AN OVERVIEW OF RIPARIAN AREAS IN INTERIOR ALASKA: THEIR FUNCTION AND PROCESSES

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Introduction

Interior Alaska faces increasing pressures on fish, wildlife and their habitats. This is particularly true in areas of concentrated human activity and development, such as the Fairbanks North Star Borough. Alaskan waterways have been and continue to be used by humans for travel, sustenance, mineral extraction, and recreation. The natural elasticity of these aquatic resources allows for limited disturbances to occur without much influence on the system itself. Indeed, the integrity of a river system depends on the ever-changing water flows, water velocity, sediment loads, temperature gradients, vegetation, nutrients, and channel morphology. These changing components within the system are key to the maintenance and stability of the waterway.

Humans have tried to engineer predictability into aquatic systems to achieve economic and social objectives. In most cases, the abundance of Alaska's water resources has absorbed the changes and manipulations induced by human development. However, the increased demands made on these resources over the past 40 years have impacted systems in significant ways. Flood control, channel manipulation, destruction of vegetation, erosion, and the introduction or elimination of fish species have negatively affected ecological processes and, therefore, the stability and biological diversity of some Alaskan river systems.

Habitat alteration and contamination are two of the most significant impacts on aquatic ecosystems. These impacts can be controlled, minimized, and sometimes eliminated by the use of riparian buffer zones. Sedimentation, nutrient overload, organic contamination, and toxic waste (pesticides and metals) can be controlled or their effects lessened by the preservation of riparian buffer zones (Moyle and Sato 1991, Cooper 1993). Extensive forested floodplains can ameliorate the negative effects of record floods (which are exacerbated by the alteration of habitats within the watershed) by the uptake of nutrients, reduced water velocities, and trapped sediment loads (Michener et al. 1998).

Habitat restoration techniques have been used in riparian habitats with varying degrees of success. Recent developments in bioengineering and the use of models to examine various limiting habitat factors can be helpful when attempting to recreate or enhance riparian areas. Unfortunately, these techniques are generally expensive, labor intensive, and take years to be effective.

The following information is a brief review of monitoring and research conducted to determine factors of influence and important variables related to riparian zones. These summaries highlight some of the significant elements to consider when developing protection guidelines for riparian areas. Most research and data come from areas where habitat degradation is wide-spread (urban areas on the East Coast) or where fish resources (commercial salmon fisheries in the Pacific Northwest) have been economically devastated. The variables which are associated with or

influenced by riparian zones which are directly related to issues in Interior Alaska appear to be erosion, sedimentation, nutrients, available large woody debris, stream temperature, fisheries, and terrestrial habitat. The wealth of information brought forth by other land management experiences can be used to craft a more effective approach to manage riparian zones in Interior Alaska. The recommendations found in the conclusion are based on the following information.

Riparian Factors of Influence

A. **Erosion**

Of 748 stream bends measured in southern British Columbia after major flood events, the bends without forest vegetation were 5 times more likely to have detectable erosion and 30 times more likely to have major bank erosion (Beeson and Doyle 1995). Burckhardt and Todd (1998) looked at stream bends in 7 streams and paired forested and non-forested bends to measure the difference in local lateral migration. Non-forested bends had a migration rate 3 times higher than those that were forested. This is similar to the findings of Swanson and Dyrness (1975) in Oregon when they examined slide areas in stable and unstable zones. Clear-cutting in unstable areas increased the rate of slides 2.8 times the rate in forested areas. This would negatively affect the sediment loads of anadromous fish streams. A buffer zone width equal to one-half of tree height was considered effective at stabilizing most stream banks (O'Laughlin and Belt 1995).

