian habitat of three stream reaches contained conifer-dominated old-growth (no timber harvesting) and three were alder-dominated young-growth (31 years postclearcutting). Data from pan traps placed on stream surfaces showed that TI biomass and nitrogen inputs averaged up to 66 and 6 mg/m/day, respectively, with no significant difference between habitats. Stomach contents from coho salmon (*Onchorhynchus kisutch*), cutthroat trout (*O. clarki*), and Dolly Varden (*Salvelinus malma*) revealed that TI and aquatic-derived invertebrates (AI) were equally important prey. Additionally, salmonids from young-growth systems ingested a greater TI proportion than those from old-growth systems. There were trends but no significant differences between habitats of TI and AI biomass ingested; however, statistical power was <0.30. These results showed that TI were important juvenile salmonid prey and that a riparian overstory with more alder and denser shrub understory may increase their abundance. Riparian vegetation management will likely have important consequences on trophic levels supporting predators, including but not limited to fishes.

Xiang, W. 1993. Application of a GIS-based stream buffer generation model to environmental policy evaluation. Environmental Management 17:817-827.

In this article, a GIS method is presented for riparian environmental buffer generation. It integrates a scientifically tested buffer width delineation model into a GIS framework. Using the generally available data sets, it determines buffer widths in terms of local physical conditions and expected effectiveness. Technical burdens of data management, computation, and result presentation are handled by the GIS. The case study in which the method was used to evaluated the stream buffer regulations in a North Carolina county demonstrates its capability as a decision support tool to facilitate environmental policy formulation and evaluation, and environmental dispute resolution.