Management Recommendations for Washington's Priority Habitats

Riparian

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Washington Department of FISH and WILDLIFE

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December 1997

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Olympia, WA 98501-1091

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WASHINGTON DEPARTMENT OF FISH AND WILDLIFE REGIONAL CONTACTS

For Assistance with PHS Information Specific to Your County, Contact the Following WDFW Representative.

If you live in...	Contact...
Asotin, Columbia, Ferry, Garfield, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	John Andrews 8702 N. Division St. Spokane, WA 99218-1199 Phone: (509) 456-4082
Adams, Chelan, Douglas, Grant, Okanogan	Tracy Lloyd 1550 Alder St. NW Ephrata, WA 98823-9699 Phone: (509) 754-4624
Benton, Franklin, Kittitas, Yakima	Ted Clausing 1701 24th Ave. Yakima, WA 98902-5720 Phone: (509) 575-2740
Island, King, San Juan, Skagit, Snohomish, Whatcom	Ted Muller 16018 Mill Creek Blvd. Mill Creek, WA 98012-1296 Phone: (206) 775-1311
Clark, Cowlitz, Klickitat, Lewis, Skamania, Wahkiakum	Bryan Cowan 2108 Grand Blvd. Vancouver WA 98661 Phone: (360) 696-6211
Clallam, Grays Harbor, Jefferson, Kitsap, Mason, Pacific, Pierce, Thurston	Steve Keller 48 Devonshire Rd. Montesano, WA 98563-9618 Phone: (360) 249-4628

EXECUTIVE SUMMARY

By virtue of its high productivity, diversity, continuity, and critical contributions to both aquatic and upland ecosystems, riparian habitat provides a rich and vital resource to Washington's fish and wildlife. Riparian habitat occurs as an area adjacent to rivers, perennial or intermittent streams, seeps, and springs throughout Washington. Because it is generally a narrow band, riparian habitat covers a relatively small portion of the state. Riparian areas contain elements of both aquatic and terrestrial ecosystems which mutually influence each other and occur as transitions between aquatic and upland habitats.

Seventy-seven species of fish inhabit freshwater in Washington. Riparian habitat performs many functions that are essential to fish survival and productivity, and it is critical in supporting suitable instream conditions necessary for the recovery of imperiled native salmon stocks. Vegetation in riparian areas shades streams maintaining cool temperatures needed by most fish. Plant roots stabilize stream banks and control erosion and sedimentation, and vegetation creates overhanging cover for fish. Riparian habitat contributes leaves, twigs, and insects to streams, thereby providing basic food and nutrients that support fish and aquatic wildlife. Large trees that fall into streams create pools, riffles, backwater, small dams, and off-channel habitat that are necessary to fish for cover, spawning, rearing, and protection from predators. Pools help maintain riffles where gravel essential for spawning accumulates. Riparian vegetation, litter layers, and soils filter incoming sediments and pollutants thereby assisting in the maintenance of high water quality needed for healthy fish populations. Riparian habitat moderates stream volumes by reducing peak flows during flooding periods and by storing and slowly releasing water into streams during low flows.

Approximately 85% of Washington's terrestrial vertebrate species use riparian habitat for essential life activities and the density of wildlife in riparian areas is comparatively high. Forested riparian habitat has an abundance of snags that are critical to cavity-nesting birds and mammals and to many insectivorous birds. Downed logs are common and provide cover and resting habitat for amphibians, reptiles, and small mammals. Intact riparian habitat has well-developed vegetation, usually with multiple canopy layers. Each layer consists of unique habitat niches that together support a diversity of bird and mammal species. The relatively mild microclimate of riparian areas offers relief from hot, dry summers and cold, snowy winters which is especially important to deer, elk, and moose. Riparian habitat forms natural corridors that are important travel routes between foraging areas, breeding areas, and seasonal ranges, and provides protected dispersal routes for young. Protected access to water is also an essential attribute of intact riparian habitat.

Riparian habitat is limited geographically, however, and is vulnerable to loss and degradation through human activities and land uses. Since the arrival of settlers in the early 1800s, at least 50% and as much as 90% of riparian habitat in Washington has been lost or extensively

modified. Protecting riparian habitat may yield the greatest gains for fish and wildlife across the landscape while involving the least amount of area.

The Washington Department of Fish and Wildlife (WDFW) has developed statewide riparian management recommendations based on the best available science. Nearly 1,500 pieces of literature on the importance of riparian areas to fish and wildlife were evaluated, and land use recommendations designed to accommodate riparian-associated fish and wildlife were developed. These recommendations consolidate existing scientific literature and provide information on the relationship of riparian habitat to fish and wildlife and to adjacent aquatic and upland ecosystems. These recommendations have been subject to numerous review processes.

Recommendations on major land use activities commonly conducted within or adjacent to riparian areas are provided, including those relative to agriculture, chemical treatments, grazing, watershed management, roads, stream crossings and utilities, recreational use, forest practices, urbanization, comprehensive planning, restoration, and enhancement. Management recommendations for riparian areas are generalized for predictable application across the Washington landscape and include the following standard riparian habitat area (RHA) widths.

Standard recommended Riparian Habitat Area (RHA) widths for areas with typed and non-typed streams. If the 100-year floodplain exceeds these widths, the RHA width should extend to the outer edge of the 100-year floodplain.

Stream Type	Recommended RHA widths in meters (feet)
Type 1 and 2 streams; or Shorelines of the State, Shorelines of Statewide Significance	76 (250)
Type 3 streams; or other perennial or fish bearing streams 1.5-6.1 m (5-20 ft) wide	61 (200)
Type 3 streams; or other perennial or fish bearing streams <1.5 m (5 ft) wide	46 (150)
Type 4 and 5 streams; or intermittent streams and washes with low mass wasting* potential	46 (150)
Type 4 and 5 streams; or intermittent streams and washes with high mass wasting* potential	69 (225)

*Mass wasting is a general term for a variety of processes by which large masses of rock or earth material are moved downslope by gravity, either slowly or quickly.

Management recommendations for riparian habitat are developed to meet the goal of maintaining or enhancing the structural and functional integrity of riparian habitat and associated aquatic systems needed to perpetually support fish and wildlife populations on both site and landscape levels. Riparian habitat characteristics required by fish and wildlife include habitat connectivity; vegetation diversity in terms of age, plant species composition, and vegetation layers; vegetation vigor; abundance of snags and woody debris; unimpeded occurrences of natural disturbances and minimization of human-induced disturbances; an irregular shape; and a width that is adequate to retain riparian habitat functions. Although generalized for use across the landscape, these same characteristics can serve as performance guidelines if alternative site-specific management activities are pursued. Ideally, planning for riparian areas should be done from the perspective of an entire watershed.

It is expected that these management recommendations will contribute to the scientific component of planning, protection, and restoration efforts for fish and wildlife. These efforts include the Growth Management Act; habitat conservation plans (e.g., the Department of Natural Resources Habitat Conservation Plan); the WDFW Hydraulic Code; the Puget Sound Action Plan; the Timber, Fish, and Wildlife Agreement; individual landowner farm and forest plans; and restoration projects conducted through the Jobs for the Environment Program, Regional Fisheries Enhancement Groups, State Conservation Commission, For the Sake of the Salmon, and other efforts. Habitat requirements for salmon recovery outlined in WDFW's Wild Salmonid Policy were derived, in part, from these management recommendations. These recommendations may provide a basis for WDFW participation in other planning processes that address riparian management strategies; however, WDFW will defer to negotiated agreements (e.g., the TFW Forestry Module) regarding riparian management that may result from our participation in those planning processes.

INTRODUCTION

Fish and wildlife are public resources. Although the Washington Department of Fish and Wildlife (WDFW) is charged with protecting and perpetuating fish and wildlife species, the agency has very limited authority over the habitat on which animals depend. Instead, protection of Washington's fish and wildlife resources is currently achieved through voluntary actions of landowners and through the State Environmental Policy Act (SEPA), Growth Management Act (GMA), Forest Practices Act (FPA), Shoreline Management Act (SMA), and similar planning processes that primarily involve city and county governments. Landowners, agencies, governments, and members of the public have a shared responsibility to protect and maintain fish and wildlife resources for present and future generations; the information contained in this document is intended to assist all entities in this endeavor.

The Washington Department of Fish and Wildlife has identified those fish and wildlife resources that are a priority for management and conservation. Priority habitats are those habitat types with unique or significant value to many fish or wildlife species. Priority species are those fish and wildlife species requiring special efforts to ensure their perpetuation because of their low numbers, sensitivity to habitat alteration, tendency to form vulnerable aggregations, or because they are of commercial, recreational, or tribal importance. Descriptions of those habitats and species designated as priority are published in the Priority Habitats and Species (PHS) List (Wash. Dept. Fish and Wildl. 1996).

PHS Management Recommendations

The department has developed management recommendations for Washington's priority habitats and species to provide planners, elected officials, landowners, and citizens with comprehensive information on important fish, wildlife, and habitat resources. These management recommendations are designed to assist in making land use decisions that incorporate the needs of fish and wildlife. Considering the needs of fish and wildlife can help prevent species from becoming extinct or increasingly threatened and may contribute to the recovery of species already imperiled.

Agency biologists develop management recommendations for Washington's priority habitats and species through a comprehensive review and synthesis of the best scientific information available. Sources include professional journals and publications, symposia, reference books, and personal communications with professionals on specific habitats or species. Management recommendations are reviewed within the Department and by other resource professionals and potential users of the information. The recommendations may be revised if scientists learn more regarding a priority habitat or priority species.

Because PHS management recommendations address fish and wildlife resources statewide, they are generalized. Management recommendations are not intended as site-specific prescriptions but as guidelines for planning. Because natural systems are inherently complex and because human activities have added to that complexity, management recommendations may have to be modified for on-the-ground implementation. Modifications to management recommendations should strive to retain or restore characteristics needed by fish and wildlife. Consultation with fish and wildlife professionals is recommended when modifications are being considered.

Habitat management recommendations are directed at maintaining and enhancing habitat needed for a wide array of species. Although the management recommendations attempt to incorporate general requirements of most individual species, particular species with special needs are not covered in detail. Management recommendations for these particular species have been written in separate documents for each species. If differences exist in the documents, then the most protective recommendation should be implemented.

The locations of priority habitats and species are mapped statewide. The maps represent WDFW's best knowledge of Washington State's fish and wildlife resources based on research and field surveys conducted over the past 20 years. Management recommendations should be addressed whenever priority habitats and species occur in a particular area whether or not the WDFW maps show that occurrence. These maps can be used for initial assessment of fish and wildlife resources in an area, but they should also be supplemented with a field survey or local knowledge to determine the presence of priority habitats or priority species. The PHS data show WDFW's knowledge of important fish and wildlife resources but cannot show the absence of these resources.

In summary, management recommendations for Washington's priority habitats and species...

Are:	Are not:
Guidelines	Regulations
Generalized	Site specific
Updated with new information	Static
Based on fish and wildlife needs	Based on other land use objectives
To be used for all occurrences	To be used only for mapped occurrences

Goals

Management recommendations for Washington's priority habitats and species are guidelines based on the best available scientific information and are designed to meet the following goals:

- Maintain or enhance the structural attributes and ecological functions of habitat needed to support healthy populations of fish and wildlife.

- Maintain or enhance populations of priority species within their present and/or historical range in order to prevent future declines.

- Restore species that have experienced significant declines.

Format

Management recommendations for each priority habitat are written in six sections:

DEFINITION	Explains those parameters that make a habitat type a priority in terms of biota, extent, structure, and function
RATIONALE	Outlines the basis for designating the habitat as priority.
DISTRIBUTION	Summarizes information on the geographic extent of the habitat in Washington.
HABITAT DESCRIPTION	Delineates and characterizes plant communities and related abiotic factors, habitat structure and function, and topography; describes statewide habitat variation.
FISH AND WILDLIFE USE	Describes fish and wildlife use of the habitat; identifies factors that limit use of the habitat.
IMPACTS OF LAND USE	Identifies past and present land uses or practices that affect fish and wildlife use of the habitat.
MANAGEMENT RECOMMENDATIONS	Provides management guidelines based on a synthesis of the best available scientific information.

Management recommendations for Washington's priority habitats and species are intended to be used in conjunction with mapped and digital data which display important fish, wildlife, and habitat occurrences statewide. Data can be obtained by calling the PHS Data Request Line at (360) 902-2543. Questions and requests for additional PHS information may be directed to:

Priority Habitats and Species
WDFW Habitat Program
600 Capitol Way N
Olympia, WA 98501-1091

Riparian Management Recommendations

Riparian habitats associated with aquatic systems containing perennial or intermittent flowing water (e.g., rivers and streams) are addressed in this document. Riparian habitats associated with marine and standing water systems (ponds, lakes, and wetlands) have different characteristics and will be discussed in a separate document. Although many of its discussions are pertinent to instream (below the high-water line) conditions, this document addresses riparian habitat and does not focus on instream habitat.

This document is designed for landowners and managers. It consolidates existing scientific literature and provides information on the importance of riparian habitat to fish and wildlife and the relationship of riparian habitat to aquatic and upland ecosystems. From this information, land use recommendations designed to maintain or enhance fish and wildlife associated with riparian systems are developed.

Despite numerous efforts to develop riparian management strategies (e.g., Budd et al. 1987, Gregory and Ashkenas 1990, U.S. Bur. Land Manage. 1991, Reeves and Sedell 1992, Schaeffer and Brown 1992, U.S. For. Serv. et al. 1993, Cederholm 1994, Ecosystem Standards Advisory Committee 1994, U.S. For. Serv. and U.S. Bur. Land Manage. 1994, Spence et al. 1996), no single approach has yet gained widespread acceptance and application. Coordinated planning across land ownership and management boundaries would yield the best results for fish, wildlife, and riparian systems.

It is expected that these management recommendations will contribute to the scientific component of planning, protection, and restoration efforts for fish and wildlife. These efforts include the Growth Management Act; habitat conservation plans (e.g., the Department of Natural Resources Habitat Conservation Plan); the WDFW Hydraulic Code; the Puget Sound Action Plan; the Timber, Fish, and Wildlife Agreement; individual landowner farm and forest plans; and restoration projects conducted through the Jobs for the Environment Program, Regional Fisheries Enhancement Groups, State Conservation Commission, For the Sake of the Salmon, and other efforts. Habitat requirements for salmon recovery outlined in WDFW's Wild Salmonid Policy were derived, in part, from these management recommendations. These recommendations may provide a basis for WDFW participation in other planning processes that address riparian management strategies; however, WDFW will defer to negotiated agreements (e.g., the TFW Forestry Module) regarding riparian management that may result from our participation in those planning processes.

DEFINITION

While many definitions of riparian habitat are based on a few selected attributes (e.g., moist soils and plants that are adapted to wet conditions), WDFW utilizes a structural and functional definition that is more ecologically complete and better describes the needs of fish and wildlife.

A riparian habitat area (RHA) is defined as the area adjacent to aquatic systems with flowing water (e.g., rivers, perennial or intermittent streams, seeps, springs) that contains elements of both aquatic and terrestrial ecosystems which mutually influence each other.

Riparian habitat encompasses the area beginning at the ordinary high water line and extends to that portion of the terrestrial landscape that directly influences the aquatic ecosystem by providing shade, fine or large woody material, nutrients, organic and inorganic debris, terrestrial insects, or habitat for riparian-associated wildlife. It includes the entire extent of the floodplain because that area significantly influences and is influenced by the stream system during flood events. The riparian habitat area encompasses the entire extent of vegetation adapted to wet conditions as well as adjacent upland plant communities that directly influence the stream system.

Although many riparian areas have been severely altered from their natural state, they are considered riparian habitat in this document because they still exert influence on the aquatic system. That influence may be detrimental if the riparian area is heavily damaged. Riparian habitat exists in a wide variety of conditions ranging from severely damaged to pristine. Depending on its condition, each riparian area has a different ability to support fish and wildlife. Because of the critical nature of the influence riparian habitat has on aquatic habitat, all riparian areas are a significant management concern.

The terms riparian habitat, riparian area, riparian ecosystem, and riparian corridor are used interchangeably throughout this document, and all refer to the ecologically defined area adjacent to streams. Riparian vegetation refers specifically to plant communities that are adapted to wet conditions, are distinct from upland communities, and that occur immediately adjacent to aquatic systems. The terms riparian zone and riparian buffer refer to administrative or management areas associated with riparian habitat.

RATIONALE

Protection of riparian habitat, compared to other habitat types, may yield the greatest gains for fish and wildlife while involving the least amount of area. Riparian habitat:

- covers a relatively small area yet it supports a higher diversity and abundance of fish and wildlife than any other habitat;
- provides important fish and wildlife breeding habitat, seasonal ranges, and movement corridors;
- is highly vulnerable to alteration;
- has important social values, including water purification, flood control, recreation, and aesthetics.

High Fish and Wildlife Diversity

"Natural riparian corridors are the most diverse, dynamic, and complex biophysical habitats on the terrestrial portion of the earth" (Naiman et al. 1993:209). Wildlife occurs more often and in greater variety in riparian habitats than in any other habitat type. Although riparian areas constitute a small portion of the surface landscape, approximately 85% of Washington's wildlife species have been known to use riparian habitat associated with rivers and streams (Thomas et al. 1979, Brown 1985). In addition, habitat for many upland and aquatic species is directly enhanced by the presence of adjacent riparian habitat. Several species listed as State or Federal Endangered, Threatened, Sensitive, or Candidate, including the Snake River sockeye salmon, Snake River spring and fall chinook salmon, bald eagle, Dunn's salamander, northern goshawk, and fisher (scientific names of fish and wildlife species referenced in this document are found in Appendix A), are associated with or dependent on riparian habitats (Shuster 1980, Ehrlich et al. 1988, Knight 1988, Freel 1991, Nehlsen et al. 1991). Some sources listing species known to use riparian or associated aquatic habitats include: Thomas et al. (1979), Wydoski and Whitney (1979), Brown (1985), O'Connell et al. (1993), and Andelman and Stock (1994)

A principal reason for high fish and wildlife diversity is that riparian habitat is an exceptionally productive ecosystem. Riparian areas are characterized by available water, mild microclimate, and relatively fertile soils. These factors enhance the growth of plant communities and support a complex food web that includes a rich variety and abundance of plants, bacteria, fungi, invertebrates, fish, amphibians, reptiles, birds, and mammals (Cummins 1974, Johnson and Carothers 1982, Mitsch and Gosselink 1986).

Fish and Wildlife Habitat

Many terrestrial vertebrates are uniquely suited to riparian habitat conditions and appear to be dependent on them for at least one life requisite (O'Connell et al. 1993). They are generally either aquatic or semi-aquatic species that use riparian habitat in addition to aquatic areas for vital resources. Examples of these species are the Pacific giant salamander, red-legged frog, tailed frog, great blue heron, harlequin duck, belted kingfisher, American dipper, water vole, beaver, and river otter. In addition, other groups of wildlife find optimal conditions in riparian habitat and use it to meet at least some of their life requisites. For example, many neotropical migrant birds rely heavily on riparian habitat for breeding during spring and summer. Of the 118 species of neotropical migrants in Washington, 67 are supported by riparian habitat (Andelman and Stock 1994). The conservation of neotropical migrants in the western United States will depend very much on protection and restoration of riparian woodlands (Bock et al. 1993).