Long term channel changes were documented on the Merced River in Yosemite National Park between areas that were heavily impacted by human disturbance and areas of minimal human impact (Madej et al. 1994). Bank erosion and an increase in channel width were prevalent in areas where human use was concentrated. Six bridges were placed in the same high use area, resulting in a decrease in the average width of the channel to 38% of the original width, causing severe erosion. In the area of minimal human use, the channel width had increased only 4% and had narrowed along some sections since 1919. Erosion occurred only on meanders, and only one bridge was built in this area. Channel widening was positively correlated to the percent bare ground on banks; low bank stability was strongly associated with high human use. The direct impacts from human activities were destruction of riparian vegetation, bridge construction and channel revetments. This is similar to the impacts from logging, stream channelization and bank stabilization projects discussed by Li et al. (1987), which are some of the leading causes in the decline of fish assemblages in the Pacific Northwest.

B. **Sedimentation**

Resource managers have tried to minimize sedimentation caused by development projects by building structures (such as weirs, log jams, and boulders) that mimic the natural features of streams. Structures placed in streams to improve fish habitat in Oregon and Washington had a median failure or impairment rate of 60% (Frissell and Nawa 1992). They were found to be ineffective in streams with high or elevated sediment loads, high peak flows, or highly erodible banks. Frissell and Nawa (1992) recommended that natural restoration of watersheds and riparian areas was needed to re-establish highly productive fish bearing streams. Although there

are many factors that influence the ability of riparian buffers to filter sediments, several studies suggest that a buffer of at least 10 m is sufficient to maintain water quality (Osborne and Kovacic 1993). Buffer widths from 60-80 m were recommended by O'Laughlin and Belt (1995) to minimize sedimentation due to logging road construction.

More than 50% of the sediment load from agricultural practices in North Carolina was deposited within 100 m of the fields (Cooper et al. 1987). An increase in buffer zone width along larger streams was recommended by Cooper et al. (1987). This is due to larger streams having increased water flow, subsequently increasing transport capacity and decreasing opportunities for deposition. Cooper et al. (1987) also proposed preserving natural flood plain swamps as the best structure to retain fine sediments, such as clay. Daniels and Gilliam (1996) recommended using the vegetated flood plain (13-20 m wide) as a filter for sediments and nutrients.

Riparian vegetation adjacent to highly developed agricultural areas in Illinois was found to be important in reducing suspended solids, due to the minimal algal production at low flows or higher summer temperatures (Schlosser and Karr 1981). In areas without riparian vegetation during low seasonal flows, instream algal production increased suspended solids, turbidity and phosphorus concentrations. Schlosser and Karr (1981) also determined when riparian vegetation was protected; water quality would improve during surface runoff by reducing the scour of stream banks.

Lloyd et al. (1987) studied the effects of placer mining on Interior Alaska streams. They found increased turbidity (a result of sedimentation) led to a decrease in primary plant production, an important factor in the stability of invertebrate and fish populations. They also found invertebrate populations were significantly lower in mined streams than unmined streams and almost non-existent in heavily mined streams. Several fish species, including Arctic grayling and coho and chinook salmon, were directly influenced by turbidity; fish were smaller, less abundant, and sometimes avoided turbid waters altogether.

C. **Nutrient Filter**

Good water quality in agricultural watersheds is dependent upon riparian vegetation available for nutrient uptake and storage (Lowrance et al. 1984). In the hardwood forests of the Georgia coastal plain, nitrogen had a very high retention rate through the buffer zone (68%), while calcium, phosphorus and magnesium had moderate retention rates. If the riparian forests were removed, nutrient levels in the stream would rise and water quality would be lowered (Lowrance et al. 1984). Although there are exceptions, effectiveness of a riparian buffer in removing nutrients generally increases with the width of the buffer (Osborne and Kovacic 1993). In Maryland, riparian buffers 30-60 m wide were most efficient in intercepting and retaining nutrients (particularly nitrates) migrating from adjacent cropland (Jordan et al. 1993).

Because riparian zones are the final level of terrestrial processes before resources enter aquatic ecosystems, they play a critical role in controlling the flux of nutrients from watersheds (Gregory et al. 1991). In both deciduous and coniferous riparian areas of the Cascade Mountains of Oregon, rates of nitrogen removal were greater in the soils of the riparian areas than in the soils

found farther upslope or in adjacent upland sites.

D. **Large Woody Debris**

Complex stream habitats (those which contain high levels of woody debris, riffles, and cascades to create hydrologically diverse channels) serve as refugia for fish in central Oregon during high water events (Pearsons et al. 1992). Riparian buffer zones provide for replacement of large woody debris in streams to help maintain stream complexity. Large woody debris contributes to pool formation and the creation of backwaters and eddies, which are critical in trapping nutrients and organic debris, creating depositional zones and lateral habitats, and providing rearing areas for juvenile fish (Gregory et al. 1991, Roni and Quinn 2001). Large woody debris in streams on the Olympic Peninsula of Washington retained 43% of salmon carcasses for more than one week (Cederholm et al. 1985). Unlogged stretches of streams had more woody debris than logged stretches and retained more carcasses. The retention of salmon carcasses added to nutrient levels along riparian zones when scavengers moved carcasses to the stream banks and also provided an important food source for scavengers.

Although logging operations may leave debris in streams, these structures tend to result in fewer, larger jams than what is typically deposited by natural riparian areas (Hicks et al. 1991). Streams need large woody debris to create diverse hydraulic gradients and microhabitats, both of which are positively associated with salmonid abundance. In the Pacific Northwest removal of riparian forests which supply the large woody debris structure decreases essential winter cover and destabilizes the stream channel, thereby causing high winter mortality of salmonid eggs, alevins, and juveniles (Bisson et al. 1987).

In western Oregon, over 100 times more pieces of wood were found in streams which had pristine riparian areas than found in streams which had logged riparian areas (Sedell et al. 1988). In addition, the logs in the pristine areas averaged 10 m in length, whereas the logs averaged <5 m in the streams in the logged areas. Shorter logs, usually smaller diameter and less well-anchored, disappear more rapidly than bigger, older debris. There may be smaller, younger debris introduced to the streams in the logged areas, but the reduced time these smaller trees are in the water results in less cover and fewer pools than the streams which have intact riparian areas (Sedell et al. 1988). O'Laughlin and Belt (1995) recommended a buffer zone equal to one site-potential tree height to maintain the maximum potential for large woody debris in streams of the Pacific Northwest.

E. **Stream Temperature**

Trout streams in southern Ontario were found to have an average weekly temperature <22° C (mid-May through August), whereas streams with average weekly temperatures >22° C did not support sustaining trout populations (Barton et al. 1985). Stream temperature was found to be directly related to the presence of forested riparian buffer strips. Logging operations which left buffer zones of <30 m significantly increased stream temperatures in Tasmania, Australia (Davies and Nelson 1994). Barton et al. (1985) concluded that length and width of buffer strips needed to be considered when determining impacts to trout streams. For example, minimum 10

m-wide buffer was necessary for at least 3 km to provide an adequate shade component. A buffer zone width of one site-potential tree height is recommended for both sides of the stream to maximize the stream shading effect for temperature control (O'Laughlin and Belt 1995).

Net thermal radiation was determined to be the most significant factor in predicting stream temperatures in Oregon, while convection and evaporation played minor roles (Brown 1969). Forested streams varied only 1.5° F in temperature, but the nonforested streams varied 11° F in temperature during the same time period. This is consistent with studies from the midwest and western United States (Karr and Schlosser 1977, Gregory et al. 1991), which determined that riparian vegetation plays a major role in modifying solar inputs and influencing stream temperatures. Buffer zones from 10-30 m wide have been shown to maintain stream temperatures in Illinois, although geographical location, groundwater input, vegetation composition, and density also influence the effect of riparian buffers (Osborne and Kovacic 1993).