Because of its continuous form, intact riparian areas function as connectors and travel corridors for terrestrial wildlife (Forman and Godron 1986, Lee et al. 1987). They also assist in providing stream systems that allow successful fish migration (e.g., woody debris provides resting pools and stair steps up steep gradients). A number of species, such as marbled murrelet, elk, marten, some types of bats, beaver, and bald eagle, use riparian areas as travel corridors for seasonal migration, dispersal of young, or daily movements (Thomas et al. 1979, Stalmaster 1980, Allen 1983, Eisenhawer and Reimchen 1990, Bjornn and Reiser 1991, Freel 1991). In developed landscapes where direct connections between natural habitats are often broken, riparian areas provide invaluable habitat connectors, wildlife reserves, and temporary refuges (Beissinger and Osborne 1982, Lee et al. 1987). Many ecological issues related to land use and environmental quality, such as habitat fragmentation, could be addressed with effective riparian corridor management (Naiman et al. 1993).

Riparian areas influence the instream habitat of fish. Seventy-seven species of fish inhabit freshwater in Washington for all or a portion of their lives (Wydoski and Whitney 1979); these include native salmon, trout, char, sculpins, shiners, chubs and suckers, as well as introduced species such as smallmouth bass and walleye. Riparian areas provide these critical functions (Cummins 1974, Harmon et al. 1986, Beschta et al. 1987, Sullivan et al. 1987, Debano and Schmidt 1990, Meehan and Bjornn 1991, Swanston 1991):

- cooling water in summer and warming it in winter;
- purifying water;
- storing and conserving water;
- stabilizing stream channels;
- providing nutrient input to the aquatic system;
- providing downed woody debris which creates pools and riffles that offer deep, low velocity, protected waters for hiding cover, overwintering habitat, and juvenile rearing;
- facilitating successful migration.

Native salmonids have declined in number and diversity of genetic types in Washington (Wash. Dept. Fisheries et al. 1993). While loss of estuarine habitat, competition from hatchery fish, salmon harvest, and consequences of El Niño all have contributed to these reductions, degradation of the quality and quantity of freshwater habitat is one of the largest contributors (Nehlsen et al. 1991, U.S. For. Serv. et al. 1993).

Of the 435 wild salmon and steelhead stocks identified in the 1992 Washington State Salmon and Steelhead Stock Inventory (Wash. Dept. Fisheries et al. 1993), 43% were rated as healthy, 28% depressed, 3% critical, and 26% of unknown status. In an earlier effort to assess salmon status in Washington, the American Fisheries Society identified 214 stocks of anadromous salmon and trout in California, Idaho, Oregon, and Washington in need of special management considerations because of low or declining population numbers (Nehlsen et al. 1991). At least 38 native stocks of Washington salmon have become extinct (Nehlsen et al. 1991). In addition, the bull trout is a Federal Candidate for listing as Threatened or Endangered, and the Olympic mudminnow, margined sculpin, and pygmy whitefish are State Candidates for listing as Threatened, Endangered, or Sensitive.

Riparian Habitat Vulnerability

In addition to their importance as fish and wildlife habitat, riparian areas provide other resources such as timber, livestock forage, road locations, sources of sand and gravel, farming, recreation, and building sites. Although comprehensive inventories of riparian habitat are lacking, it has been estimated that 70-90% of the nation's original riparian areas have been subjected to extensive alteration (Hirsch and Segelquist 1979, Lee et al. 1987, Kauffman 1988). A 1982 nationwide rivers inventory examined 5.23 million km (3.25 million mi) of streams in the lower 48 states and found that only 2% were considered "high natural quality" (Benke 1990). These trends hold true for Washington as well. Canning and Stevens (1989) reported that there were approximately 404,700 ha (1,000,000 ac) of designated wetlands and riparian areas in Washington; this represents an estimated 50-67% of the pre-settlement acreage. In the biologically productive lowlands, about 70% of wetland and riparian areas have been converted to other uses. Many heavily urbanized areas have experienced 100% loss or severe alteration of wetland and riparian areas (Canning and Stevens 1989). Along the Columbia River, over 90% of the original riparian habitat has been lost through inundation by dams or conversion to agriculture (U.S. Fish and Wildl. Serv. 1979). Canning and Stevens (1989) also estimate an annual loss of wetland and riparian area in Washington to be 823 ha (2,034 ac) per year.

This loss of riparian habitat has resulted in degradation of instream habitat. For example, the U.S. Forest Service (1993a:2) concluded a "loss of vegetative structure, in particular large trees, has led to a simplification of some ecosystems. As an example, many streams now exhibit fewer pools for fish habitat. One of the reasons most often associated with a reduction of pools is loss of in-channel structure such as large wood. There is also a general increase in intermediate tributary stream temperatures from the past. Increased temperatures are typically associated with loss of riparian shade or channel widening."

Clean Water and Flood Control

Riparian areas are important to people because they help provide clean water. Much of our drinking water either flows or percolates through riparian areas (Freeze and Cherry 1979). Intact riparian vegetation and soils filter and biodegrade 40-99% of the organic debris and environmental pollutants carried in surface flows before they can reach main stream channels (Lowrance et al. 1984, Rhodes et al. 1985).

Riparian areas provide an area for flood waters to spill over banks, spread out, lose velocity and energy, deposit silt, and percolate into the soil (Swanson et al. 1982, Debano and Schmidt 1989, Gregory et al. 1991, Naiman et al. 1992). This lessens flooding episodes downstream. Riparian areas also retard bank cutting and erosion of the stream channel and a subsequent loss of fish habitat. Together, riparian areas and floodplains accommodate natural flooding, help reduce the severity of floods, and prevent flood damage (Griggs 1984, Roseboom and Russell 1985, Booth 1991).

Riparian vegetation, litter layer, and silty soils absorb and store water during wet periods. This water is then returned to the stream system gradually during the dry season. Stored water in riparian areas typically maintains stream flows for three to four months in rainless periods (Griggs 1984, Szaro and Debano 1985, Debano and Schmidt 1990). Allen et al. (1992) estimated that each acre of functional riparian habitat provides an annual $18,000 in services toward flood protection, groundwater recharge, and water purification.

Recreation

Riparian and wetland areas support hunting and fishing recreation that contribute over one billion dollars annually to Washington’s economy (U.S. Fish and Wildl. Serv. 1992a). A single mature chinook salmon had a value of approximately $290 (Theurer et al. 1985). Similarly, Theurer et al. (1985) estimated that if riparian vegetation in the Tucannon River was restored to recover the river’s thermal regime, the recreational value of all the salmon in the restored river would be $6.9 million. Recreational activities that derive much of their benefit from functional riparian habitat include fishing, hiking, bird watching, picnicking and camping, hunting, scenic viewing, boating, and tourism.

Intrinsic Value

Riparian areas have intrinsic value. Although the aesthetic qualities of riparian habitat are difficult to quantify, most people value the knowledge that natural areas still exist and are protected, even though they may not use the resource directly (O’Toole 1978). In developed settings, preserved or restored riparian areas enhance liveability and add to the quality of life of residents and visitors (King County Planning Division 1980, Carleton and Taylor 1983, Field et al. 1985). Other riparian habitat values that are assumed but for which quantitative data are sparse include air quality improvement, climate regulation, noise abatement, visual screening from adjacent and surrounding development, and educational and scientific opportunities.

DISTRIBUTION

Rivers, streams, and their associated riparian habitat are distributed in a dendritic pattern forming a continuous network linking high mountain slopes to lowland and coastal areas. Although riparian habitat occurs statewide, it covers a relatively small area; however, this has not been precisely measured. Riparian ecosystems were estimated to cover 10% of non-federal forest lands in Washington State (Wash. Dept. Ecol. 1985). Estimates of the proportion of riparian habitat in other parts of the country range from 0.1% to 12% across various landscapes (Ohmart and Anderson 1986, Elmore and Beschta 1987, Lee et al. 1987, Gregory and Ashkenas 1990, U.S. For. Serv. 1993b). Some of these estimates, however, are based on riparian vegetation as opposed to riparian habitat. According to WDFW's definition, riparian habitat would encompass more than these estimates of riparian vegetation.

HABITAT DESCRIPTION

In riparian habitat the vegetation, water table, soils, microclimate, and wildlife inhabitants are influenced by perennial or intermittent water. In turn, the biological and physical properties of the aquatic ecosystem are influenced by the adjacent vegetation, influx of nutrients and sediments, terrestrial wildlife, and organic debris from the riparian area (Meehan et al. 1977, Swanson et al. 1982, Gregory and Ashkenas 1990). Riparian habitat contains plant and soil systems with attributes of both wetland and upland areas and provides the transition between forest and stream, hillside and valley, and terrestrial and aquatic ecosystems (Everett et al. 1994).

The nature of the influences that the aquatic and terrestrial ecosystems exert on each other is complex and will be discussed in further detail in following sections. As a result of its relationship with aquatic systems, intact riparian habitat generally exhibits (Bottorff 1974, Meehan et al. 1977, Lee et al. 1987, Bilby 1988, Finch 1989):

- an oblong or curvilinear shape with a high edge-to-area ratio; this edge forms important ecotones (border regions) with both aquatic and upland habitats;
- a moist and mild microclimate (warmer in winter, cooler in summer) relative to adjacent uplands;
- signs of frequent disturbance (evidence of flooding, tree breakage, numerous snags and downed logs, canopy gaps, patches of early-successional vegetation);
- a mixture of coniferous and deciduous trees;
- generally higher productivity than surrounding areas;

- a high degree of structural diversity (multiple canopy layers, a well-developed shrub layer, and variability in tree age, shape, and species);
- high density and diversity of wildlife and plant species;
- unique soils having a heterogeneous mineral character derived from stream deposits, and more exposed soils;
- variable organic matter (litter) distribution--it is sparse in areas of high energy flooding where organic matter gets flushed downstream, and it is very abundant in receiving areas where it accumulates;
- soils with high organic matter content due to elevated moisture and accelerated decomposition of vegetation.

Riparian habitat is a product of both aggradation and degradation processes that continually operate throughout a watershed (a watershed is defined as the drainage basin that contributes water, organic matter, dissolved nutrients and sediments to a common watercourse). Natural disturbances remove resources (e.g., logs, boulders, nutrients) from one area and relocate them to other areas.

The riparian area is one of the most dynamic areas of the landscape (Gregory et al. 1991). This dynamic nature is related to variable flood regimes, geomorphic channel processes, altitudinal climate shifts, and upland influences on the river corridor (Naiman et al. 1993). These processes result in a high degree of structural and compositional diversity over space and time. Fish and wildlife have evolved to take advantage of the diversity of resources provided by these disturbances. The rate and magnitude of natural disturbances is generally lower than that of human-induced disturbances. See Swanston (1991) for a summary of expected natural disturbance recurrence frequencies that affect fish habitat.

Riparian habitat is not easily delineated, but is comprised of mosaics of land forms, plant communities, and environments that vary in width and shape within the larger landscape (Gregory et al. 1991). Riparian areas do not stop at an arbitrary, uniform distance away from the stream. These concepts are illustrated in Figures 1, 2, and 3.

The Influence of Stream Size

The characteristics of riparian habitat and its interaction with the aquatic habitat area are largely related to stream size (Bilby 1988); however, stream gradients, channel dynamics, hydrologic regimes, and local geomorphology also play a role (Wash. Dept. Ecol. 1985, Gregory and Ashkenas 1990, Naiman et al. 1992). Generally, riparian habitat associated with small streams is narrower and less distinct than that associated with large streams or rivers. The influence exerted by the riparian area on the aquatic system is greater in smaller streams than larger ones. Conversely, the influence of the aquatic area on the riparian area is less in smaller streams. An illustration of characteristics of riparian habitat as stream size changes is shown in Figure 4.

Riparian areas adjacent to small, headwater streams in mountainous terrain are often constrained by steep side slopes that restrict the extent of typical riparian vegetation. Where side slopes are not as steep, the small amount of water carried in small streams results in a relatively narrow band of moist soil (Bilby 1988). Riparian vegetation composed of plants associated with wet conditions is then limited to that narrow band of moist soil. Large organic and inorganic debris (e.g., large logs, root wads, or boulders) are rarely transported in small streams. Obstructions imposed by this debris greatly influence the stream channel shape and control the deposition of sediments (Sullivan et al. 1987, Bilby 1988). These structures provide habitat diversity and maintain water quality, and thus significantly affect fish and wildlife use. Riparian vegetation adjacent to small streams can potentially shade the entire stream, thereby producing stable, cool temperatures year-round (Bilby 1988). Fully-shaded small streams acquire most of their energy from organic matter (plant and animal) falling into the stream from the riparian area. This influences the biotic community that can be supported in small streams (Cummins 1974, 1975).

As the size of the stream increases, the influence of the aquatic system on the riparian area increases because of a larger volume of water present (Bilby 1988). Conversely, the influence of riparian habitat on the aquatic area decreases as stream size increases. Along mid-sized to large streams, the riparian area is wider than along small streams and is generally more distinct than the surrounding vegetation. The area adjacent to large streams is often characterized by well-developed and complex floodplains, long periods of seasonal flooding, lateral channel migration, meanders, oxbow lakes and wetlands in old river channels, a diverse vegetative community, and a large area with moist soils (Wash. Dept. Ecol. 1985, Gregory and Ashkenas 1990, Naiman et al. 1992). These factors give rise to a wide and distinct area of riparian habitat.

Riparian areas associated with wide, low gradient rivers or streams are often composed of a greater proportion of deciduous vegetation. Because large woody debris is more mobile in large streams, its effect on channel structure and function is less than in small streams (Bilby 1988, Bilby and Ward 1989). As stream width increases, the amount of the water surface that is shaded by riparian vegetation decreases. Therefore, the influence of streamside vegetation on water temperature of large streams is less than in smaller streams. Stream temperature in large rivers is more dependent on water coming from upstream reaches (Oregon-Washington Interagency Wildlife Committee 1979, Bryant 1984, Beschta et al. 1987). When a stream becomes too wide to be completely shaded, the energy source shifts from terrestrial inputs to the in-stream production of organic matter through the growth of algae and other aquatic plants (Bilby 1988). The invertebrate and vertebrate communities change in response to this different source of energy (Cummins 1975).

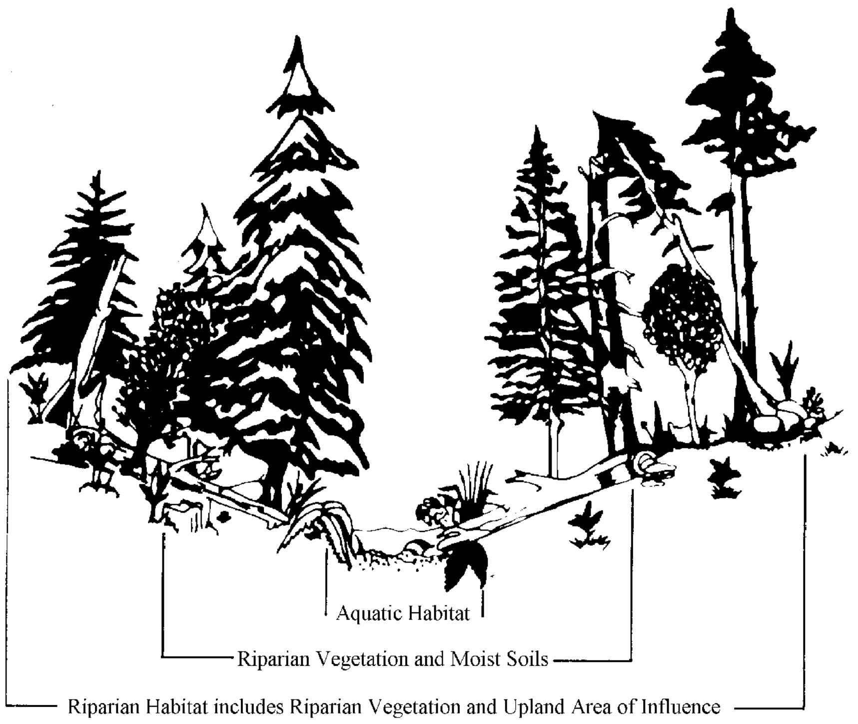

Figure 1. Riparian habitat in a forested landscape (adapted from Reeves et al. 1991).

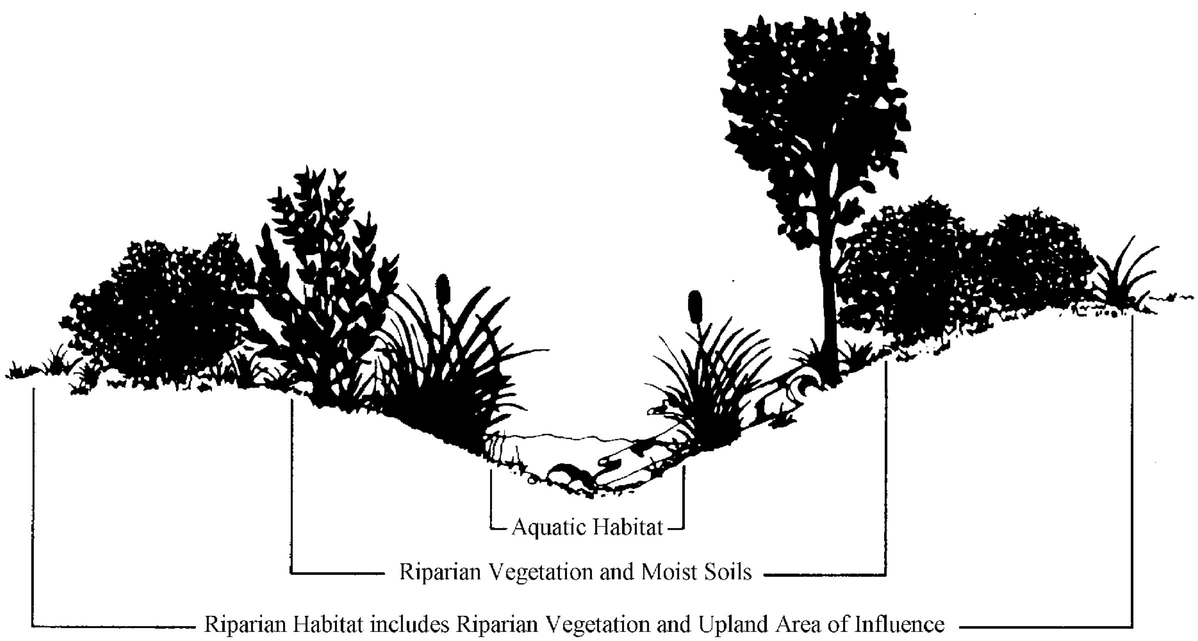

Figure 2. Riparian habitat in arid, steppe, or open landscapes (adapted from Thomas 1979).