F. **Fisheries**

Salmonids occupy a variety of streams that vary dramatically in size and flow. In general, spawning and rearing in forested watersheds takes place in second- to fourth-order streams. These streams play a significant role in downstream habitat quality. They also are the ones most easily affected by alterations in the riparian zones, such as those changes created by logging activities (Chamberlin et al. 1991, Davies and Nelson 1994). The cumulative impacts of timber harvest and other land development activities can have significant impacts on fish reproduction areas, as well as impact the downstream habitat components. These impacts on fish habitats can be generally categorized as changes in the timing and magnitude of run-off events, changes in streambank stability, changes in the supply of sediments to channels, changes in structure supply (such as large woody debris), and changes in energy relationships of water temperature, snowmelt, and freezing (Chamberlin et al. 1991). While logging riparian areas may improve invertebrate production as a food resource by salmonids, the lethal effect of the accompanying increase in stream temperature outweighs the increased food supply (Baltz and Moyle 1984, Gregory et al. 1987, Murphy and Meehan 1991). In Alaska, the effect of an increase in temperature of some streams improves food availability enough to outweigh the possible negative physiological effects to fish. However, in backwater sloughs and oxbows, an increase in stream temperature needs is detrimental to production and survival of native fish species (Alaska Department of Fish and Game, unpublished data on file at Fairbanks Field Office).

Some degree of riparian control, prevention of industrial and agricultural pollution, and protection from channelization and impoundment is needed to protect and maintain the diversity found in higher order streams (Sheldon 1988). Cumulative habitat loss or degradation due to land-use activities such as logging and road construction plays a significant role in the decline of native fish species throughout the western United States (Bisson et al. 1987, Nehlsen et al. 1991, McIntosh et al. 1994). Alaskan stream systems have also been affected by habitat loss, such as that documented on the Kenai River (Liepitz 1994). Even if logging activities are focused in upper watershed streams where salmonids are not found, the cumulative thermal and sediment loadings can negatively affect critical salmonid habitats in lower stream reaches very quickly

(Murphy and Meehan 1991). The average number of juvenile chinook and coho salmon in the Chickamin River, Alaska increased from <10 per site in areas with no woody debris to 200 per site in areas with woody debris present (Sedell et al. 1988). In the semi-arid region east of the Cascades in Oregon and Washington, where most native salmon runs have been listed as endangered, habitat degradation is one of the primary causes for the decline in anadromous fish populations (Henjum et al. 1994, McIntosh et al. 1994). Logging operations, mining activity, livestock grazing and road construction are developments which have caused the most severe degradation of riparian areas and consequently have been the main causes of loss of fish habitat in the area.

The loss of fish species and the decline of aquatic resources in watersheds not affected by dams or diversions are directly related to the extensive and cumulative effects that are brought about by logging and other human disturbance activities (Frissell 1993). Food and cover are impacted by the loss of riparian vegetation causing changes in sediment and nutrient loads, large woody debris supply for pool formation and slack water areas, and freezing events (Murphy and Meehan 1991). Fish usually inhabit the areas associated with large woody debris where pools create deeper and slower water (Sedell et al. 1988). Salmonids rely on these micro-habitats for protection when floods or other high velocity events occur. Juvenile coho salmon densities were 1.8 times higher in summer and 3.2 times higher in winter in streams where large woody debris was placed at a density of 1.8 to 2.9 times higher than streams where no structures were placed (Roni and Quinn 2001). Fish species found in boreal lakes of northwest Ontario can also be negatively affected by logging activities (Newcombe and McDonald 1991, France 1997, and France et al. 1998).

G. **Terrestrial Habitat Component**

Several studies have documented the importance of riparian forest characteristics and the availability of those specific parameters to avian species (Thomas et al. 1979, Stauffer and Best 1980, Emmerich and Vohs 1982, Croonquist and Brooks 1993, Spackman and Hughes 1994, Darveau et al. 1995). Kilgo et al. (1998) recommended riparian buffer strips at least 500 m wide to maintain avian community diversity in bottomland hardwoods. Total species richness and neotropical migrant species richness were positively associated with greater stand width. This is comparable to the recommendations of Hodges and Krementz (1996), who determined that neotropical migrant species richness and abundance increase with an increase in riparian forest corridor width. They advised leaving buffer strips of at least 100 m to protect neotropical avian species from project impacts. Keller et al. (1993) advised land managers to have riparian forests of at least 100 m wide, preferably wider, to provide adequate nesting habitat for area-sensitive species. Corridors ≥76 m wide had a 50% probability of having area-sensitive species occur within the corridor. They documented an increase in neotropical migrant species using riparian areas as the width of riparian forests increased. Their recommendations were to first preserve the widest corridors possible, while secondly, create or increase riparian forest where little or none exist.

When riparian zones of 14, 37, and 70 m wide were compared in southeastern British Columbia riparian forests, the density of all birds combined increased (along with the density of all

riparian-associated birds and the density of 3 of 4 riparian associated species) when zone width increased (Kinley and Newhouse 1997). Riparian zones had greater species diversity, greater density of all species combined, and greater density of 3 individual species than upland zones. These differences may be attributed to the structural differences found in the riparian forests. Riparian zones had greater canopy cover with fewer trees, a greater tall shrub component, and possibly more coarse woody debris than did upland forest zones (Kinley and Newhouse 1997). Areas in Kentucky which were clearcut but included protection of a 15-23 m buffer strip supported more bird species and a higher bird diversity than did clearcuts without riparian buffer strips (Triquet et al. 1990). Triquet et al. (1990) also found that mature-forest bird species may not use riparian buffer strips if the adjacent upslopes are clearcut. They recommended that forest managers use uneven-aged harvest techniques in areas adjacent to riparian buffer strips. This also emphasizes the importance of maintaining the riparian forest's structural attributes to provide landscape-scale habitat variability, since the riparian forest makes up a relatively small part of the landscape (Kinley and Newhouse 1997).

The presence or absence of some neotropical migrants both in urban riparian corridors and a forest preserve was dependent on a corridor width at least as wide as their home range (Smith and Schaeffer 1992). Vegetation composition was a significant habitat factor in urban riparian corridors, i.e., shade intolerant shrubs may flourish where tree density is low, providing little or no habitat suitable for species which forage close to the ground. Corridors in the urban study area ranged from 20-60 m wide.

Spackman and Hughes (1995) examined third- and fourth-order streams and varying riparian buffer zone widths in Vermont to determine the minimum width of buffer zones needed to conserve species richness and distribution. These streams were chosen due to the high biodiversity and also because these types of streams have the greatest potential for agricultural development and are highly desirable for housing and recreational areas. Results indicated that corridors need to be >75-175 m wide to include 90% of the potential number of bird species, but only 10-30 m wide to include native streamside plant species. They also believed that extensive, stream-specific surveys were needed to evaluate the necessary riparian corridor width in any given area. Minimum width estimates were considered to be conservative when determining habitat parameters to sustain viable populations. This varied zone width recommendation is similar to O'Laughlin and Belt (1995) who offered 30-190 m as a zone width depending on the targeted species' habitat needs.

Conclusions

Riparian areas interact with virtually all other river system components in various ways. Riparian buffer zones maintain or increase stream debris, protect fish habitat, allow increases in primary productivity, and can increase the abundance of fry and parr (Murphy et al. 1986). Significant changes in the amount and composition of riparian vegetation can negatively affect water temperature, sediment loads, water velocity, wildlife and fish species diversity, bank stability, and nutrient interception. Riparian area conservation is one of the easiest and most influential methods to alleviate development impacts to the riverine environment. However, a standardized riparian buffer zone which provides habitat maintenance and satisfies human demands does not

exist (Budd et al. 1987) . Land managers must consider the potential uses and the environmental constraints of an individual stream length before any protection zone can be determined.

Naiman and Rogers (1997) supported maintaining viable populations of all species across their natural range of variation to maintain the ecological potential of species and their ecosystems. They noted that biodiversity and ecological stability of river corridor systems have declined on a global scale due to ineffective land management policies. They recommended comprehensive, rather than piecemeal, approaches to protect the integrity of these complex river systems. This approach was echoed by Michenor et al. (1998) and Naiman et al. (1993) when they commented on the lack of comprehensive planning including ecological and economic considerations when developing long-term land management strategies. Georgia's 25-foot buffer zone on Piedmont trout streams to sustain the trout resource is an example of narrowly-focused planning. Michenor et al. (1998) presented the extensive benefits (i.e., reduced sediment and nutrient loads, improved fish and mollusk communities, and increased stream biotic integrity) of a more inclusive plan that protects other intact flood plains, not just trout streams.