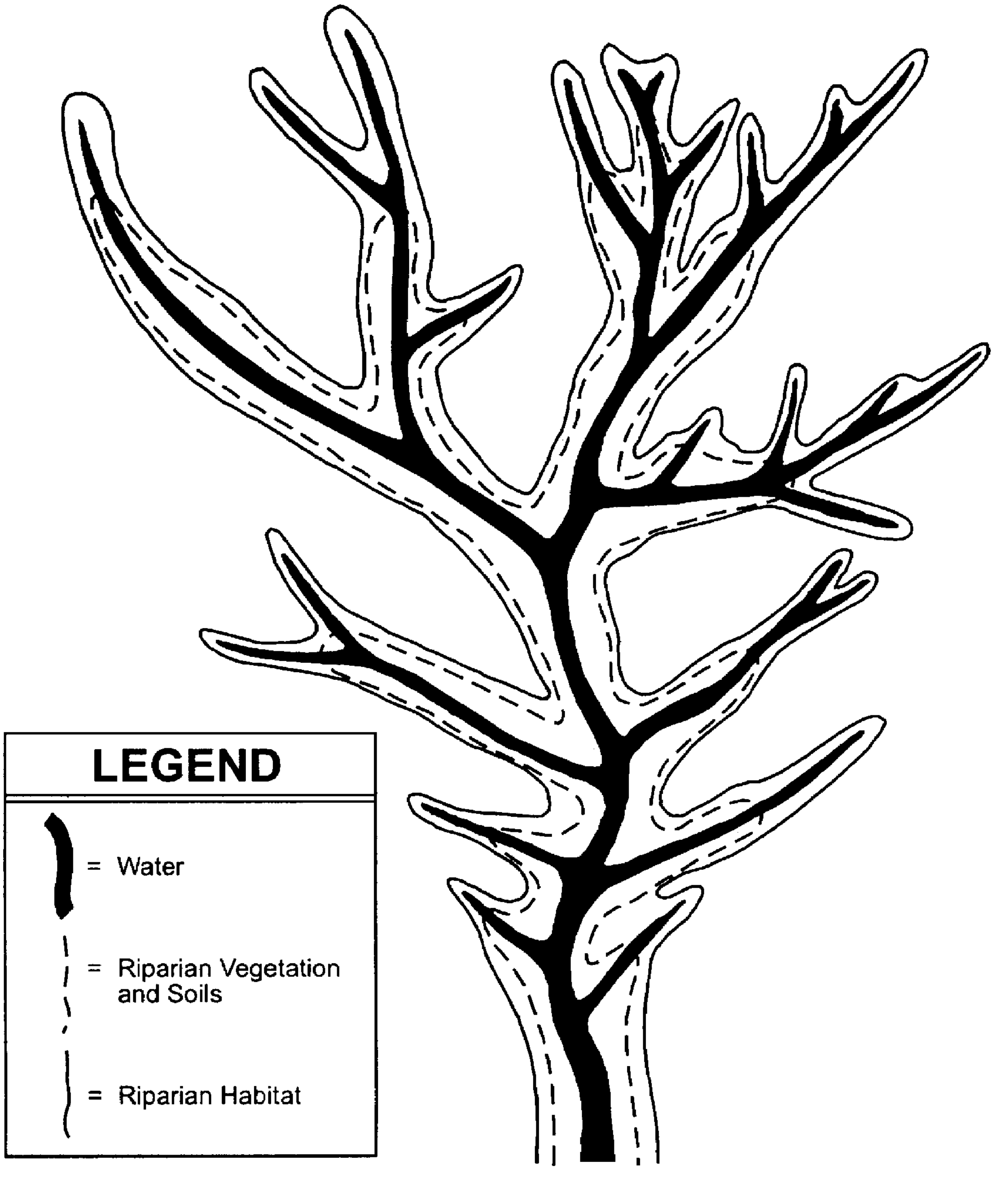

Figure 3. Overhead view of a watershed and its associated riparian network (adapted from Thomas, 1979). Note the characteristic curvilinear shape, high edge-to-interior ratio, and potential as a wildlife travel corridor. Headwater areas often do not have any characteristic riparian vegetation but have a functional riparian habitat. Also of importance are the frequent “nodes” where smaller streams join larger streams; these are areas of increased riparian extent and intensified fish and wildlife use (Forman and Godron 1986).

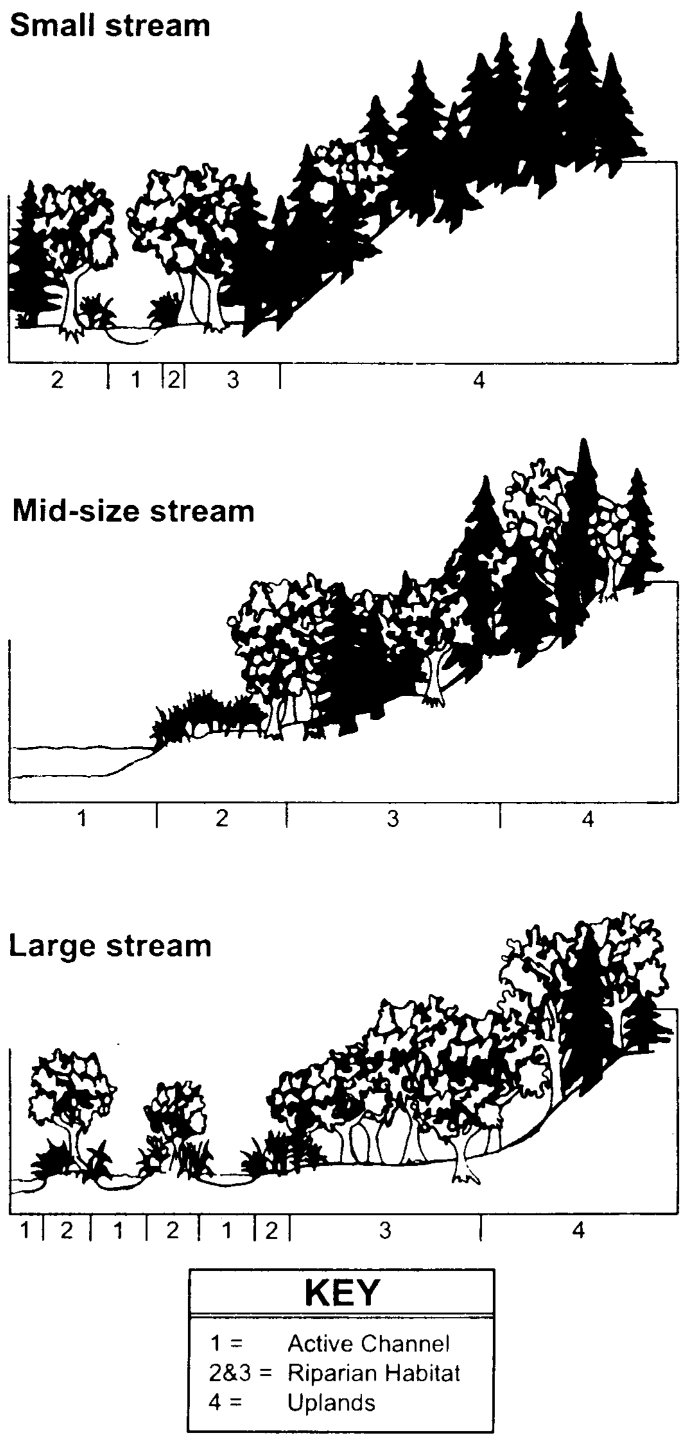

Figure 4.
Natural characteristics of riparian habitat relative to stream size. In small and mid-sized streams, the links between the riparian forest and the stream are strong. In large rivers, the links are not as strong in the main channel but they do remain strong in the secondary channels (modified from Naiman et al. 1992).

Small, non-fish bearing streams significantly influence fish habitat because they carry water, sediment, nutrients, and woody debris downstream (Chamberlin et al. 1991). Because small streams are more intimately related to their riparian area (e.g., litter fall, woody debris), the removal of riparian vegetation may have a relatively great effect. Conversely, due to the lesser influence of riparian habitat on large streams, the removal of riparian vegetation along large streams has less effect on the stream structure and function. Larger rivers are more profoundly affected by dams, water diversions, agricultural practices, and pollution from urban lands (Sullivan et al. 1987, Bilby 1988).

Types of Riparian Habitat

There are two basic types of riparian habitats: those in forested or previously forested settings, and those in arid, non-forested settings (Figs. 2 and 3). In forested areas, the vegetation of riparian areas is often younger and lower in profile than surrounding upland forest (except in logged or disturbed landscapes, or in steep canyons where riparian trees may be spared from wildfire). In arid, non-forested settings, the riparian vegetation is usually strikingly prominent, being taller and/or greener than the surrounding landscape (Hirsch and Segelquist 1979, Kauffman 1988).

Riparian areas are highly variable in size, shape, and vegetative character (Fonda 1974, Swanson et al. 1982, Carlson et al. 1990). However, certain vegetative communities are commonly associated with riparian areas in three distinct regions of Washington: forested areas in western Washington, forested areas in eastern Washington, and the non-forested shrub-steppe region of eastern Washington.

Forested Riparian Areas, Western Washington

Riparian habitats in western Washington forests are associated with wet environmental conditions. They are composed of vegetation in various stages of development depending on the time since the last disturbance. Riparian plant communities vary depending on the upland plant communities, stream gradient, elevation, soil, aspect, topography, and water quality and quantity (Oakley et al. 1985). General characteristics of forested riparian habitat in western Washington are described below.

- Trees are usually but not always present.
- Tree species are a mixture of coniferous and deciduous trees; deciduous trees are relatively more abundant where disturbance (by annual flooding, bank erosion, or human activities) is frequent (Fonda 1974, Swanson et al. 1982, Agee 1988).

- Conifer trees that tolerate shady and periodically saturated conditions include western hemlock, western red cedar, and Sitka spruce (Fonda 1974, Taber 1976, Topik et al. 1986, Henderson et al. 1989).

- Red alder is an ubiquitous associate in young stands or where there are gaps in the canopy (Franklin and Dyrness 1988).

- Small streams often have narrow zones of riparian vegetation and are commonly dominated by conifers; after 30-60 years of post-disturbance succession, such streams may be primarily shaded and influenced by upland tree species such as Douglas-fir and bigleaf maple (Swanson et al. 1982).

- Sites with frequent flooding and/or gravelly soils, such as river bars, support mainly black cottonwood, willow, and red alder. Lowland forested swamps are characterized by black cottonwood, red alder, and vine maple, with occasional cascara, willow, western red cedar, Sitka spruce, and western hemlock (Fonda 1974, Topik et al. 1986).
- Snags are abundant (Small 1982).

- Multiple canopy layers are the rule, with middle layers often consisting of small trees and shrubs such as vine maple, willow, red-osier dogwood, oceanspray, Pacific ninebark, western serviceberry, snowberry, hawthorne, red alder, devil's club, salmonberry, and red elderberry. The herb layer is equally diverse and includes hydrophytes (e.g., skunk cabbage, coltsfoot, lady-fern, sedges, and water-parsley) and species which also occur on drier sites (Oakley et al. 1985).

In many cases, riparian corridors in agricultural and urbanized settings within previously forested environments are highly altered. Typically, they appear as narrow strips of shrubs and deciduous trees in non-forested landscapes. Many natural streams have been channelized into drainage or irrigation ditches (Hirsch and Segelquist 1979). Where trees have been removed, banks and channels are often choked with reed canarygrass, an aggressive exotic plant that reduces plant and wildlife diversity and blocks streams, which can impede fish passage (Taber 1976).

Forested Riparian Habitats, Eastern Washington

Riparian habitats in forested areas of eastern Washington are typically found in deeply incised ravines in mountainous terrain (Carlson et al. 1990). At lower elevations the moist soils and temperate microclimate characteristic of these sites support communities of cedar, western hemlock, big leaf maple, quaking aspen, water birch, and other deciduous trees. A variety of shrubs and herbs occur in the understory and includes willow, Oregon boxwood, red-osier dogwood, mountain alder, ninebark, ocean spray, tall Oregon grape, serviceberry, devil's club, thimbleberry, trillium, queencup beadlilly, and ladyfern (Tabor 1976, Franklin and Dyrness 1988). Large diameter snags and downed woody debris are abundant in unmanaged areas.

At drier sites characterized by ponderosa pine in the uplands, trees of the riparian zone include Douglas-fir, paper birch, black cottonwood, and quaking aspen. Oregon white oak occurs in riparian areas at the northern periphery of its range in western and southcentral Washington (Taber 1976). Where it occurs, its value to wildlife is extremely high (Wash. Dept. Wildl. 1994). Shrubs include common snowberry, spirea, bearberry, and Oregon boxwood; pinegrass is an ubiquitous herb.

High elevation (especially alpine) riparian sites are distinguished more by understory species and saturated soils than by tree species. Where trees exist, sites are dominated by subalpine fir or Engelmann spruce (Williams and Lillybridge 1983, Kauffman 1988). Trees in older stands support mosses and lichens, an important food source for deer and woodland caribou (Hanley et al. 1984). Woody debris is abundant on the forest floor due to slow decomposition in this cold environment. The shrub and herb layer is stunted but floristically rich and includes giant horsetail, bunchberry dogwood, Sitka alder, prickly currant, and twinflower. A more complete description of plant associations in eastern Washington forested riparian areas is given by Kovalchik (1992).

Shrub-Steppe Region, Eastern Washington

The native riparian vegetation in the shrub-steppe region of the Columbia Basin is characterized by a mosaic of shrubby thickets with patches of deciduous trees and grass/forb-dominated plant communities. However, conifer trees, including ponderosa pine and Douglas-fir, are widely scattered in eastern Washington riparian areas and were likely more common historically than at present. They are currently restricted to canyons or valleys with steep rocky walls along mid- to high-gradient streams where they are inaccessible to harvest and where microclimates are conducive to supporting trees (Evans 1989). A diversity of shrub and deciduous tree species occurred historically and still occur in some places, and they include snowberry, wild rose, black hawthorn, hackberry, parsnip, common chokecherry, bittercherry, mock orange, red osier dogwood, water birch, willow, black cottonwood, and quaking aspen. Succulent herbs of the ground layer include sticky geranium, northern bedstraw, fescue, waterleaf, and bracken fern. Evans (1989) provides a complete description of plant communities occurring in riparian areas of the Columbia Plateau.

Shrub thickets are exceedingly rich in wildlife species and numbers (Mudd 1975, Tabor 1976, Johnson and Carothers 1982, Kauffman 1988) and historically consisted of a diverse mixture of plant communities along the smaller streams and rivers in the Columbia Basin (Evans 1989). They tend to a have a naturally disjunct distribution, occurring in patches of various sizes at irregular intervals along streams, interspersed with grass and forb-based riparian communities.

Examples of such undisturbed systems are now rare due to the impacts of grazing and cultivation (Franklin and Dyrness 1988; Evans 1989; T. Thompson, pers. comm.).

In many eastern Washington riparian areas, the regeneration of palatable shrubs and trees such as black hawthorn, chokecherry, black cottonwood, and associated herbage has been suppressed by decades of unmanaged overgrazing. Overgrazing has also caused the replacement of native plants with more grazing-resistant non-native plant communities of bluegrass and exotic weeds such as thistle, teasel, dandelion, and reed canarygrass. Remnant cottonwoods and other deciduous trees are occasionally found, but these are usually mature trees tall enough to be out of reach of browsing livestock. Tree seedlings and saplings are notably absent in many of these riparian areas (Franklin and Dyrness 1988).

Small, intermittent streams and draws may naturally have little or no characteristic riparian vegetation. Instead, they consist of largely upland plant species, including big sagebrush, bitterbrush, rabbitbrush, and spiny hopsage. The presence of woody and herbaceous vegetation assists in moderating stream temperature, sedimentation, water quality and quantity, and debris flows downstream.

FISH AND WILDLIFE USE

The riparian ecosystem is a bridge between upland habitats and the aquatic environment. The combination of shape, moisture, depositional soils, and disturbance regime unique to riparian areas contributes to their exceptional productivity in terms of plant growth, plant diversity, and structural complexity of the vegetation (Johnson and Carothers 1982, Mitsch and Gosselink 1986, Lee et al. 1987). Animals, in turn, have evolved to exploit directly or indirectly the rich vegetative habitat provided by riparian areas. Riparian areas provide more niches than any other habitat type (Oakley et al. 1985).

The ability of riparian areas to attract and support fish and wildlife is dependent on the structural and functional integrity of three interrelated ecosystems: aquatic, riparian, and upland (Bilby 1988, McGarigal and McComb 1992). Features and functions of riparian habitat that are of primary importance to fish and wildlife are discussed below.

Riparian Contributions to Fish Habitat

Fish, and salmonids in particular, have evolved life history strategies that depend on natural conditions found in Pacific Northwest streams. Behaviors related to breeding, feeding, resting, and avoidance of predation have developed to work with natural stream flow conditions, rates of erosion and sedimentation, and inputs of organic materials including food sources and woody debris. For example, salmonids have evolved with the natural spatial and temporal variation in stream velocity and depth. Salmonid behaviors involving reproduction and migration have adapted, in part, to time those flow-dependent behaviors with adequate flows (Sullivan et al. 1987). When the rate and magnitude of various stream functions change substantially from natural levels, including changes resulting from human activities, fish populations may be reduced, species composition will likely change, and fish habitat quality and quantity will decline (Sullivan et al. 1987).

Fish have specialized and unique habitat requirements that are met in part by healthy, functioning riparian habitat. For salmon and trout, these requirements include:

- adequate but not excessive stream flows;
- cool, well-oxygenated, unpolluted water;
- streambed gravels that are relatively free of fine sediments;
- an adequate food supply;
- instream structural diversity (interposed pools, riffles, hiding and resting cover).

These habitat attributes are inter-dependent. For example, adequate stream flows must be present in order for fish to access and use pools and hiding cover provided by root wads and large organic debris positioned at the periphery of the stream channel (Wesch 1980, Bisson et al. 1987). Stream flow is influenced by microclimate, soil hydration, and the level of water in subsurface aquifers; these factors are in turn influenced by riparian and upland vegetation. Vegetation and the humus layer intercept rainfall and surface flows. This moisture is later released in the form of humidity and gradual, metered outflow through subsurface aquifers. Through this process, stream flows are maintained during periods of drought (Geiger 1965, Budd et al. 1987, Debano and Schmidt 1990, Chamberlin et al. 1991).

Because of the interconnected nature of stream systems, the habitat quality of most streams is important to fish production. Even small headwater streams (DNR Water Types 4 and 5) that have no fish influence the habitat quality downstream in fish-bearing waters. For example, small streams recruit large organic debris that may later be transported to fish habitats (Bisson et al. 1987). Small streams can also provide storage and the slow release of sediments, thereby regulating the flow of sediments downstream (Sullivan et al. 1987, Benda 1988). Many damaging landslides begin in small headwater streams as a result of logging roads, timber harvest, or other activities in the upper watershed. Retaining intact riparian habitat along small headwater streams is essential to protecting downstream fish habitat, particularly in areas with unstable soils (Cederholm 1994).

Influence on Stream Flow

Stream flow is moderated by riparian vegetation as well as vegetative cover in the uplands. Riparian areas, in particular, assist in regulating stream flow by intercepting rainfall, contributing to water infiltration, and using water via evapotranspiration (Swanston 1991). Plant roots increase soil porosity, and vegetation helps to trap water flowing on the surface, thereby aiding infiltration. Water stored in the soil is later released to streams through subsurface flows. Through these processes, riparian and upland vegetation help to moderate storm-related flows and reduce the magnitude of peak flows and the frequency of flooding (Debano and Schmidt 1989). When flooding does occur, the floodplain restricts the area affected by flood waters. A mixing of nutrients between the aquatic and riparian areas occurs and contributes nutrients and organic materials to both habitats (Junk et al. 1989).

Influences on Water Temperature and Dissolved Oxygen

Stream temperature is moderated by the shade of adjacent vegetation, especially trees (Geiger 1965, Beschta et al. 1987). In well-forested watersheds, mid-day summer water temperatures rise only 1-2 C (1-1.8° F) above year-round averages (Moring 1975, Beschta et al. 1987). Conversely, unbuffered streams in clear-cut watersheds may experience temperature increases of 7-16 C (10-27° F), approaching temperatures that are lethal to salmon and other cold-water fish (Moring 1975, Wash. Dept. Ecol. 1985, Beschta et al. 1987, Budd et al. 1987).

In order to maintain water temperature control, stream surfaces should have 60-80% shade throughout the day (Oregon-Washington Interagency Wildlife Committee 1979, Budd et al. 1987). Shading from side banks exerts less influence on very broad streams and rivers [those greater than 15 m (50 ft) wide]. Fish habitat in these systems depends on the temperature and quantity of water feeding into them and on the availability of cool, shaded pools and backwaters along the main stem (Oregon-Washington Interagency Wildlife Committee 1979, Bryant 1984, Beschta et al. 1987). Water entering fish-bearing streams from small tributaries, rivulets, and seeps is cooled by passing through shaded soils and forest litter.

Cool, well-oxygenated water is required by salmon, trout, other cold-water fish, and many aquatic invertebrates, with preferred temperature range of 5.5-14.4 C (40-58° F), and dissolved oxygen levels of greater than 5 parts per million (Oreg. Dept. Fish and Wildl. 1977; Bell 1973, 1986; Everest and Harr 1982). As stream temperatures rise, their dissolved oxygen content is reduced. Water temperatures of approximately 23-25 C (73-77° F) are lethal to salmon and steelhead (Theurer et al. 1985), and genetic abnormalities or mortality of salmonid eggs occurs above 11 C (51.8° F).

Temperature increases and consequent reductions in available oxygen tend to have deleterious effects on fish and other organisms by:

- inhibiting their growth and disrupting their metabolism;
- amplifying the effects of toxic substances;
- increasing susceptibility to diseases and pathogens;
- encouraging an overgrowth of bacteria and algae which further consume available oxygen, a condition referred to as “eutrophication” (Theurer et al. 1985, Terrell and Perfetti 1989).

Theurer et al. (1985) found that the change in temperature regime caused solely by the loss of riparian vegetation explained the reduction in salmonid populations in the Tucannon River in eastern Washington.

Riparian vegetation also prevents rapid and excessive cooling of the stream during winter. When stream edges and tributaries freeze too rapidly or too extensively, a condition called "anchor ice" may develop, wherein ice forms under the water surface or on submerged structures such as gravel and soil. The ice then mechanically heaves gravel and soil out of their places during the subsequent thaw, which can result in significant erosion of stream banks and inputs of sediment (Swanston 1991). Snow and ice in streams is a major cause of winter fish mortality. Furthermore, freezing water reduces or eliminates the flow of oxygen over incubating fish eggs, thereby increasing mortality. Intact riparian vegetation aids in the formation and maintenance of narrow, deep channels that are less susceptible to ice formation, thus providing better winter conditions for fish. In addition, riparian vegetation contributes to the formation of pools and beaver ponds that are important habitat components for wintering trout in mountain streams (Chisholm et al. 1987).

The Regional Ecosystem Assessment Project (U.S. For. Serv. 1993a) evaluated historical and current stream temperatures and found that current temperatures were generally either at or above historical maximum temperatures. This increase in stream temperature was attributed to removal of shade-producing riparian vegetation along both small and large streams.

Control of Stream Sedimentation

In undisturbed watersheds, the frequency and volume of sediment input to streams is less than in disturbed (i.e., developed or intensively managed for resource extraction) watersheds, except during the relatively rare events of catastrophic natural disturbance such as fire, large-scale landslides, or severe flooding (Bilby 1984, Lowrance et al. 1984, Everest et al. 1987). Accordingly, native fish stocks evolved in an environment with very high water quality, and they are acutely sensitive to changes in water purity and clarity (Everest et al. 1987, Hicks et al. 1991b).

When erosion and subsequent stream sedimentation exceeds natural rates, particularly with fine sediments that are 0.85 mm (0.033 in) and smaller, fish and other aquatic life may be negatively impacted by (Oregon-Washington Interagency Wildlife Committee 1979, Theurer et al. 1985, Cederholm and Reid 1987, Chapman and McLeod 1987, Everest et al. 1987, Sullivan et al. 1987, Bjornn and Reiser 1991, Ecosystem Standards Advisory Committee 1994):

- rearing pools and spawning gravels filled with sediment;
- decreased or eliminated oxygen flow through the gravel, which suffocates fish eggs and developing fry;

- elimination of hiding and resting places for juvenile fish and aquatic insects;
- decreased available space for attachment of algae, which reduces food sources;
- suppressed macroinvertebrate food sources;
- decreased bed roughness which increases flow velocities so that aquatic insects and young fish cannot maintain positions;
- clogged or abraded gills of fish;
- inhibited feeding and growth;
- ceased or delayed migration;
- avoidance of some waters by salmonids;
- widened and de-watered stream channels resulting from the deposition of porous materials into the streambed through which water percolates and becomes subsurface rather than surface flow.

Peterson et al. (1992) reported that in unmanaged forests an average of 11% of spawning gravel sediments consisted of particle sizes 0.85 mm (0.033 in) or smaller. They recommended using 11% as a sediment standard because abundant and diverse communities of fish and aquatic organisms have generally evolved under those conditions as indicated by current data. This standard is used in Watershed Analysis (Washington Department of Natural Resources) and in Ecosystem Standards developed under House Bill 1309 (Ecosystem Standards Advisory Committee 1994) as an indication of streams with healthy spawning habitat conditions. When the proportion of fine sediments is above 15% in spawning areas, the stream is considered at risk.

Riparian vegetation inhibits sediment from entering streams by dissipating the energy of water, thereby suppressing the erosional processes that move sediment. The roots, stems, and downed debris of riparian and upland vegetation hold soils and banks in place, preventing gullying and mass earth failures (Oregon-Washington Interagency Wildlife Committee 1979, Thomas et al. 1993). Riparian vegetation mechanically filters and stores sediments borne in surface flows before they can enter the stream channel. Riparian areas have been described as a depositional environment in an otherwise eroding landscape (Brinson 1988). Riparian leaf litter and humus intercept muddied waters flowing toward streams. The water soaks into the substrate where it collects and eventually rejoins the stream through subsurface routes that often parallel root systems. Fine silt is caught and held along the immense surface area of fallen leaves and other litter (Boggs 1984, Lowrance et al. 1985, Swanston 1991). Coarser materials are held by fallen logs and standing vegetation (Wilford 1982).

Heavy rains, floods, fire, tree uprooting, and other destabilizing events cause sediment to enter streams on a regular basis even in unaltered watersheds (Hecht 1984, Swanston 1991). But in unaltered riparian areas, sediment entering the stream channel is soon sequestered and stored behind large instream logs and in naturally occurring catchment areas (Sullivan et al. 1987). Consequently, most sediment is trapped in local stream reaches and does not have an opportunity to further scour stream channels or impact downstream habitats (Bilby 1984, Andrus et al. 1988).

Riparian areas associated with all sizes of streams are important in regulating the amount of sediment that enters aquatic habitats. Intact riparian vegetation along small streams is particularly important because many soil-destabilizing events occur in small streams high in watersheds surrounded by steep slopes (S. Jackson, pers. comm.). The cumulative effect of uncontrolled sediment entry from many small streams can significantly impact larger reaches downstream. Because large organic and inorganic debris readily accumulates in small streams, their ability to control the transportation of sediments is great (Sullivan et al. 1987, Bilby 1988). This also helps to regulate the flow of sediments downstream.

Control of Stream Pollution

Major potential stream pollutants include nutrients such as nitrates and phosphates, as well as compounds such as insecticides, herbicides, and industrial chemicals (Lowrance et al. 1984, 1985). Unaltered riparian areas seem uniquely suited to detoxifying significant amounts of chemicals and animal waste (Whigham et al. 1988). The pathway by which most nitrogenous wastes are degraded prior to entering streams is denitrification by soil bacteria. Remaining nitrogen is taken up by riparian vegetation. In healthy riparian systems, virtually all incoming nitrogenous waste is intercepted and converted to gaseous form or plant biomass (Lowrance et al. 1984). Phosphates and heavy metals tend to be trapped and stored along with fine sediments in the humus layer (Hemond and Benoit 1988, Whigham et al. 1988).

The fate of pesticides and other chemicals in riparian systems varies, as described by Lowrance et al. (1985). Soluble, non-ionic substances such as picloram and aldicarb are dissolved in run-off and subsurface leachates and move readily through riparian systems. However, in unaltered systems the paths for surface and subsurface run-off are typically so long that pollutants are substantially degraded before entering the stream. On the other hand, heavy, slowly degrading substances such as paraquat and chlordane are deposited along with fine sediments in the leaf litter and herb layer of riparian plant communities. Here they are slowly degraded or taken up into the tissues of plants. Heavy storm flows may flush these toxic substances out and into water systems.

Contributions to the Food Web

Riparian areas are the dominant contributor to the aquatic food web (Cummins 1974, Adamus and Stockwell 1983, Budd et al. 1987). About half of this energy input is in the form of dissolved compounds such as nitrates and lignin that enter the stream in leachates and surface flows; the other half is in the form of particulate matter (Cummins 1974). Streamside vegetation provides a nearly constant rain of leaves, wood, insects, spores, and other materials that fall or are transported into the aquatic ecosystem. These materials are the basis of a complex food chain that involves bacteria, fungi, and aquatic invertebrates. Some fish (e.g., suckers, whitefish, and minnows) feed directly on vegetative detritus (Wydoski and Whitney 1979). Others (e.g., salmon and trout) feed primarily on aquatic invertebrates (Cummins 1974, Murphy and Meehan 1991, Meehan 1996).

A mixture of deciduous and coniferous litter, as well as instream coarse woody debris, provide optimal year-round instream food sources for fish and aquatic invertebrates. Deciduous leaves have a large surface area and decompose rapidly, providing an excellent food base during summer and fall. Conifer needles, on the other hand, decompose slowly, providing a more constant food source throughout the year (Cummins 1974, Gregory and Askenas 1990). Fallen trees and limbs provide essential food and cover for aquatic invertebrates (Harmon et al. 1986).

Structural Diversity: Large Woody Debris

Approximately 70% of structural diversity within streams is derived from root wads, trees, and limbs that fall into the stream as a result of bank undercutting, mass slope movement, normal tree mortality, or windthrow (Franklin et al. 1981, Bilby 1984, Heede 1985, Carlson et al. 1990). This woody material is referred to as woody debris. The most valuable type of woody debris is provided by logs greater than 51 cm (20 in) in diameter and is referred to as large woody debris (LWD). In seeking its path around the obstruction posed by LWD, water creates complex hydraulic patterns that carve pools and side channels, form falls, enhance channel sinuosity, and impose numerous physical variations within the stream. The structural diversity created by instream woody debris is essential in providing adequate fish habitat, particularly for spawning and rearing, in all sizes of streams and rivers (Bilby 1984, Harmon et al. 1986, Bisson et al. 1987, Robison and Beschta 1990, Morman 1993).

In addition to structural diversity, LWD serves many vital functions, including (Cummins 1974, Franklin et al. 1981, Harmon et al. 1986, Martin et al. 1986, Bisson et al. 1987, Cederholm et al. 1989):

- dissipation and redirection of water force;
- capture and storage of sediments and organic material, including spawning gravels and leaf litter;
- streambed stabilization;
- formation of cover from predators and for protection during high stream flows and winter storms;
- water aeration and mixing;
- facilitation of fish passage in high gradient streams by providing "stair-steps" up the channel which alternate with resting pools;
- retention of spawned-out salmon and steelhead carcasses for consumption by eagles and other wildlife;

- contributions to instream food webs through decomposition and by providing habitat for aquatic invertebrates;
- input of nitrogen.

The majority of LWD is recruited from forests growing within 45 m (150 ft) of the stream (45 m is the average of all literature sources; see Appendix C for citations). Recruitment is a dynamic process; as old logs decay, are buried, or are washed downstream, they are replaced by new logs that are usually derived from dead and dying trees leaning or suspended over the channel (Heede 1985, Robison and Beschta 1990). In contrast to other riparian habitat features (e.g., well-developed shrub and herb layer) that are restored rapidly, the process of depositing large woody debris into channels and floodplains requires the longest time and therefore should be a major reason for adequate riparian buffers containing mature trees (Gregory and Ashkenas 1990).

Large logs of decay-resistant species such as western red cedar, Douglas-fir, and western hemlock are the most valuable because they form stable features that may persist in the streambed for over 100 years (Franklin et al. 1981). Conifer logs persist longer than deciduous logs (Anderson et al. 1978b, Swanson and Lienkaemper 1978, Keller and Tally 1979), and therefore they have a greater capacity to form and maintain diverse structural features needed by fish and wildlife.

Large conifer logs are particularly abundant in streams within old-growth forests (Franklin et al. 1981). Froehlich (1973) contrasted the amount of large debris found in streams in old-growth and second-growth stands. He found an average of 50.6 kg/m^2 (10.1 lbs/ft^2) in old-growth stands compared to 19 kg/m^2 (3.8 lbs/ft^2) in second-growth stands. Although riparian stands less than 40 years old may contribute woody debris to streams, the debris is small in diameter and less likely to accumulate and form stable habitat features needed by fish (Franklin et al. 1981). Mobbs and Jones (1995) inventoried numerous streams in primarily second growth stands from the Queets River Basin south to the Chehalis River Basin. They found that the proportion of woody debris that was large [i.e., greater than 51 cm (20 in) dbh] was 11-17%, substantially below the expected 40-80% reported for unmanaged forests (Ralph et al. 1994).

The dominance of deciduous trees in second growth riparian areas (Mobbs and Jones 1995) may last beyond 60 years after harvest (House and Bowen 1986). The amount of LWD in streams adjacent to stands dominated by deciduous trees may be inadequate to support healthy stream populations (Bilby and Ward 1991).

The role of LWD in stream channel development is affected by channel slope. Beechie and Sibley (1997) found fewer and smaller pools on moderate-slope channels compared to low-slope channels in northwestern Washington. They suggested that because some juvenile salmonid species preferentially select pools as rearing habitat, any changes in the number or size of pools could affect juvenile salmonid abundance or species age-class distribution.

Structural Diversity: Off-Channel Habitats

Riparian areas frequently contain numerous streamside channels, sloughs, and seasonal wetlands. These off-channel habitats are often more productive than the main stream and provide critical overwinter habitat, especially for coho salmon, eastside spring chinook, and cutthroat trout (Peterson 1982; Bryant 1984; Cederholm and Reid 1987; Idaho Dept. Fish and Game 1990; P. Harvester, pers. comm.).

Side channels and wetlands are created through complex geomorphic processes that determine the specific path of water flow (Mitsch and Gosselink 1986, Brinson 1988). Relationships between riparian and side-channel areas are subtle and mutually supportive; generally, neither will persist in the absence of the other. The following are some ways in which riparian areas influence the formation and longevity of off-channel areas:

- LWD may cause the initial diversion of water flow that creates the channel (Sedell and Froggatt 1984, Agee 1988);
- LWD tends to protect channels that are already formed by armoring banks and deflecting high velocity water currents (Robison and Beschta 1990);
- beaver, a riparian-dependent species, are prime creators of off-channel wetlands and ponds (Allen 1983, Bryant 1984, Medin and Clary 1991);
- stream banks and landforms (such as islands) associated with side-channel habitats are stabilized by riparian vegetation (Sullivan et al. 1987).

Relationship to Uplands

Riparian areas function as a moderator of changing environmental conditions involving precipitation, stream flow, temperature, microclimate, nutrient input, and food chain development. Their moderating effect lessens the impacts of extreme events and stabilizes habitat conditions both in the riparian area itself and in the associated aquatic area. The ability of riparian areas to moderate habitat conditions depends on its canopy closure, plant diversity, and surface area covered. In addition, activities in upland areas have a strong influence on the functioning of the riparian area. Although they can moderate the effects of upland events, riparian ecosystems do not stand alone; they cannot fully moderate water temperatures or filter impurities if the hydrologic flow from the uplands as a result of rain-on-snow events, erosion, urbanization, or loss of vegetation is excessive or heavily polluted (Swanson et al. 1982, Harr 1986).

Riparian Contributions to Terrestrial Wildlife Habitat

Approximately 85% of Washington's terrestrial vertebrate species use riparian habitat for essential life activities (Thomas et al. 1979, Brown 1985). Riparian areas provide more niches, and thus higher species diversity, than any other habitat type (Oakley et al. 1985). Many researchers note high bird diversity and abundance in riparian areas (Bottorf 1974, Stevens et al. 1977, Hehnke and Stone 1978, Knopf 1985, Knight 1988). Wildlife density may also be very high in riparian areas; as many as 1,500 birds/100 ac were found in riparian forests along the Columbia River (Tabor 1976). Small mammals are more diverse and abundant in riparian compared to upland habitats (Doyle 1990). Amphibians reach densities of three per square meter in small streams and seeps in the Pacific Northwest (Bury et al. 1991).

Four attributes of riparian areas that contribute to this diversity and abundance of wildlife are:

- structural complexity;
- connectivity with other ecosystems;
- abundant food source and available water;
- moist and moderate microclimate.

Structural Complexity

Structural complexity is the co-occurrence of a variety of vegetative and physical features that provide a number of niches for wildlife (Anderson et al. 1978a, Marzluff and Lyon 1983, Renken and Wiggers 1989). This complexity allows a diversity of species to live together in the same place by partitioning the environment (Bull and Skovlin 1982). In healthy riparian ecosystems, structural complexity is expressed in four general ways: 1) plant species are diverse; 2) multiple canopy layers are present, especially a well-developed shrub layer; 3) snags and downed woody debris are available; and 4) there is a high percentage of edge habitat (Cline and Phillips 1983, Marzluff and Lyon 1983). These attributes are briefly discussed below.

Plant species diversity. Diversity of animal species often parallels diversity of plant species (MacArthur and Wilson 1967). The reasons for this involve plant-animal and animal-animal interrelationships that are based on food and breeding site availability (Oakley et al. 1985). Riparian habitats generally harbor a rich diversity of plant species that contributes to diversity of wildlife. Conversely, riparian habitats that are botanically impoverished as a result of grazing or other modification have sharply decreased wildlife diversity (Mudd 1975, Stauffer and Best 1980, Jones 1988).

Multiple canopy layers. Multiple canopy layers are formed by the crowns of trees and shrubs growing at varying heights, as well as the vegetative strata provided by herbs and grasses. The humus layer may also be considered a canopy layer because of its importance to reptiles, amphibians, and other ground-dwellers (Jones 1988, Doyle 1990). Researchers have long noted relationships between foliage height diversity and breeding bird diversity (MacArthur and Wilson 1967, Anderson and Ohmart 1977, Finch 1989). Similar relationships have been identified for amphibians (Jones 1988), bats (Bell 1980), and rodents and other mammals (Dickman 1987). High species diversity and abundance is probably related to increased availability of hiding cover, breeding sites, favorable microclimate, and foraging substrates in structurally diverse habitats (O'Connell et al. 1993).

Multiple canopy layers are typical of riparian areas. Separation between canopy layers that provide open space for flight or travel is important to some species of bats and to northern goshawks and northern spotted owls (Hayward and Escano 1989, Thomas et al. 1993). This space is generally well developed in a mature riparian forest. Conversely, dense shrub layers in riparian areas are particularly important to breeding songbirds (Bull and Skovlin 1982, Finch 1989, Sanders 1995).

Snags and downed woody debris. Many kinds of wildlife are dependent on the close association of both water and standing or downed woody debris (Harmon et al. 1986). These include cavity-nesting ducks, amphibians, raptors, and many mustelids (mink family). For example, wood ducks require large snags or live trees with cavities within 183 m (600 ft) of water (Grice and Rogers 1965) with an average distance of 80 m (262 ft) (Gilmer et al. 1978).

Along large streams or rivers in unmanaged watersheds, snags may be more abundant and of better quality (i.e., large conifer species) in upper/outer portions of the riparian area than immediately next to the watercourse where disturbance encourages a younger, more deciduous forest community (McGarigal and McComb 1992). The reverse is true in arid settings, where snags and downed woody debris are chiefly supplied by riparian vegetation in close proximity to the aquatic habitat (Clary and Medin 1990).