There are a number of factors that can be used to determine a protected riparian zone width. These include aquatic resource functional values, sediment removal and erosion control, excess nutrient and metal removal, moderation of storm water runoff, moderation of stream temperature, maintenance of habitat diversity, wildlife species richness and diversity, and reduction of human disturbance (Castelle et al. 1994). While many agencies require a single buffer size requirement (usually determined by political acceptability), buffer zones based on site-specific parameters and specific resource needs should provide flexible width requirements for sufficient physical, chemical, and biological protection. The following are recommendations for Interior Alaska riparian habitats that could form the foundation of site-specific evaluations when determining buffer widths:

- A minimum buffer zone of 15-20 m provides for the maintenance of the natural physical and chemical characteristics (erosion control, contaminant interception, nutrient filter, channel hydrology) of aquatic resources.

- A minimum buffer zone of 25-30 m provides structural elements (e.g. large woody debris, overhanging vegetation) necessary to maintain most of the biological components of streams.

- A minimum buffer zone of 75-100 m (possibly more depending on the target species) is needed to maintain habitat quality for some avian species present in a stream corridor.

The importance of riparian area protection was best summarized by Reeves et al (1991) who stated, "The importance of preventing habitat degradation now, instead of being forced to rebuild habitats in the future because of today's poor management practices, cannot be over emphasized. Protection of habitat is by far the most effective stream rehabilitation and enhancement method."

References

Baltz, D. M., and P. B. Moyle. 1984. Influence of riparian vegetation on stream fish communities of California. Pages 183-187 *In* Warner, R. E. and K. M. Hendrix, eds. California riparian systems: ecology, conservation and management. University of California Press. Berkley, CA.

Barton, D. R., W. D. Taylor, and R. M. Biette. 1985. Dimensions of riparian buffer strips required to maintain trout habitat in southern Ontario streams. North American Journal of Fisheries Management 5:364-378.

Beeson, C. E., and P. F. Doyle. 1995. Comparison of bank erosion at vegetated and non-vegetated channel bends. Water Resources Bulletin 31:983-990.

Bisson, P. A., R. E. Bilby, M. D. Bryant, C. A. Dolloff, G. B. Grette, R. A. House, M. L. Murphy, K. V. Koski, and J. R. Sedell. 1987. Large woody debris in forested streams in the Pacific Northwest streams: past, present, and future. University of Washington Institute of Forest Resources Contribution 57:143-190.

Brown, G. W. 1969. Predicting temperatures of small streams. Water Resources Research 5(1):68-75.

Budd, W. W., P. L. Cohen, P. R. Saunders, and F. R. Steiner. 1987. Stream corridor management in the Pacific Northwest: I. Determination of stream-corridor widths. Environmental Management 11(5):587-597.

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 Resource Association 34:179-184.

Castelle, A. J., A. W. Johnson, and C. Conolly. 1994. Wetland and stream buffer size requirements - a review. Journal of Environmental Quality 23:878-882.

Cederholm, C. J., and N. P. Peterson. 1985. The retention of coho salmon (*Oncorhynchus kisutch*) carcasses by organic debris in small streams. Canadian Journal of Fisheries and Aquatic Science 42:1222-1225.

Chamberlin, T. W., R. D. Harr, and F. H. Everest. 1991. Timber harvesting, silviculture, and watershed processes. American Fisheries Society Special Publication 19:181-205.

Cooper, C. M. 1993. Biological effects of agriculturally derived surface water pollutants on aquatic systems - a review. Journal of Environmental Quality 22:402-408.

Cooper, J. R., J. W. Gilliam, R. B. Daniels, and W. P. Robarge. 1987. Riparian areas as filters for agricultural sediment. Soil Scientists Society of America Journal 51:416-420.

Croonquist, M. J., and R. P. Brooks. 1993. Effects of habitat disturbance on bird communities in riparian corridors. Journal of Soil and Water Conservation 48(1):65-70.

Daniels, R. B., and J. W. Gilliam. 1996. Sediment and chemical load reduction by grass and riparian filters. Soil Scientists Society of America Journal 60:246-251.