Beaver ponds often feature snags standing in open water. Partially submerged snags are very important to cavity-nesting ducks, tree swallows, woodpeckers, and osprey for nesting purposes (Hair et al. 1978, Burns and Dahlgren 1983, Vana-Miller 1987). They are also used by owls, hawks, and other raptors as hunting perches (Knight 1988).

Downed logs are an important habitat component for a wide range of species and perform numerous essential functions (Harmon et al. 1986):

- hiding and resting cover for amphibians, reptiles, rodents, and larger mammals;
- small mammal "runways;"
- a food substrate for fungi and invertebrates, which are then consumed by vertebrates;
- den sites for bobcat, black bear, wolverine, and a number of other species;

- ecological bridges between aquatic and terrestrial habitats formed by partially submerged logs and used by turtles for basking, great blue herons for hunting, waterfowl for nesting and loafing, and muskrat, beaver and otter for denning;
- acting as sponges by absorbing water during wet periods and releasing it later during drought, thereby contributing substantially to the moist microclimate characteristic of riparian areas and which is of particular importance to amphibians.

Edge Habitat. An edge, or ecotone, is the place where two different plant communities, successional stages, or vegetative conditions meet (Thomas 1979). This junction is either a well-defined boundary or a transition zone where plant and associated wildlife communities grade into one another (Yahner 1988). Due to their linear shape and their long and irregular border with both aquatic and upland ecosystems, riparian areas possess an abundance of edge habitat (Meehan et al. 1977). Even though it is well established that edge habitat is beneficial to many wildlife species, the value of edge habitat diminishes rapidly and the detrimental effects can outweigh its many benefits if the edge is created rapidly, if the amount of edge habitat is excessive, or if the contrast between adjoining habitats is high (Reese and Ratti 1988).

Edges are structurally diverse because they contain vegetative communities that are characteristic of each adjoining habitat as well as vegetative communities that are unique to edges (Kroodsma 1984, Logan et al. 1985). Riparian edges have physical features that are attractive to wildlife, such as tall perches in forest cover that look out over open water or low profile upland habitat. In addition, shrubs are especially abundant at riparian ecotones and provide ideal hiding cover for wildlife (Gates and Giffen 1991). Food sources such as berries and insects tend to be more abundant along edges (Anderson et al. 1978a, Kroodsma 1984).

Many species use riparian areas because they provide ready access to two or more habitat types in close proximity. For example, beaver, muskrat, and river otter are highly dependent on riparian habitat because of its close proximity to the water environment. Beaver do the majority of feeding and tree felling within 200 m (656 ft) of the water's edge (Allen 1983). River otters may venture far afield to hunt and look for mates, but they usually construct dens in downed logs, burrows, or under tree roots in near-shore riparian vegetation (Habitat Suitability Model: River Otter *in* Every and McShane 1986). Raptors and other birds often use perches in trees, shrubs, or snags as hunting posts, nest trees, or territorial lookouts at the aquatic/riparian or the riparian/open upland interface (Small 1982, Vana-Miller 1987, Knight 1988). Several species of bats roost in riparian areas but preferentially hunt over open water (Bell 1980, Cross 1988).

Many animals use the riparian/open upland interface as a zone of protection; that is, they prefer foraging in grassy or open habitats but don't stray far from the protective cover provided by the taller and denser vegetation of riparian habitat. Deer, elk, coyote, bear, and many bird species share this behavior (Mudd 1975, Thomas et al. 1979). Riparian ecotones in agricultural areas are often rich in wildlife because of the close proximity of attractive food sources (agricultural fields) and protective cover provided by riparian and hedgerow vegetation (Conine et al. 1978, Carson and Peek 1987, Croonquist and Brooks 1993).

Although edge habitat can foster high wildlife diversity, it can also lead to the elimination of some species associated with interior portions of forests (e.g., fisher, marten, brown creeper, golden-crowned kinglet) or that require large, undisturbed areas (e.g., mountain lion, grizzly bear, gray wolf) (Harris 1984). An excessive amount of edge and edges with high contrast can be detrimental to some wildlife populations (Cline et al. 1980, Stauffer and Best 1980, Reese and Ratti 1988, Skovlin et al. 1989, Yahner 1988, Lehmkuhl and Ruggiero 1991). Edges make interior forest songbirds vulnerable to nest predators such as crows, raccoons, and jays, and brood parasites such as brown-headed cowbirds (Terborgh 1989, Gates and Giffen 1991). These and other predatory species may be attracted to edge habitats and fragmented landscapes (Reese and Ratti 1988). The effect of increased predation and nest parasitism extends for a considerable distance into forest interiors. This distance has been shown in eastern forests to extend up to 600 m (2,000 ft) from the edge (Reese and Ratti 1988, Wilcove et al. 1986). Newly created edges (e.g., those created by a new clear-cut or agricultural field) expose interior forest species to competition for resources by open-environment and habitat-generalist species (Lehmkuhl and Ruggiero 1991). Interior species are often less competitive and hence less successful in this situation. Species requiring large undisturbed areas are also indirectly affected by an increase in abrupt edge habitat because such habitat is usually associated with greater habitat fragmentation (Reese and Ratti 1988, Yahner 1988).

Many riparian-associated bird species respond negatively to excessive exposure to edges and require minimum widths of wooded vegetation in order to breed successfully. Required widths vary from 25 m (82 ft) for downy woodpecker to 200 m (657 ft) for American redstart (Stauffer and Best 1980). One researcher in Virginia found that interior forest birds only occurred in riparian corridors of at least 50 m (164 ft) in width (Tassone 1981). In another eastern United States study, a minimum riparian buffer width of 100 m (328 ft) was recommended to support area-sensitive neotropical migrant species (Keller et al. 1993). Similarly, a researcher in eastern Canada found that riparian strips >60 m (197 ft) wide were able to sustain forest-dwelling birds (e.g., golden-crowned kinglet, Swainson’s thrush, some warblers, brown creeper, spruce grouse), while narrower widths only sustained the more ubiquitous species (e.g., American robin, tree swallow, dark-eyed junco) (Darveau et al. 1995). In unmanaged forested landscapes, sufficient width is provided by adjacent, unbroken upland forests (Gates and Giffen 1991, McGarigal and McComb 1992). A balance between edge and interior habitat is needed to support forest interior species, reduce nest predation, and provide resources for edge species. By providing riparian habitat areas of sufficient width to support forest interior species adjacent to developed lands, both interior and edge habitats can be provided.

Connectivity with Other Ecosystems

By virtue of their protective cover and connectivity throughout watersheds, riparian areas function as wildlife travel corridors (Thomas et al. 1979, Forman and Godron 1986, Noss 1993). Animals often use riparian areas for daily, seasonal, or once-in-a-lifetime travel. Mobile species such as marten, fisher, bobcat, cougar, deer, great blue heron, and marbled murrelets frequently have established daily travel routes that parallel streams (de Vos and Guenther 1952, Thomas et al. 1979, Eisenhawer and Reimchen 1990, Noss 1993). Species that tend to migrate seasonally, such as Rocky Mountain elk and bald eagle, often follow riparian corridors up and down elevational gradients or use them as horizontal routes to and from wintering and breeding grounds (Thomas et al. 1979, Stalmaster 1980). Smaller or less mobile animals that use both aquatic and upland areas travel through riparian areas to access them (Noss 1993).

Although a key function of riparian areas is to provide a safe corridor for animals to move from area to area, Noss (1993) outlined other important functions of riparian corridors. These other functions include facilitating dispersal and consequent gene flow between populations, “rescue” of small populations from extinction, and allowing long-distance range shifts of species, such as in species’ responses to climate change. Riparian corridors that facilitate wildlife movement help maintain the health of species’ gene pools and prevent isolation and perhaps extirpation of sub-populations (Harris 1988). Gradual population expansions may also occur along riparian routes. For example, woodland birds have colonized new areas by following treed riparian corridors within open prairie environments (Finch 1989). Corn and Bury (1989) found that amphibian populations slowly recolonized stream reaches after logging. Opportunities for recolonization may be lost, however, if species are extirpated from watersheds by deleterious activities occurring at critical points along the stream. Corn and Bury (1989) reported the disappearance of the tailed frog and Olympic torrent salamander, which are highly sensitive to sedimentation, from streams where the headwaters were logged.

The importance of riparian areas as travel corridors and routes for dispersion is amplified in developed or fragmented landscapes because alternative overland travel routes are often unavailable, discontinuous, or life endangering (Carleton and Taylor 1983, Blake 1986). Dispersing juveniles or adults of some species are prone to predation while traveling through open areas. In highly developed landscapes, riparian corridors may provide essential connections between isolated natural areas. Some animals may be able to meet their large areas requirements by traveling between several patches of natural habitat linked by corridors (Noss 1993). MacClintock et al. (1977) found that breeding songbirds of the forest interior occurred in higher diversity and abundance in small forest fragments connected to larger forests by a corridor than in isolated forest fragments. Riparian areas also function as habitat islands, or small reserves, wherein wildlife species can find permanent or temporary refuge in a largely hostile landscape (MacArthur and Wilson 1967, Brode and Bury 1984, Simberloff and Cox 1987, Nixon et al. 1991).

Natural corridors (including riparian habitat) must be carefully designed to be successful in providing suitable habitat for fish and wildlife, and width is the most important consideration (Noss 1993). A corridor that is too narrow may impose greater detriments than advantages on sensitive wildlife. Narrow corridors are entirely edge habitats and attract a large number of predatory, parasitic, and opportunistic species (e.g., great horned owl, brown-headed cowbird, European starlings). Competition and high mortality rates of sensitive species may therefore result (Wilcove et al. 1986, Henein and Merriam 1990).

Abundant Food Sources and Available Water

The moist microclimate, rich depositional soils, and other favorable environmental conditions in riparian areas lead to enhanced growth of plants. Plants, bacteria, fungi, and other lower organisms are at the base of a complex and highly productive food web in riparian areas (Cummins 1974, Strong and Bock 1990). Seeds are abundant for seed-eating birds and mammals. Herbaceous vegetation and fruits are heavily used by ungulates, small and large mammals, and birds. Insectivores such as bats, shrews, amphibians, salmon, and many birds find abundant terrestrial and aquatic insect resources. Fungi are prevalent and used by small mammals, and predators benefit from the abundance of these prey species (Anderson et al. 1978a, O'Connell et al. 1993).

Some researchers propose that the availability of food in riparian areas contributes significantly to its use by wildlife (Strong and Bock 1990, Gates and Giffen 1991, O'Connell et al. 1993). Evidence for this can be found in the close spatial association of upland-adapted species, such as the pileated woodpecker, with riparian ecosystems. Although this species' habitat needs for breeding sites and protective cover would seem to be adequately met in upland habitats, it usually locates its nests and focuses daily activities within 500 m (1,640 ft) of streams and wetlands (Small 1982, Hayward and Escano 1989, Mellen et al. 1992). For species like the pileated woodpecker, increased availability of prey sources in riparian areas appears to be an important determinant in habitat selection (Mellen et al. 1992). A large proportion of pileated woodpecker foraging occurs on downed logs; downed logs tend to be more numerous and contain more invertebrates in riparian habitats (Harmon et al. 1986, Renken and Wiggers 1989). Similarly, fish-eating species like raccoon, bear, mustelids, some birds, and garter snakes are attracted to riparian areas (H. Beecher, pers. comm.).

Another attraction to riparian zones involves the availability of drinking water. A number of species of birds, ungulates, and small and large mammals require free water (Thomas et al. 1979, Carson and Peek 1987, O'Connell et al. 1993). The cooler, moister microclimate found in riparian areas also assists wildlife in conserving body water.

Moist and Moderate Microclimate

The presence of surface and sub-surface water, topographic features, and abundant vegetation in riparian areas results in a microclimate that is generally more moist and mild (cooler in summer and warmer in winter) than the surrounding areas. Riparian areas have higher humidity, increased rates of plant transpiration, and greater air movement than upland areas (Thomas et al. 1979). This unique microclimate may extend up to two tree lengths [160 m (525 ft)] into adjacent forests (Harris 1984, Franklin and Forman 1987). These conditions provide an environment that is desirable to many species, particularly amphibians year-round and ungulates and other large mammals during hot, dry summers and severe winters.

Examples of Wildlife Use

The following are discussions of major wildlife groups and their particular association with riparian habitats. Unless otherwise noted, these discussions are based on a literature review by O'Connell et al. (1993).

Amphibians. Eighty percent of Washington amphibian species are considered obligates of stream or wetland-related riparian habitat (i.e., they are most frequently found in aquatic and riparian habitats or they breed exclusively in aquatic habitats). Amphibians rely on streams and associated pools to provide foraging areas, cover, reproduction sites, and habitat for aquatic larvae. While four amphibian species may be completely aquatic, others may never enter streams yet require the moist and cool environmental conditions provided by riparian habitat.

Because amphibians generally have a very limited range, most of their life requisites need to be in close proximity. Woody debris, aquatic areas, riparian vegetation, and a well-developed litter layer are key features that provide their requirements. Many species feed on aquatic plants and invertebrates. Those foraging on terrestrial invertebrates find an abundance in riparian habitat. Seventy-nine percent of Washington amphibians use streams, ponds, and temporary waters for mating, egg deposition, and larval development (Nussbaum et al. 1983). Small, non fish-bearing streams are particularly important to amphibians, in part because they are free from competition and predation by fish (Gomez 1992). Amphibian numbers and biomass in these small streams are often greater than that of coldwater fishes in analogous streams (Bury et al. 1991). Because of their limited range, limited mobility, and sensitivity to water temperature and quality (particularly sedimentation), amphibians are particularly sensitive to alterations of riparian and aquatic habitat (Nussbaum et al. 1983).

Several species of amphibians have been extirpated in specific areas of the Northwest, and range reductions have occurred in others. Forest-dwelling amphibians have suffered the worst declines (Corn and Bury 1989, Blaustein and Wake 1990). As a result, several amphibians are currently considered candidates for listing under the Endangered Species Act (U.S. Fish and Wildl. Serv. 1992b).

Reptiles. Three Washington reptiles use aquatic/riparian systems for most of their life requisites: the western pond turtle, painted turtle, and western terrestrial garter snake (Nussbaum et al. 1983, Bury 1988, O'Connell et al. 1993). These species feed, breed, and find cover requirements in aquatic habitat and riparian areas adjacent to ponds, marshes and slow-moving streams. Large woody debris is particularly important as cover and basking sites for these species. Sharptail snakes and common garter snakes are also commonly found in moist habitats throughout Washington.

Birds. High species diversity and abundance of birds has been well documented in riparian areas (Thomas et al. 1979, Oakley et al. 1985, Wash. Dept. Ecol. 1985). One group of birds that is particularly attracted to riparian habitat are neotropical migrants. Andelman and Stock (1994) document that of the 118 species of neotropical migrants occurring in Washington, 67 (57%) use riparian habitat while they are in North America. Although many are habitat generalists (i.e., they use more than one habitat type), their high use of riparian habitat for breeding and other requirements has prompted the identification of riparian habitat as a priority for their protection (Andelman and Stock 1994).

The mosaic of plant communities and successional stages present in riparian areas provides a variety of resources for birds. Both early and late-successional species find breeding, feeding, and cover requirements met, at least in part, in riparian habitat. Many birds use riparian habitat because high foliage density associated with deciduous trees protects nests from predation (Martin 1988).

Some birds are particularly sensitive to riparian habitat alterations, while others may show few or no effects or perhaps even population increases with some human activities (especially forest practices). Forest interior songbirds, cavity or large tree nesters (e.g., woodpeckers, owls, cavity-nesting ducks, some passerines and raptors), bark-gleaning insectivores (e.g., brown creeper, red-breasted nuthatch), and some foliage-gleaning insectivores (e.g., winter wren) are generally more sensitive to loss of forest vegetation within or adjacent to riparian areas. Species that only inhabit riparian areas (e.g., American dipper, marbled murrelet, harlequin duck) are also sensitive to riparian vegetation loss. Early-successional (open habitat) and edge species that often include granivores (e.g., white-crowned sparrow, spotted towhee), insectivores (e.g., vireos, warblers), and ground and shrub nesters (e.g., Macgillivray's warbler, song sparrow) often respond positively to forest vegetation removal (Medin 1985, Ehrlich et al. 1988, O'Connell et al. 1993).

When land is converted from natural vegetation to other uses, the retention of adequate riparian buffers can provide remnant habitat sufficient to support a broad variety of bird species. Wider riparian buffers appear to result in greater bird use; Manuwal (1986) found a 58% increase in bird use with a 50% increase in the size of the riparian zone.

Small Mammals. At least six small mammals are considered obligate inhabitants of streamside zones: water shrew, marsh shrew, nutria, muskrat, beaver, and water vole (O'Connell et al. 1993). Another nine species of small mammals concentrate in riparian habitat in some areas or seasons. Six other mammals are known to occur in moist areas adjacent to streams, springs, or in moist meadows. Riparian areas typically support all or most species found in adjacent uplands, so small mammal species richness is usually high.

Presence of water, abundance of food (including aquatic vegetation, aquatic and terrestrial invertebrates, and riparian vegetation), moist microclimate, abundance of edge habitat, and dense cover provide resources to support a high abundance and diversity of small mammals. Because many small mammals are burrowing animals, soil characteristics are of particular importance. The presence of moist soils with high levels of organic matter and an abundance of exposed soils make riparian habitat particularly useful to many species. Some small mammals (e.g., southern red-backed vole, mountain beaver) also require high moisture (in succulent vegetation or free water) because of poorly developed physiological mechanisms of water conservation. Because small mammals are relatively poor dispersers, they must meet all their habitat requirements in a small area. Abundant edge habitat available in riparian areas often supplies these requirements. Small streams in particular provide micro-habitat features important to many small mammals, thus supporting abundant and diverse populations (Gomez 1992).

Small mammals that have relatively large home ranges, are poor dispersers, or are specifically dependent on riparian habitat are likely to decrease as a result of resource extraction or land use changes in riparian areas. Grazing activities in riparian areas reduce small mammal populations because of vegetation loss and soil compaction (Ohmart and Anderson 1986). O'Connell et al. (1993) concluded that to be useful management tools for small mammals, riparian buffers need to be large enough and retain sufficient habitat value to allow taxa that depend on riparian habitat, as well as taxa that are characteristic of late-successional stages, to persist until tree canopy is reestablished on adjacent uplands.

Bats. Riparian areas appear to be of primary importance to all bat species. Although most bats feed and roost in many habitats, riparian and aquatic habitat provide an essential source of drinking water and abundant food resources that attract bats. All Washington bat species are insectivorous and consume mostly flying insects. Many bats forage over water more frequently than in forests, fields, or clearings. Intact riparian habitat helps support abundant insect populations that provide food for bats.

Although bat roosting does not occur exclusively in riparian areas, these areas are commonly used for both foliage-roosting and cavity or crevice-roosting bats. An abundance of deciduous trees and dead or dying trees provide necessary roosting structures in close proximity to key foraging habitat.

Studies to examine the effects of forestry and other activities on bats are limited. However, evidence exists regarding bat preference for old-growth forests relative to young forests and clear-cuts. Bat activity was found to be 2-10 times greater in old-growth forests than in younger stands (Thomas and West 1991). High bat activity in old-growth forests in the early evening indicates that old-growth forests are used primarily for roosting rather than foraging.

Carnivores. River otter and mink are closely associated with riparian habitat. A number of other carnivores (e.g., raccoon, red fox, black and grizzly bears, gray wolf, bobcat, fisher, marten, ermine, long-tailed weasel) exhibit some preference for riparian areas. Carnivore occurrence in riparian habitats is largely due to the abundance of animal prey. Because most carnivores are also omnivorous, plant food resources (particularly berries and other fruits) in riparian areas complement a diet of meat.