Darveau, M., P. Beauchesne, L. Belanger, J. Huot, and P. Larue. 1995. Riparian forest strips as habitat for breeding birds in boreal forest. Journal of Wildlife Management 59(1):67-78.

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.

Emmerich, J. M., and P. A. Vohs. 1982. Comparative use of four woodland habitats by birds. Journal of Wildlife Management 46(1):43-49.

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(6):452-455.

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

Frissell, C. A. 1993. Topology of extinction and endangerment of native fishes in the Pacific Northwest and California (U.S.A.). Conservation Biology 7(2):342-354.

Frissell, C. A., and R. K. Nawa. 1992. Incidence and causes of physical failure of artificial habitat structures in streams of western Oregon and Washington. North American Journal of Fisheries Management 12:182-197.

Gregory, S. V., G. A. Lamberti, D. C. Erman, K. V. Koski, M. L. Murphy and J. R. Sedell. 1987. Influence of forest practices of aquatic production. Pages 233-255 *In* Salo, E. O., and T. W. Cundy, eds. Streamside management: forestry and fishery interactions. University of Washington Institute of Forest Resource Contributions 57:234-255.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones: Focus on links between land and water. Bioscience 41(8):540-551.

Henjum, M. G., J. R. Karr, D. L. Bottom, D. A. Perry, J. C. Bednarz, S. G. Wright, S. A. Beckwitt, and E. Beckwitt. 1994. Interim protection for late-successional forests, fisheries, and watersheds. The Wildlife Society. Technical Review 94-2. Bethesda, MD. 245 pp.

Hicks, B. J., J. D. Hall, P. A. Bisson, and J. R. Sedell. 1991. Responses of salmonids to habitat changes. American Fisheries Society Special Publication 19:483-518.

Hodges, M. F., and D. G. Krementz. 1996. Neotropical migratory breeding bird communities in riparian forests of different widths along the Altamaha River, Georgia. Wilson Bulletin 108(3):496-506.

Jordan, T. E., D. L. Correll, and D. E. Weller. 1993. Nutrient interception by a riparian forest receiving inputs from adjacent cropland. Journal of Environmental Quality 22:467-473.

Karr, J. R. and I. J. Schlosser. 1977. Impact of nearstream vegetation and stream morphology on water quality and stream biota. U. S. EPA Ecological Research Series EPA-600/3-77-097. Athens, GA.

Keller, C. M. E., C. S. Robbins, and J. S. Hatfield. 1993. Avian communities in riparian forests of different widths in Maryland and Delaware. Wetlands 13(2):137-144.

Kilgo, J. C., R. A. Sargent, B. R. Chapman, and K. V. Miller. 1998. Effect of stand width and adjacent habitat on breeding bird communities in bottomland hardwoods. Journal of Wildlife Management 62(1):72-83.

Kinley, T. A. and N. J. Newhouse. 1997. Relationship of riparian reserve zone width to bird density and diversity in southeastern British Columbia. Northwest Science 71(2):75-86.

Leipitz, G. S. 1994. An assessment of the cumulative impacts of development and human uses on fish habitat in the Kenai River. Alaska Department of Fish and Game. Technical Report 94-6.

Li, H. W., C. B. Schreck, C. E. Bond, and E. Rexstad. 1987. Factors influencing changes in fish assemblages of Pacific Northwest streams. Pages 193-202 *In* Mathews, W. J., and D. C. Heins, eds. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press. Norman, OK.

Lloyd, D. S., J. P. Koenings, and J. D. LaPerriere. 1987. Effects of turbidity in fresh waters of Alaska. North American Journal of Fisheries Management. 7:18-33.

Lowrance, R., R. Todd, J. Fail, O. Henderson, R. Leonard, and L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. Bioscience 34(6): 374-377.

Madej, M. A., W. E. Weaver, and D. K. Hagans. 1994. Analysis of bank erosion on the Merced River, Yosemite Valley, Yosemite National Park, California. Environmental Management 18:235-250.

McIntosh, B. A., J. R. Sedell, J. E. Smith, R. C. Wissmar, S. E. Clarke, G. H. Reeves, and L. A. Brown. 1994. Management history of Eastside Ecosystems: changes in fish habitat over

50 years, 1965-1992. U. S. Forest Service Publication. PNW-GTR-321.

Michenor, W. K., E. R. Blood, J. B. Box, C. A. Couch, S. W. Golladay, D. J. Hippe, R. J. Mitchell, and B. J. Palik. 1998. Tropical storm flooding of a coastal plain landscape. Bioscience 48(9):696-705.

Moyle, P. B., and G. M. Sato. 1991. On the design of preserves to protect native fishes. Pages 155-169 *in* Minckley, W. L., and J. E. Deacon, editors. Battle against extinction: native fish management in the American West. University of Arizona Press. Tucson, AZ.

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.

Murphy, M. L., and W. R. Meehan. 1991. Stream ecosystems. American Fisheries Society Special Publication 19:17-46.

Naiman, R. J., H. DeCamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3(2):209-212.

Naiman, R. J., and K. H. Rogers. 1997. Large animal and system-level characteristics in river corridors. Bioscience 47(8):521-529.

Newcombe, C. P., and D. D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11:72-82.

Nelsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4-21.

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

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

Pearsons, T. N., H. W. Li, and G. A. Lamberti. 1992. Influence of habitat complexity on resistance to flooding and resilience of stream fish assemblages. Transactions of the American Fisheries Society 121:427-436.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. Bioscience 47(11):769-784.

Reeves, G. H., J. D. Hall, T. D. Roelofs, T. L. Hickman, and C. O. Baker. 1991. Rehabilitating and modifying stream habitats. American Fisheries Society Special Publication 19:519-557.

Roni, P., and T. P. Quinn. 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Aquatic Science 58:282-292.

Schlosser, I. J., and J. R. Karr. 1981. Water quality in agricultural watersheds: impact of riparian vegetation during base flow. Water Resources Bulletin 17(2):233-240.

Sedell, J. R., P. A. Bisson, F. J. Swanson, and S. V. Gregory. 1988. What we know about large trees that fall into streams and rivers. Pages 47-81 *in* Maser, C., R. F. Tarrant, J. M. Trappe, and J. F. Franklin, editors. From the forest to the sea: a story of fallen trees. U.S. Forest Service Publication PNW-GTR-229.

Sedell, J. R., G. H. Reeves, F. R. Hauer, J. A. Stanford, and C. P. Hawkins. 1990. Role of refugia in recovery from disturbances: modern fragmented and disconnected river systems. Environmental Management 14(5):711-724.

Sheldon, A. L. 1988. Conservation of stream fishes: patterns of diversity, rarity, and risk. Conservation Biology 2(2):149-156.

Smith, R. J., and J. M. Schaeffer. 1992. Avian characteristics of an urban riparian strip corridor. Wilson Bulletin 104(4):732-738.

Spackman, S. C., and J. W. Hughes. 1995. Assessment of minimum stream corridor width for biological conservation: species richness and distribution along mid-order streams in Vermont, USA. Biological Conservation 71:325-332.

Stauffer, D. F., and L. B. Best. 1980. Habitat selection by birds of riparian communities: evaluating effects of habitat alterations. Journal of Wildlife Management 44(1):1-15.

Swanson, F. J., and C. T. Dyrness. 1975. Impact of clear-cutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geology 3:393-396.

Swanston, D. N. 1991. Natural processes. American Fisheries Society Special Publication 19:139-179.

Thomas, J. W., C. Maser and J. E. Rodiek. 1979. Riparian zones. Pages 40-47 *in* J. W. Thomas ed. Wildlife habitats in managed forests: The Blue Mountains of Washington and Oregon. U. S. Department of Agriculture, Forest Service Agricultural Handbook No. 553. Pacific Northwest Research Station. Portland, OR.

Triquet, A. M., G. A. McPeek, and W. C. McComb. 1990. Songbird diversity in clearcuts with and without a riparian buffer strip. Journal of Soil and Water Conservation July-Aug:500-503.