Coarse woody debris in riparian habitat and adjacent aquatic areas provides hollow trees, snags, and debris piles used for resting and denning sites for many carnivores, particularly otter, bobcat, lynx, mink, and marten. Dense vegetation in riparian habitat provides bedding areas for grizzly bears. Carnivores frequently follow stream corridors in their daily and seasonal travel where food, cover, and water are all available.

Evidence indicates that marten and fisher are particularly sensitive to a loss of mature forest habitat in riparian and adjacent forests. Some evidence also suggests that timber harvest provides suitable habitat for bobcat and red fox because of increased prey availability in open environments.

Ungulates. Riparian habitat plays a major role in providing essential habitat for most ungulates. The endangered Columbian white-tailed deer is currently restricted to the bottomlands at the mouth of the Columbia River and uses riparian habitat extensively. Deer, elk, moose, and caribou are all known to use riparian areas for food, cover, travel routes, and water to varying degrees depending on season, local temperature and moisture regimes, and other habitat types available on a landscape level.

Strong relationships exist between the availability of drinking water and habitat use by ungulates, especially in the arid shrub-steppe region. The high quality and quantity of forage in riparian areas are used by all ungulates, especially in the spring because riparian vegetation generally “greens up” earlier than in other areas. Ungulates also utilize riparian areas in late fall because these areas maintain moisture throughout the summer and thus retain green vegetation when upland areas have dried out.

Riparian areas with dense and structurally diverse vegetation provide thermal and hiding cover for ungulates. Thermal cover is provided with a canopy of >12 m (39 ft) in height and at least 70% tree canopy coverage. This cover is important year-round, especially during winter when riparian areas may be the only habitat where snow does not render the habitat unsuitable for ungulates such as deer, elk, and moose. These mammals also use riparian areas for fawning and calving. Deer and elk populations that migrate between summer and winter ranges commonly utilize riparian areas for these movements.

Although deer, elk, and moose are known to increase in abundance with vegetation removal that results in early-successional vegetation, closed canopy forests (for thermal and hiding cover) and water must be in close proximity.

IMPACTS OF LAND USE

Riparian ecosystems are considered the most sensitive to environmental change (Naiman et al. 1993) and have the highest vulnerability to alteration (Thomas et al. 1979). These ecosystems are formed and maintained by natural disturbances (e.g., landslides, debris torrents, flooding) which serve to contribute resources (e.g., woody debris, spawning gravel, nutrients) to riparian and instream habitat. The same natural disturbance that erodes features in one area may create or revitalize habitat conditions elsewhere. Stable channels and optimal stream habitat conditions occur when some balance exists between the supply of resources and the ability of the channel to store or transport them.

Natural systems evolve and become adapted to a particular rate of natural disturbances over long periods. Land uses alter stream channel processes and disturbance regimes that affect aquatic and riparian habitat (Montgomery and Buffington 1993). Human-induced disturbances are often of greater magnitude and/or frequency compared to natural disturbances. These higher rates may reduce the ability of riparian and stream systems and the fish and wildlife populations to sustain themselves at the same productive level as in areas with natural rates of disturbance.

Other characteristics also make riparian habitats vulnerable to degradation by human-induced disturbances. Their small size, topographic location, and linear shape make them prone to disturbances when adjacent uplands are altered. The unique microclimate of riparian and associated aquatic areas supports some vegetation, fish, and wildlife that have relatively narrow environmental tolerances. This microclimate is easily affected by vegetation removal within or adjacent to the riparian area, thereby changing the habitat suitability for sensitive species (Thomas et al. 1979, O'Connell et al. 1993).

Because riparian habitat more strongly influences the structure and function of small streams compared to large streams, small streams are more prone to pronounced impacts from the removal of riparian habitat than are large streams and rivers. Land uses that affect water quantity and quality (e.g., dams, agriculture, urban areas), are more likely to affect large streams and rivers because their habitat quality is largely controlled by the input of water from upstream and upland areas (Sullivan et al. 1987, Bilby 1988). When water quantity is reduced in large streams, riparian habitat is likely to be negatively impacted.

Because of its high primary productivity, riparian habitat often responds well to restoration efforts (Kinch 1989). In many cases, ceasing or modifying human activities that negatively impact riparian habitat, coupled with restoration efforts, can bring about relatively rapid and dramatic recovery of lost ecosystem function (Hair et al. 1978, Kinch 1989, Clary and Medin 1990). However, the invasion of exotic plant species may delay or even preclude re-establishment of the original plant community.

Major land uses that impact riparian areas are grouped into seven categories for discussion: forest practices, roads, agriculture, grazing, urbanization, dams, and recreation.

Forest Practices

Forest practices, including timber harvest and its associated activities (e.g., road building, pre-commercial thinning, controlled burning, herbicide and insecticide spraying), temporarily or permanently alter the character of forested landscapes, including riparian habitat. Because riparian areas topographically occur below uplands, they receive water, soil, and organic debris from upland areas. Forest practices in uplands and in riparian areas are often responsible for delivery of these resources to streams at rates significantly different than natural rates, resulting in changes to structural and functional elements of riparian areas.

Moring et al. (1994) summarized four studies that examined the effects of logging on fish habitat. They reported that bank stability was reduced and solar radiation to the stream increased in areas without intact buffer strips of riparian vegetation. Water temperatures rose above 30 C, dissolved oxygen reached critically low levels, sediment loads increased significantly, and particulate organic matter increased tenfold. They also reported population declines of reticulate sculpins, cutthroat trout, and other salmonids.

Vegetation removal, road construction, and soil disturbance are the chief mechanisms by which forest practices influence riparian areas. These disturbances result in:

- hydrologic (relating to water flow) effects;
- soil destabilization, erosion, and sedimentation;
- stream temperature increases and a more severe microclimate;
- loss of large woody debris;
- fish and wildlife effects;
- cumulative effects.

Hydrologic Effects

Changes in basin hydrology may occur as a result of forest practices. These effects are characterized by changes in the amount of water available for run-off (water yield) as well as changes in how water is routed through the watershed during winter storms. Removal of a mature forest canopy generally results in a temporary increase in water available for run-off due to: 1) reductions in evaporative losses from the soil moisture reservoir (via evapotranspiration) and from the canopy itself (interception), and 2) increases in snow accumulation and melt in clear-cuts and young stands in areas where snow is a significant contributor to run-off. In absolute terms, most of the increased water is generated during the winter season; however, in relative terms, the largest (and the most important for fish) increases occur during the period of lowest flow. In certain instances, however, significant decreases in summer water yield have been observed in areas where fog drip provides a substantial water input during the summer (Harr 1982) and where phreatophytic (deep rooted plants which obtain their water from the water table or the layer of soil just above it) hardwoods (e.g., red alder, willow, cottonwood) have replaced conifers in the riparian area (Hicks et al. 1991a).

Changes in the water yield and in the magnitude and frequency of peak flows can arise from changes in snow accumulation and melt. Snow accumulation in clear-cuts and young stands can be two to three times greater than that found in mature forest stands (Berris and Harr 1987). Rates of snow melt are also greater in clear-cuts and young stands, due to greater exposure to radiative and advective energy inputs (Harr and Coffin 1992). In areas where spring snow melt is a dominant hydrologic process, clear-cuts and young stands result in increased total snow melt run-off and a very small increase in the snow melt peak with no change in run-off during the recession (late spring/summer) phase (Troendle and Leaf 1981). In areas where rain-on-snow is a dominant peak-flow generating process, there exists the potential for substantial increases in peak flows if large portions of a watershed are in clear-cuts and young stands (Christner and Harr 1982, Harr 1989). Increases in the magnitude of peak flows over a period of 10-20 years also increases the frequency of flows capable of eroding channel banks and bottoms and scouring salmon redds (Quinn and Peterson 1994).

In areas where rainfall alone is the primary peak flow-generating process, significant increases in peak flows associated with timber harvesting are associated only with the first few storms in the fall (Harr 1980). These increases are attributable primarily to wetter, more hydrologically responsive soils found in recently harvested stands as a result of reduced evapotranspiration. For larger winter storms, harvested and unharvested watersheds respond similarly.

Changes in hydrologic response attributable to timber harvest of a site are inherently temporary in nature as recovery towards pre-harvest conditions occurs during growth of the new stand. Time required for full hydrologic recovery varies with site conditions and with each hydrologic component. Some examples of assumed recovery times include (K. Lautz, pers. comm.):

Hydrologic Response Variable	Treatment	Recovery Period
Water yield - Summer	Clear-cut	2-3 years
Water yield - Annual	Partial Cut (25-33%)	10 years
Water yield - Annual	Clear-cut	25+ years
Peak Flows - Rain-on-Snow	Clear-cut	25-30 years

Broadcast burning and wildfire, if hot enough, can increase soil surface water repellency for a short period, thereby significantly reducing water infiltration in the first year post-burn (Skaugset 1992). If this effect occurs over a large portion of the watershed and is closely followed by moderate to high intensity precipitation, then potentially catastrophic erosion and subsequent habitat damage can occur.

Considerations of spatial scales are important when evaluating potential hydrologic effects. Smaller watersheds tend to be more sensitive than larger ones, given that smaller watersheds are more likely to have a relatively larger proportion of their area affected by forest practices. In the case of peak flows, the cumulative response of many small sub-basins in a larger watershed is likely to be curbed by naturally occurring desynchronization of the sub-basin peaks (Harr 1989). Therefore, potential hydrologic effects can be minimized if clear-cuts and young stands occupy a relatively small proportion of any watershed (U.S. For. Serv. et al. 1993).

Soil Destabilization, Erosion, and Sedimentation

Excessive sedimentation in streams, particularly within spawning and rearing areas, is one of the most significant effects of forest practices. Forest practices, including logging, road construction and use, and broadcast burning, have been found to increase the frequency and magnitude of soil destabilization, erosion, and eventual stream sedimentation (Ice 1985, Everest et al. 1987, Sullivan et al. 1987, Swanson et al. 1987, Cafferata 1992). Ice (1985) found that clear-cutting followed by broadcast burning increased soil movement in the form of debris slides by two to four times the rate of non-harvested areas. He also found that slide erosion from roads can be several hundred times higher than in forested areas. Soil destabilization and erosion reduces riparian vegetation, and the resultant sedimentation in streams affects water quality and fish habitat, especially in spawning and rearing areas.

Timber harvest can result in the loss of soil-stabilizing roots and standing vegetation along stream banks and in upland areas. Also, timber harvesting coupled with broadcast burning can scarify soils, compact the humus layer, and remove ground litter (Cafferata 1992). These impacts can reduce soil stability, increase erosion, and/or increase mass wasting potential in affected areas. This causes the introduction of detrimental amounts of fine and coarse sediment into streams (Everest et al. 1987). Furthermore, the removal of downed woody debris and its sources (standing snags and trees) during harvest operations results in a loss of natural damming material on the forest floor. Large recumbent logs have an important role in soil stabilization, often holding considerable amounts of eroded soils and large cobble on their uphill side (Wilford 1982).

Timber harvest and associated road construction can increase the frequency and amount of sediment production through mass failures (Swanson et al. 1987). Mass failures are a major source of sediment, particularly in steep landscapes. Mass failures can occur adjacent to streams or in uplands. Mass failures adjacent to streams and debris flows through channels carve stream banks, thereby reducing riparian vegetation. Debris flows also move large woody material to floodplain areas or to concentrated locations, which reduces the availability of large woody debris throughout the stream system (Swanson et al. 1987). The revegetation of riparian areas damaged by debris flows and mass wasting is different than in areas that do not suffer significant erosion. The high amount of bare ground in eroded areas favors revegetation by fast-growing red alder rather than a diversity of other plants (Swanson et al. 1987). Although riparian areas are naturally dynamic because of disturbance, the increase in frequency and severity of mass failures associated with forest practices may exceed natural conditions, resulting in a reduction in water quality and a loss of mature riparian habitat.

Increased fine-grained sediments in stream channels fill in the spaces within spawning gravel beds, thereby inhibiting the interchange of oxygenated water and causing egg suffocation (Cederholm and Reid 1987). Based on an analysis of field and laboratory experiments, Cederholm and Reid (1987) concluded that: 1) survival of eggs and alevins (larval fish) decreases as the percentage of fine sediments in spawning gravels increases, 2) suspended sediments cause stress to juveniles during summer, 3) disruption or blockage of small winter refuge channels can reduce smolt survival, 4) aggradation of coarse sediments can cause loss of summer rearing habitats, and 5) stream bed stability may be locally reduced by removal of woody debris. Landslides from logging roads and clear-cuts can overload stream channels with coarse sediments. This may cause pools essential to fish to be filled (Sullivan et al. 1987) and cause the channel to aggrade, which can force a greater portion of the stream flow beneath the bed during the summer and reduce availability of summer rearing habitat (Hicks et al. 1991b).

Stream Temperature and Microclimate

In an ecological assessment of forested areas of the Pacific Northwest, the U.S. Forest Service (1993a) found that the current maximum stream temperatures exceeded or were in the upper portion of the range of naturally occurring temperatures in the majority of rivers. Timber harvest removes shading vegetation from uplands and riparian areas, exposing the land and water to increased sunlight. Water temperatures increase directly, and water flowing over the surface of warmer land eventually reaches streams and further increases water temperatures (Beschta and Taylor 1988).

Warmer stream temperatures can have both positive and negative effects on salmonid production (Hicks et al. 1991b). In some situations, higher temperatures and increased light to the stream can lead to increased production of instream microorganisms, algae, fungi, and macroinvertebrates, thereby boosting food availability for salmonids and increasing salmon production (Murphy et al. 1986, Bisson et al. 1988, Hicks et al. 1991b). Warmer stream temperatures may also accelerate fry emergence and extend the growing season, thereby enhancing fish growth (Murphy et al. 1986). These possible positive effects generally occur during summer months and are often offset by fish losses during the winter because of reduced protective cover from LWD in logged streams (Murphy et al. 1986, Hicks et al. 1991b). Possible positive effects can also be negated by other stresses caused by streamside timber harvest, including increased sedimentation, elevation of stream temperatures beyond tolerable levels, and decreased stream stability (Murphy et al. 1986, Hicks et al. 1991b). Furthermore, elevated stream temperatures may favor production of nonsalmonids that can out-compete salmonids in some situations (Bisson et al. 1992).

When water temperatures increase, levels of dissolved oxygen decrease. Low levels of oxygen sharply reduce habitat suitability for fish (Theurer et al. 1985, Beschta et al. 1987). In small streams, clear-cutting has resulted in dissolved oxygen decreases of 40% that persisted for at least 3 years after logging (Hall and Lanz 1969, Ringler and Hall 1975). Water temperatures above normal may also alter the fish species composition, favoring some non-salmonid species (e.g., red shiner) over salmonids (Reeves et al. 1987, Beschta 1997). Higher than normal water temperatures in winter have been found to cause early emergence and vulnerability of coho fry to early season high flows (Scrivener and Andersen 1984). Elevated summer stream temperatures beyond optimal levels can reduce growth and vigor of fry, increase susceptibility to disease, and may also induce early smolt migration that results in reduced survival of juveniles in the ocean (Holtby 1988).

Beyond the effects on stream temperature, timber harvest causes changes in local microclimates that affect the use of riparian areas by climate-sensitive species such as amphibians. Harvested sites become drier, hotter in summer, colder in winter, and accumulate more snow and ice as a result of (Geiger 1965, Beschta et al. 1987):

- loss of shading by forested vegetation;
- loss of fog drip and other sources of humidity;
- increased evaporation due to exposure and wind;
- reduced or lost interception of snowfall by forest canopies;
- loss of heat and cold-moderating forest canopy and interior microclimate.

Loss of Large Woody Debris

One of the most significant long-term effects of forest management on fish and wildlife habitat quality involves the reduction of large woody debris in streams and on the land (Harmon et al. 1986, Sedell et al. 1988). Past and present timber harvest in and adjacent to riparian areas typically removes the large, durable conifers that contribute a constant source of large woody debris to streams. Large woody debris recruitment is further reduced when forests are managed with short rotation intervals. Because of this, smaller and fewer deciduous and coniferous logs are typical in streams in managed landscapes (Bisson et al. 1987, Agee 1988, Andrus et al. 1988, Morman 1993), resulting in an overall decline in quality and quantity of fish and wildlife habitat.

Historically, large logs were removed from riparian areas, streams, and rivers for timber and to facilitate instream transportation of felled trees. Dams were constructed to impound water and hold logs. When the impoundments were full, the water was released and logs and water were sluiced downstream in a flood to carry logs to the mill. This transportation system scoured stream channels and banks, removed woody debris, and damaged riparian vegetation. Some medium to large-sized streams and rivers are still recovering from that damage (Sedell and Luchessa 1982).

Early misconceptions regarding the effect of woody debris left in streams after logging resulted in a common practice of woody debris removal following logging between 1950 and 1970. It was believed that woody debris was a concern regarding water quality, permeability of spawning gravel, and reduced fish passage (Froehlich 1970, Narver 1970, Hall and Baker 1975, Bryant 1980). The combination of timber harvest, instream transportation, and the intentional removal of woody debris from streams to supposedly enhance fish production have resulted in a substantial loss of large woody debris in most streams (Sedell and Swanson 1984). Scientists and land managers now more universally recognize the vital role of woody debris in aquatic and terrestrial ecosystems.

Large logs are important in providing instream channel structures, such as pools and riffles, that are critical to salmon spawning and rearing (Montgomery and Buffington 1993). As the size of individual logs or log accumulations increases, the size and stability of pools that are created also increase (Beschta 1983). Small logs may not have the capacity to provide the same habitat features as large logs. The abundance and size of woody debris declines over the short-term with timber harvest and over the long-term with short rotation periods. On the Olympic Peninsula, Cederholm and Peterson (1985) found an average of 29.4 pieces of LWD/100 m (328 ft) in harvested streams versus 59.9 pieces of LWD/100 m (328 ft) in areas not logged. This trend is also supported by Sedell et al. (1985) and Grette (1985). Reductions in the amount of large woody debris occurred in many harvested areas even though some attempt was made to protect the stream bank and retain some riparian vegetation. Riparian forests that undergo harvesting of large trees take on second-growth characteristics and do not provide the same level of woody debris as do unmanaged, old-growth systems (Bisson et al. 1987). Sufficiently wide, carefully managed riparian buffers that retain a full complement of ages, sizes, and species of native trees and vegetation can, however, provide adequate large woody debris to streams (Bisson et al. 1987, Murphy and Koski 1989, Morman 1993).

Large conifer logs are the most valuable source of woody debris because of their size and durability (Bisson et al. 1987). In the absence of reforestation, logged riparian areas are often naturally revegetated with deciduous hardwoods (e.g., red alder and bigleaf maple). Although some woody debris is provided to the stream system by deciduous hardwoods, it is generally smaller in diameter and much shorter lasting than debris provided by conifers. Grette (1985) found that after clear-cutting, the majority of woody debris contributed to streams was deciduous; not until 60 years after logging did conifers begin to contribute woody debris. It can take considerably longer for conifers to re-establish riparian areas, grow to large sizes, die, and become large woody debris in streams. Because historical land use practices in riparian areas generally involved tree removal and natural revegetation, there is currently an overabundance of riparian areas dominated by deciduous trees and a consequent paucity of large conifer woody debris in streams (Grette 1985, Bisson et al. 1987).

Forest management does contribute woody debris to stream systems, but it is often delivered in episodic events and is usually small in diameter (Swanson and Lienkaemper 1978). Debris inputs in managed forests occur in association with timber harvest or with erosion related to roads or hydrologic changes. Post-harvest loading of streams with small diameter woody debris has been documented by a number of researchers (Lammel 1972, Froehlich 1973, Toews and Moore 1982, Swanson et al. 1984, Hogan 1986). For a period of time after harvest, the movement of small diameter debris to streams may continue during flood events (Osborn 1981, Bilby 1984). The effect on habitat of a change from large to small diameter debris in stream systems is not yet clear. However, it is expected that small debris will not remain in a stable location long enough to form habitat features associated with large logs, and it is not clear whether those features can even form with small debris. Efforts to clean streams after timber harvest have generally resulted in additional fish habitat degradation rather than improvements (Bisson et al. 1987).

It would seem that old-growth conditions should provide the model for optimal quantities of woody debris because fish and wildlife have evolved with a large portion of forests in that condition. However, a clear scientific understanding of optimal quantities of woody debris has not yet been established. In the absence of such information, Bisson et al. (1987) offer the following characteristics of streams that do not have adequate amounts of large woody debris:

- insufficient numbers and quality of pools;
- lack of storage sites for sediment and organic matter;
- loss of hydraulic complexity;

- lack of hiding places from predators;
- loss of winter cover.

In contrast, they offer a similar description of characteristics of streams with excessive woody debris:

- the presence of debris dams that completely block upstream spawning migrations;
- a substantial impairment of water quality;
- the presence of numerous floatable debris pieces that have a high probability of being moved during storms and which pose a significant threat to life, property, or aquatic habitat downstream;
- debris accumulations that strongly interfere with important recreational uses such as fishing, swimming, and boating.

Present forest management regulations and guidelines have focused on the riparian habitat functions of stream temperature control and erosion control and have not adequately addressed the provisioning of large woody debris to support fish production and wildlife dependent on snag and woody debris (Bisson et al. 1987).

Fish and Wildlife Effects

The short-term response of fish populations to the effects of timber harvest have not been clearly quantified in terms of population numbers (Reeves 1994). However, long-term responses of fish populations in clear-cut watersheds are more clearly identified as negative (Bilby and Ward 1991, Schwartz 1991, Reeves et al. 1993). This negative response is a result of cumulative effects of increased sedimentation, temperature changes, loss of LWD, and changes in hydrology. In response to changing instream habitat conditions that largely result in habitat simplification, changes in the fish species composition will also occur (Sullivan et al. 1987).

When riparian areas or adjacent forests are logged, the composition of terrestrial wildlife that previously occupied the area changes. Tree removal in or adjacent to riparian habitat often results in a shift of wildlife species from forest interior and riparian habitat specialists to habitat generalists, early-successional species, or edge-loving species (Haga 1960, Gashwiler 1970, Medin 1985). Survival of displaced interior animals depends on whether mature forest stands with sufficient resources (e.g., food, cover) to support additional animals exist nearby. Species that tend to decrease or are eliminated locally as a result of clear-cutting include microclimate-sensitive amphibians, interior forest and riparian associated neotropical migrants, cavity-nesting species (including woodpeckers and many owls and raptors), late-successional species, cavity or crown-dwelling mammals (including the northern flying and Douglas' squirrels), and members of the mink family (Gashwiler 1970, Medin 1985, Triquet et al. 1990). Regenerating clear-cuts or remnant riparian strips adjacent to clear-cuts, on the other hand, support enhanced populations of ground-foraging or fly-catching songbirds, open-country raptors (notably the red-tailed hawk), and mammals adapted to foraging in herbaceous or shrubby habitats (e.g., deer mice and black-tailed deer) (Hagar 1960, Gashwiler 1970, Kessler and Kogut 1985, Medin 1985).

In general, changes in wildlife abundance and diversity are brought about by the following consequences of forest practices (Harris 1988, Gates and Giffen 1991):

- loss of interior forest habitat within and adjacent to riparian areas;
- loss of snags and downed woody debris;
- loss of late-successional forest stages;
- loss of hiding cover;
- direct human disturbance, which is exacerbated by lack of cover and the presence of roads;
- habitat fragmentation;
- deleterious “edge effects,” including encroachment by nest predators and early-successional plant species;
- degradation of the aquatic habitat.

In general, forest practices reduce the relative abundance of rare and more specialized riparian or aquatic species, forest interior species, those requiring intact forest canopies, and species dependent on snags and downed woody debris. Logging in the uplands affects the riparian habitat wildlife community because the two are in close functional association with respect to wildlife usage (McGarigal and McComb 1992).

Cumulative and Long-Term Effects

Forest practices can cause significant changes in the character of streams and their associated riparian habitat across the landscape and over the long-term. In general, both instream and riparian habitats are simplified over time (Bisson et al. 1992, Franklin 1992). This simplification causes a shift in the composition and organization of animal communities and reduces the ability of riparian and aquatic systems to support abundant and diverse populations of fish and wildlife. Habitat simplification causes the elimination or reduction of particular guilds of fish and wildlife that have specific requirements or that are sensitive to habitat disturbance. Reduction in habitat quality and habitat simplification can also cause a shift in baseline levels of fish growth, survival, and abundance (Geppert et al. 1984).

Cumulative effects are the result of the interaction between multiple forest practice actions over time. Geppert et al. (1984) described the principal forest practices that contribute to such effects on riparian ecosystems.

- Actions that physically disturb or alter the soil (roading and timber harvest). This results in accelerated erosion and an increase in mass wasting that results in water quality degradation and changes in the timing and volume of run-off.

- Actions that remove excessive quantities of biomass (high utilization harvesting), especially in combination with short rotations and prescribed fire. This results in a gradual decline in nutrients that leads to changes in productivity and composition of forest vegetation. It also reduces the size and quantity of dead and down woody material that affects both stream habitat quality and riparian habitat niches for many fish and wildlife species.

- Actions that change the composition and structure of flora (timber harvest and short rotations). This results in conversion of unmanaged to managed forests with decreased structural and functional diversity.

Extensive timber harvest within a watershed over a relatively short time results in a large portion of the watershed being in early-successional stages. This condition and the cumulative effect of the short-term changes noted above (e.g., loss of LWD) cause fundamental changes to stream morphology and riparian habitat structure and function, with consequent local or regional extirpation of fish stocks and wildlife species (Nehlsen et al. 1991, Franklin 1992).

Specific changes in the overall form of stream channels that may result from cumulative forest practices include (Everest et al. 1987, Hicks et al. 1991a, Bisson et al. 1992):

- decreased water levels and overall stream channel depth;
- increased channel width;
- increased bed and bank instability;
- simplification of the stream channel, including loss of instream habitat features (e.g., logs), and a reduction of pools, side channels, and stream braiding.

Long-term changes to the riparian habitat character also result from multiple forest practices over time. These changes to riparian habitat structure and function include (Geppert et al. 1984, Franklin 1992, Wissmar et al. 1994):

- simplification of the plant community, both in composition and structure;
- reduction in area;
- changes in microclimate and water balance.

The nature and severity of cumulative effects are highly variable. Slopes, soils, climate, timing, and the size and extent of timber harvest will all influence the above processes. Large-scale clear-cutting of watersheds, high road densities, and broadcast burning are practices that have been associated with the most severe impacts to both riparian and upland ecosystems

(Swanson et al. 1987, Agee 1988). However, with consideration of the cumulative effects on fish and wildlife habitat and careful watershed level planning, and with the implementation of new innovative approaches to forest practices, cumulative impacts can be reduced (Franklin 1992).

Short rotation intervals in intensively managed forests increase the frequency of harvest, thereby increasing the frequency of disturbances related to harvest (e.g., human disturbance, road construction and maintenance, vegetation disturbance, and soil disturbance). This may affect the rate of erosion by slides and surface processes on the time scale of several rotations. For example, shorter rotation lengths may increase the occurrence of land slides because a greater proportion of a drainage basin is in the sensitive condition of reduced root strength at any given time (Swanson et al. 1987).

Eastern Washington Forest Health

Concern regarding the overall health of eastern Washington forests, including riparian habitat, has been raised by Everett et al. (1994). The decline in ecosystem health has resulted from the combined effects of many land uses but is primarily related to forest and rangeland management (Everett et al. 1994). The problems that have developed in eastern Washington forests illustrate the need to manage large areas (e.g., watersheds, entire ecosystems) and consider all land uses and habitat types simultaneously if sustainable ecosystems are desired. It also illustrates the effects of actions in one habitat type on other habitats (e.g., fire suppression in upland forests and its effects on riparian habitat).

The U.S. Forest Service examined the history and current condition of eastside forests in order to determine actual threats to forest health. They determined that long-term productivity of present-day eastside forests, rangelands, and aquatic ecosystems are threatened by (Everett et al. 1994):

- intensified or altered disturbance regimes (fire, insects, disease, flooding, grazing);
- soil erosion and mass movements events;
- damage to soil structure, density, nutrients, microbes, and development process;
- reduction in water quality and yields;
- alterations to soil, water, and air chemistry;
- damage to riparian habitats and side slopes.

The causes of these threats are related to long-term manipulation of the land and its resources by people. The specific practices that have resulted in diminished ecosystem health (indicated by diversity and long-term productivity) are (Everett et al. 1994):

- effective fire prevention and suppression;
- selective timber harvesting and tractor logging;

- grazing by livestock and wildlife;
- pest suppression;
- roads and access management;
- management of fuels;
- custodial land management of wilderness and wildlife habitat areas;
- mining and waste disposal;
- flood control and withdrawal of irrigation water.

The U.S. Forest Service assessment found that most management practices were based on objectives inappropriate to conserving biodiversity and long-term productivity (Everett et al. 1994). Furthermore, they concluded that in order to return eastside ecosystems to a sustainable condition, disturbance effects, biological diversity, and long-term productivity should be restored to historical ranges of variability.

As a result of these land use practices, the major riparian and stream habitat changes documented for eastside forests are (Wissmar et al. 1994):

- loss of riparian vegetation and increased canopy openings adjacent to stream channels;
- loss of riparian vegetation and decline of large woody debris in stream channels;
- increases in water temperatures from minimal shading by riparian canopies and from shallow-sediment and debris-laden stream channels;
- accumulation of fine sediments and loss of gravel and pools in stream channels because of land uses that alter stream flow regimes and sediment budgets;
- loss of water in stream channels and riparian areas because of water diversion practices.

Although it has been difficult to establish quantifiable relationships between land use practices and long-term trends in fish abundance (Bisson et al 1992), the body of literature concludes that land use practices have simplified fish habitat, resulting in the loss of fish species diversity and fish numbers (Hicks et al. 1991b, Meehan 1991, Bisson et al. 1992). The Snake River spring/summer chinook and sockeye salmon have been recently listed under the Endangered Species Act. In addition, the American Fisheries Society has listed 76 native anadromous salmonid stocks in the Columbia River Basin as at a high or moderate risk of extinction (Nehlsen et al. 1991). Anadromous stocks in the Yakima River Basin are also particularly imperiled (McIntosh et al. 1994). These population declines have occurred simultaneously with reductions in riparian and instream habitat quality and diversity over the last 50 years (McIntosh et al. 1994).

Riparian habitat problems somewhat unique to eastern Washington forested areas (compared with western Washington) are related to fire management, livestock grazing, mining, and irrigation. Impacts of livestock grazing are discussed in the section on grazing (p. 60), and impacts related to irrigation are discussed in the section on agriculture (p. 56).

The effect of fire suppression has influenced riparian and stream habitat (Wissmar et al. 1994). Eastern Washington forests evolved with a natural fire regime that included both high-intensity crown fires and low-intensity underburns. Because of the dry climate and resultant fire history, most forest stands were replaced at intervals of 300 years or more (Agee 1994, Wissmar et al. 1994). During those intervals, frequent (5-10 year) low-intensity fires maintained open stands with mostly fire-tolerant tree species. Modern fire suppression, selective timber harvest of fire-resistant species, and livestock grazing over the last century have collectively changed the fire disturbance pattern in eastern Washington forests. This has resulted in stands with dense understories, dense reproduction, and more fire-intolerant species (Mullan et al. 1992). Compared to historical levels, there are now higher fuel accumulations in eastern Washington stands and more intense and destructive fires as a consequence (Wissmar et al. 1994).

The increase in fire severity causes increases in sediment, debris, and water flow to streams. Nutrient loading of organic nitrogen also increases after intense fires (Wissmar et al. 1994). Massive debris torrents that are 10 to 28 times greater than before these intense fires have been documented for the Entiat River Basin (Helvey 1980). These large inputs of sediments and debris overwhelm the transport capacity of the stream channel, thereby altering habitat complexity and dynamics. Fine sediment deposition can destroy spawning grounds, suffocate fish eggs, and displace juvenile fish and aquatic insects, although new habitat may be created elsewhere with the redistribution of large woody debris (Wissmar et al. 1994). The increased dynamics of stream channels that result from these more frequent intense fires increase riparian habitat dynamics beyond natural levels.

Although it is unclear as to the magnitude of mining impacts on riparian and stream systems across eastern Washington, some general effects have been documented. Recent effects of mining on stream and riparian ecosystems include water contamination with leachates from leach mining (e.g., cyanide chemical-leach mining for gold) and the excavation of stream channels and floodplains for sand and gravel (Wissmar et al. 1994). A leach mine is currently under consideration near Chesaw in the Okanogan Highlands. Mining of sand and gravel from river beds and gravel bars has occurred in Okanogan County and many other eastern Washington areas. Removing gravel from rivers can alter flow patterns in channels and overload aquatic habitats with sediments (Rivier and Sequier 1985, Carling 1987). This causes changes in substrate composition, depth, velocity flow patterns, turbidity, suspended sediments, and temperature, all of which determine the abundance and biodiversity of aquatic organisms (Binns and Eisermann 1972, Bjornn and Reiser 1991).

The cumulative effects of timber harvest, fire suppression, livestock grazing, mining, irrigation, and other factors have greatly altered the health of river basins in eastern Washington (Wissmar et al. 1994) and has consequently lead to widespread declines in anadromous fish populations (McIntosh et al. 1994). The Eastside Forest Ecosystem Health Assessment team has concluded that in order to restore healthy forest systems, including riparian and stream habitats, disturbance regimes need to be returned to historical ranges (Everett et al. 1994). The disturbance regimes that need restoration are fire regimes, defoliator and bark beetle outbreaks, root disease and dwarf mistletoe epidemics, livestock grazing, and hydrologic regimes. Restoring disturbance regimes to natural levels will reverse the simplification of ecosystems that is generally caused by human-induced disturbances (Everett et al. 1994). Regaining natural diversity will create plant and animal communities that are more resistant to change and better able to sustain themselves over time.

Roads

Whether constructed as a part of forest practices, agriculture, recreation, or urbanization, roads may have significant and long-lasting impacts on riparian and instream habitat and their fish and wildlife populations (Larse 1970, Thomas et al. 1979, Oakley et al. 1985, Furniss et al. 1991, Hicks et al. 1991b, Noss and Cooperrider 1994). Roads of all types and locations (not including foot trails) affect riparian or stream systems by changing the drainage of a watershed, removing riparian habitat, or by causing mass soil movement, erosion, and subsequent sedimentation into streams. The degree of these effects is related to the road location, construction and maintenance techniques, and to the manner in which roads cross streams. Roads more directly affect fish and wildlife populations by removing riparian habitat, altering instream habitat, introducing human disturbance to riparian and stream areas, acting as a barrier to movement, and causing vehicle-related mortality of wildlife. To prevent or reduce impacts, road planning and route selection by an interdisciplinary team is perhaps the most important single element of road development (Larse 1970).

Although we know that the total length and density of roads have increased in expanding urban areas of Washington, no specific information on the rate of increase and on the overall road mileage, density, or distribution is available (L. Fenstermaker, pers. comm.). On National Forest land in Oregon and Washington, road mileage has risen from 33,850-36,900 km (22,000-24,000 mi) in 1962 to over 138,460 km (90,000 mi) in 1990 (Reeves and Sedell 1992). It has been estimated that about 3,000 miles of new roads are constructed annually on forest lands in the western forested area of the United States (Larse 1970). Many of these newly created forest roads are built without adequate consideration of riparian and fish habitat (Reeves and Sedell 1992). As the density of roads increases, road impacts on riparian and stream systems will inevitably worsen. Roads may have unavoidable effects on streams, no matter how well they are located, designed, or maintained (U.S. For. Serv. et al. 1993).

Effects on Hydrology

Forest road networks (including haul roads, skid trails, and landings) can have a lasting influence on hydrologic response by altering the way water is routed through the watershed (Reeves and Sedell 1992, U.S. For. Serv. et al. 1993). The alteration of water flow affects physical processes in streams and can lead to changes in stream flow regimes, sediment transport and storage, channel bank and bed configurations, substrate composition, and stability of slopes adjacent to streams. These changes can have significant biological consequences that affect virtually all components of stream and riparian ecosystems (Furniss et al. 1991).

Over a large portion of the state, undisturbed soils are highly permeable and can absorb essentially all incident precipitation; overland flow is rare. Roads and skid trails are the chief contributors to soil compaction; these surfaces are much less permeable and more likely to generate overland flow (Megahan 1972). In addition, road cuts may intercept subsurface flow and convert it to overland flow. Run-off occurring as overland flow can generate adverse impacts in several ways. During winter storms, run-off is routed more quickly through the watershed via the road drainage system; this in turn may serve to increase storm peaks if the road network is well connected to the channel network (Wemple 1994, B. Gardiner, pers. comm.). Water lost in rapid surface flows is not available for aquifer recharge and maintenance of stream flows during dry periods (Harr 1986, Chamberlin et al. 1991).

Changes in the hydrologic system caused by roads are most pronounced where road densities are the greatest (Harr et al. 1979, Ziemer 1981, Wright et al. 1990). Watersheds that are cable-logged may have up to 15% of their area in roads and landings; ground-based operations may typically have 25-35% of their area in roads, skid trails, and landings (Harr et al. 1979). The longevity of hydrologic changes resulting from roads is as permanent as the road. Until a road is removed and natural drainage patterns are restored, the road will likely continue to affect water routing throughout watersheds (U.S. For. Serv. et al. 1993). Even lightly used skid trails may take longer than 35-40 years to recover (Cafferata 1992).

Erosion and Sedimentation

Road networks in many upland areas of the Pacific Northwest are the most significant source of management-accelerated delivery of sediment to aquatic habitats (Ice 1985, Swanson et al. 1985). The sediment contribution to streams from roads is often much greater than that from all other land-management activities combined, including log skidding and yarding (Gibbons and Salo 1973). Road-related landsliding, surface erosion, and stream channel diversions frequently deliver large quantities of sediment and debris to streams, both chronically and catastrophically during large storms (Swanson and Dyrness 1975, Swanston and Swanson 1976, Beschta 1978, Gardner 1979, Yee and Roelofs 1980, Reid and Dunne 1984). Water flowing over the road surface has the potential to erode and entrain fine sediments and deliver them to streams (Furniss et al. 1991, Cafferata 1992). Drainage systems may also route excess water to high-gradient concave slopes, increasing the potential for mass wasting (Swanson et al. 1987). Improperly located, constructed, or maintained roads may initiate or accelerate events that lead to slope failure and erosion. Many older roads with poor locations and inadequate drainage control and maintenance pose high risks of erosion and sedimentation of stream habitats (U.S. For. Serv. et al. 1993). High road densities may result in increased frequency of debris avalanches which can cause massive sediment entry into streams (Reeves and Sedell 1992).

On federal lands within the range of the northern spotted owl, there are 110,000 miles of roads and an estimated 250,000 stream crossings (culverts), with an average road density of 4.22 mi/mi^2 (U.S. For. Serv. et al. 1993). The majority of these steam crossings cannot tolerate more than a 25-year flow event without failure. When stream crossings fail, a local dam-break flood usually occurs, resulting in severe impacts to water quality and habitat (U.S. For. Serv. et al. 1993). Culverts at stream crossings can also impede fish migration if their design, installation, or size is inadequate. For example, culverts that are too small to pass debris impede fish movements. Accumulations of debris at culverts can also exacerbate stream crossing failures and local flooding.

Habitat Removal, Disturbance, and Mortality

Roads within riparian habitat reduce the ability of the area to support wildlife by removing or altering habitat, introducing disturbance which makes areas unsuitable to sensitive species, and by vehicle mortality of wildlife (Thomas et al. 1979, Oakley et al. 1985, Noss and Cooperrider 1994). Roads are commonly constructed parallel to stream and river courses for scenic reasons and for ease of construction because valley bottoms generally have more gentle topography than side slopes. Roads parallel to streams isolate the stream system from uplands and remove or alter substantial amounts of riparian habitat. Roads and highways parallel to streams and rivers constrain the natural development of meanders, side channels, and attached wetlands (Everett et al. 1994). In low gradient areas, the development of sinuous stream channels creates well-developed riparian habitat and slow moving water that is good fish habitat, especially for rearing.

Roads provide easy access to live and dead wood collected for firewood. Snags are particular targets for firewood collection, but they provide a key habitat feature for cavity-nesting ducks, osprey, bald eagle, and a variety of other cavity-using species that are drawn to riparian areas (Rodrick and Milner 1991, Noss and Cooperrider 1994).

Roads are often entry points and avenues for the introduction and expansion of plants and animals, including exotic species, that thrive in disturbed environments. These invading species often out-compete native plants and animals, thereby inhibiting the re-establishment of healthy riparian communities. In the Pacific Northwest, Port Orford cedar root rot fungus, black-stain root disease fungus, spotted knapweed, and the gypsy moth are all known to disperse and invade natural habitats via roads and vehicles (Schowalter 1988).

The additional access provided by roads encourages riparian and stream use by people. Some wildlife species are more sensitive and vulnerable to disturbance than others. Examples of species that use riparian and aquatic habitat and that are vulnerable to disturbance are great blue herons, bald eagles, osprey, marten, and calving elk (Rodrick and Milner 1991). Areas where fish concentrate (e.g., spawning grounds) are also vulnerable to harassment and poaching pressure if human access is easy. These species will leave a breeding site or cease using the area if human disturbance, often facilitated by roads, is high.

Roads contribute to high mortality of some species by poaching, collecting, and high hunting pressure (Noss and Cooperrider 1994). Open road density has been found to be a good predictor of large mammal habitat suitability; population viability of some large mammals decreases as the road density increases. Research on elk in the Pacific Northwest and the Rocky Mountains has found that a road density of one mile per square mile of habitat can decrease habitat effectiveness for elk by 40% compared to roadless areas. When road density increases to 6 mi/mi^2, use of habitat by elk is negligible (Lyon 1983, Wisdom et al. 1986). Similarly, wolves cannot persist where road density exceeds about 0.9 mi/mi^2 (Thiel 1985, Mech et al. 1988). This is not because wolves avoid roads but because their use of roads for travel makes them accessible to poaching. Grizzly bears are similarly impacted by roads (McLellan and Mace 1985, Mattson et al. 1987, McLellan and Shackleton 1988), as are black bears in some locations (Brody 1984).

Barrier to Wildlife Movement

Roads act as barriers to the movement of some small animals (Noss and Cooperrider 1994). When wildlife is hesitant or unable to cross roads, habitat parcels effectively become isolated. This segregates some populations in small habitat fragments, thereby increasing their likelihood of local extinction. Roads parallel to riparian areas prevent the movement of some species between upland and riparian areas, including those whose requirements may include both ecosystems. For example, some amphibians (e.g., rough-skinned newt, Dunn's salamander, western red-backed salamander, Pacific tree frog, red-legged frog) breed and spend a portion of their time in aquatic areas, but they also use upland habitats for dispersal and other functions (Leonard et al. 1993). In an eastern Canada study, several species of small mammals were found to rarely venture onto road surfaces when the road width exceeded 20 m (Oxley et al. 1974). Another study in Germany found that two species of forest rodents and several species of carabid beetles rarely or never crossed two-lane roads and even smaller, unpaved roads (Mader 1984). Two other rodent species (dusky-footed woodrats and red-backed voles) were found near interstate highways but never in the highway right of way (Adams and Geis 1983). Roads have also been found to impede movement of small mammals in open environments (Garland and Bradley 1984, Swihart and Slade 1984). Others have documented the effect of roads as a barrier to wildlife movement for animals as large as black bears (Bennett 1991, Brody and Pelton 1989).

Agriculture

Beyond the obvious loss of riparian habitat as a result of direct conversion to agricultural land, the effects of agricultural operations on riparian areas generally consist of an excessive supply of non-point source pollution. Because riparian and aquatic systems are the eventual recipients of sediments, fertilizers, pesticides, and wastes, agricultural activities influence the function of stream and riparian ecosystems.

Soil Erosion and Sedimentation

Sediment is considered a source of non-point pollution and is the most common and easily recognizable impact of agriculture on riparian systems. Erosion from croplands accounts for 40-50% of the sediment in waterways in this country (Terrell and Perfetti 1989). As with other land use practices, careful management of croplands can greatly reduce the amount of erosion and stream sedimentation.

Beyond storm-related erosion of topsoils, irrigation water carries significant amounts of fine sediments to stream and river systems. Sheet flow and rill irrigation systems result in the greatest surface erosion. Drip irrigation and piped laterals greatly reduce sediment loading. Hop fields and vineyards are the primary contributors of sedimentation because they generally employ intensive tillage of highly erodible soils, use rill irrigation, and have significant quantities of irrigation waste water that discharges to natural streams (P. Harvester, pers. comm.).

Sedimentation in fish-bearing waters affects habitat quality and fish survival in a number of ways. Fine sediments are deposited throughout the system and cover gravel bottoms. Stream bottoms covered with fine sediments are no longer suitable for spawning. Sediments cover and suffocate fish eggs and fry. High sediment deposits also block fish passage to upper spawning reaches. Suspended sediments clog the gills of fish, decrease dissolved oxygen levels, inhibit fish feeding and growth, and suppress macroinvertebrate food sources (Oregon-Washington Interagency Wildlife Committee 1979, Theurer et al. 1985, Everest et al. 1987).

Besides directly affecting water quality, stream sedimentation has other secondary impacts. Pesticides, herbicides, toxic heavy metals, and nutrients bind to sediments and are carried into water systems in greater proportions than by water flow without sediments. Irrigation water returned to natural systems through artificial waterways are particularly laden with harmful chemicals. Turbidity caused by sedimentation also increases stream temperatures due to increased absorption of solar radiation. State temperature standards are frequently exceeded in the Yakima River (Rinella et al. 1992) and cause significant juvenile salmonid mortality, increased predation, delayed adult migration, and increased incidence of bacterial and fungal infections (P. Harvester, pers. comm.).

Sedimentation in the Yakima River downstream of extensive agricultural lands provides an example of the effects of farming-related activities. The amount of suspended sediments in river water below farmland was double that of the upper basin (Rinella et al. 1992). The largest concentrations of suspended sediments corresponded with high flows resulting from snow-melt, storm run-off, periods of peak irrigation, and the start of the irrigation season. Because of this, virtually all of the spawning habitat in the lower 100 mi of the Yakima River is considerably above sediment thresholds, and redd mortality is very high. Fall chinook stocks have been nearly eliminated from this area and remain only in a few high-gradient riffles. Coho have been extirpated here for about 20 years (P. Harvester, pers. comm.).

Pesticides and Fertilizers

Terrell and Perfetti (1989) report that impacts to fish from pesticide pollution include decreased survival rates in juvenile fish, birth defects, altered reproduction, lower productivity, and changes in fish species composition. Many insecticides kill both target and nontarget insect species, thereby reducing species diversity and populations of aquatic bottom-dwelling organisms. Aquatic plants that provide food and cover to fish can be particularly sensitive to some herbicides. Less is known about the impacts to microscopic phytoplankton.

Wildlife associated with aquatic ecosystems can also be affected by some pesticides or agricultural chemicals. Grue et al. (1986, 1989) reported direct and indirect effects of chemicals on wildlife. Direct effects included mortality to adults, juveniles, or embryos; reduced reproductive success; anorexia and loss of body-weight; and retarded growth in young. Behavioral changes included reduction in the ability to court and tend to young, and a greater susceptibility to predation. Indirectly, treatments with pesticides (particularly insecticides and herbicides) can reduce plant and insect food sources for wildlife species. Reductions in food sources can cause stress, nest abandonment, or relocation.

Amphibians are particularly sensitive to aquatic contaminants (Holcombe et al. 1987, Power et al. 1989, Hall and Henry 1992), in part because many species respire through their skin which increases absorption of water and water-borne toxins (Boyer and Grue 1995). Eggs of most amphibians develop exclusively in aquatic environments, further exposing them to aquatic toxins. A study in the Klamath Basin National Wildlife Refuge found that contaminated irrigation drain water from adjacent agricultural areas resulted in significant malformation and high mortality of developing frog embryos (Boyer 1993). Water contamination as well as habitat loss are key factors suspected in causing declines in many amphibian populations worldwide (Boyer and Grue 1995).

In an assessment of water quality trends in the Yakima River Basin between 1974 and 1983, increased concentrations of orthophosphate, ammonia, nitrites, and nitrates in the Yakima River were found downstream from the Kittitas Valley where irrigation of agricultural land occurs

(Rinella et al. 1992). These chemicals were present in higher quantities as a result of upland application of fertilizers and livestock waste. Concentrations of several trace organic compounds (found in pesticides) exceeded state water standards for chronic toxicity of freshwater aquatic life.

Animal Wastes

Unless otherwise noted, the information in this section is based on material from Terrell and Perfetti (1989).

Animal wastes carried by surface run-off contaminate the receiving water body with pathogenic and nonpathogenic micro-organisms, biodegradable organic matter, nutrients, and salts. Poor management of animal waste from feedlots, stockyards, and pastures has contributed to degraded water quality, reduced fish production, and significant fish kills. For example, nutrient concentrations (derived from both fertilizer application and animal waste) in some sites of the lower Yakima River exceeded Environmental Protection Agency's (EPA) chronic-toxicity criteria for the protection of salmonids and other sensitive coldwater fish species and, at one site, had levels exceeding EPA's National Primary Drinking Water Regulations (Rinella et al. 1992).

Animal wastes are a potential source for about 150 diseases, many of which are harmful to people. Climate, soil type, infiltration rate, and topography are factors that influence the nature and amount of disease-producing organisms reaching a water body. Feedlots, stockyards, waste treatment and control facilities (such as manure lagoons), and manure (slurry or solid form) improperly applied in or near riparian areas are concentrated sources of pollution and disease-bearing organisms. Heavily used or improperly managed pastures and rangelands may become major sources of pollution by the sheer volume of urine and feces deposited in or near a stream.

Run-off from concentrated manure sources can effectively alter water quality in streams and cause lethal conditions for fish. Animal waste contaminates water with oxygen-demanding organic matter. Upon entering a standing body of water (e.g., ponds, backwater areas on streams), manure is subject to natural decay. Biochemical oxygen demand (BOD) increases in the decomposition process. As BOD increases, dissolved oxygen decreases and ammonia is released, and these changes are stressful to fish. Manure applied to frozen soil, bare soil, or immature crops with minimal ground cover is highly susceptible to increased run-off rates, particularly during spring snow melts or high rainfall events. Fish kills may result from these situations.

Manure, like chemical fertilizers, is rich in nutrients. Deposition of manure into water bodies can alter the water's natural chemical balance and result in excessive aquatic plant and algal growth. In the short-term, such growth may provide a temporary increase in food supply and cover that is beneficial to fish. However, long-term consequences may be detrimental to fish. Decaying plants deplete oxygen and increase nitrate levels which increase the acidity of the water. Excess acidity may slow fish growth and negatively impact reproduction. Abundance and species composition of bottom-dwelling organisms in waters receiving excess nutrients is altered. As composition and abundance of bottom-dwelling organisms is altered, fish species diversity significantly decreases and the abundance of a few nutrient-tolerant fish species increases.

Salts added to livestock feed can enter a water body through the animal's wastes. Increased salinity levels of streams, ponds, and wetlands may result in a shift of plant composition from freshwater to salt-tolerant species. This has a domino effect on the types of insects these communities support as well as on other species in the food chain. High salt concentrations have been known to cause severe toxic effects and birth defects or tumors in animals.

Irrigation/Water Withdrawal

Irrigation diversions and return flows have a direct impact on riparian habitat and water quality and quantity available for fish and wildlife. Water withdrawal reduces stream flows necessary to support fish populations. The reduction in water levels, particularly during the growing season, also reduces the ability of streamsides to support riparian vegetation. This causes a direct loss of riparian habitat and indirect changes to the stream system from the loss of riparian vegetation.

Water diversions can result in an inadequate stream flow for fish spawning, rearing, and migration (Sullivan et al. 1987). Redds or nests can become dewatered, depriving developing eggs of oxygen and waste-product flushing. Pools and quiet backwater areas are lowered or dewatered, thereby eliminating essential juvenile fish rearing and amphibian habitat (U.S. For. Serv. et al. 1993, Hicks et al. 1991a). A primary limiting factor of coho salmon production is a lack of adequate rearing habitat (Bryant and Sedell 1995). Upstream and downstream migration can be blocked by low water levels. Migration delays or blockages can affect upstream spawning migration of adults as well as downstream out migration of juvenile salmon. Delays to migration can cause increased mortality, (e.g., juveniles may be physically unprepared for their ocean phase of life), and adults may be forced to spawn in unsuitable stream sections which results in reduced survival of eggs.

Beyond the obvious effects of irrigation on the amount of riparian vegetation and water available to fish, there is an interplay between irrigation, sedimentation, and agricultural chemicals and nutrients that cause secondary impacts to water quality. Some of the water used for irrigation eventually returns to stream and river systems. During the irrigation season, as much as 80% of the lower mainstem Yakima River flow comes from returning irrigation water (Rinella et al. 1992). These return flows carry fine sediments, fertilizers, other nutrients and pesticides -- all substances that degrade water quality for fish (Rinella et al. 1992). In the Yakima River Basin, the highest concentrations of DDT occurred in the lower 110 mi of the river where agriculture is most intensive and mainstem flow is dominated by irrigation returns (Rinella et al. 1993).

Irrigation contributes to increased stream temperatures in two ways (Rinella et al. 1992). First, low flows that result from irrigation diversions tend to be warmer than naturally higher flows. Second, water returned to river systems that has passed through cropland and over the surface during irrigation tends to be warmer than if it were to pass through natural riparian vegetation and groundwater systems. In the Yakima River Basin, dissolved oxygen levels at more than 50% of the sites did not meet state standards (Rinella et al. 1992). Low dissolved oxygen levels are a consequence of warm stream temperatures and higher than normal respiration that occurs in nutrient-rich waters. These warm stream conditions and low levels of dissolved oxygen can result in lethal or near lethal temperatures for some fish species. High water temperatures also create a favorable environment for disease and fungal problems which contribute to decreased fish survival rates.

The cumulative effects of agricultural activities have resulted in a decline of anadromous fish runs from one-half million fish prior to 1880 (Davidson 1965) to runs of less than 12,000 (Rinella et al. 1992). The Confederated Tribes and Bands of the Yakama Indian Nation et al. (1990) summarized nine effects of agriculture on fish production in the Yakima River Basin:

1) Fish passage problems associated with irrigation diversions in the tributaries.
2) Passage and rearing habitat restrictions resulting from low stream flows in both the mainstem and the tributaries.
3) Adverse effects on spawning and rearing habitat associated with rapid fluctuations of daily flows downstream from large storage reservoirs.
4) Erosion of agricultural soils and subsequent deposition of fine-grained sediment on fall chinook spawning beds in the lower river.
5) False-attraction flows associated with agricultural return flows.
6) Degraded rearing habitat, including the lack of large organic debris, caused by prolonged, excessively high flow augmentation for irrigation.
7) Stream temperatures higher than 24 C (75° F) in the lower river, which constitute a partial thermal block for fish passage and decrease available habitat for native, cold-water species.
8) Pesticide concentrations above safe chronic-exposure levels for fish in the mainstem and in the agricultural return flows.
9) Degradation of riparian cover caused by grazing, agricultural activities, and low stream flows.

Grazing

Overgrazing is one of the most destructive forces in riparian ecosystems (Davis 1982) and is usually the result of inappropriate livestock management (Behnke and Raleigh 1978, Oregon-

Washington Interagency Wildlife Council 1979, Platts 1979). Grazing can affect all characteristics of riparian and associated aquatic systems, including vegetative cover, soil stability, bank and channel structure, instream structure, and water quantity and quality. Overgrazing is considered one of the principal factors contributing to the decline of native salmonids in the Pacific Northwest (Behnke and Zarn 1976, Armour et al. 1991).

While the general condition of rangelands in the United States has improved over the last century (Box 1979, Busby 1979), grazed riparian areas are in worse condition. The U.S. Bureau of Land Management estimated that of 217,254 ha (536,835 ac) of riparian habitat, 181,086 ha (447,464 ac) (83%) were in unsatisfactory condition (Almand and Krohn 1979). Riparian areas that have been and continue to be subject to overgrazing are primarily those in the semi-arid and arid regions (Behnke and Raleigh 1978).

The major reason for the continued decline of the quality of riparian habitat is that riparian areas are typically managed in the same way as upland areas, despite the fact that livestock use riparian areas more than uplands (Platts 1990). Because livestock concentrate in riparian areas, and because riparian areas are more sensitive to overuse, upland management schemes have usually caused significant degradation of riparian habitat even if uplands remain in good condition (Behnke and Raleigh 1978, Debano and Schmidt 1989, Elmore 1989, Platts 1989, Platts 1990). Riparian areas have also traditionally been considered “sacrifice areas” in range management schemes (Chaney et al. 1993).

Livestock are attracted to riparian areas because of the availability of: 1) water for drinking; 2) tender, palatable, and high-protein forage throughout most of the year; and 3) protection from the elements, particularly summer heat, by relatively dense vegetation (McLean et al. 1963, Skovlin 1967, Paulsen 1969, Ames 1977, Severson and Boldt 1978, Winward 1994, Edelen 1996). Because of this attractiveness, cattle spend 20-30% more time in riparian areas than elsewhere on their range (Platts 1990). Rivier and Drueger (1982) found that although riparian habitat covered only about 2% of a Blue Mountain grazing allotment, riparian vegetation accounted for 81% of the total herbaceous vegetation removed by cattle.

Consumption of shrubs, saplings, and herbaceous vegetation by livestock, coupled with compaction and trampling of soils, impacts fish and wildlife habitat in the following ways (Behnke and Raleigh 1978, Duff 1979, Kaufman and Krueger 1984, Davis 1986, Taylor 1986, Kovalchik 1987, Clary and Webster 1989, Kinch 1989, Platts 1989, Armour et al. 1991, Kovalchik and Elmore 1992, Goguen and Mathews 1993, Clary et al. 1996):

- Reduces or eliminates regeneration of woody vegetation.
- Changes plant species composition (e.g., xeric species and highly competitive exotic species invade, perennials are replaced by annuals, and trees/willows/sedges are replaced by brush and bare soil).
- Reduces overall riparian vegetation.

- Reduces overall plant vigor.
- Increases bank and instream deformation and erosion from loss of protective vegetation, and increases soil compaction and churning by hoof action, which lead to reduced water quality and changes in bank and channel integrity.
- Causes stream channel widening, shallowing, trenching, or braiding because of increased stream bank erosion.
- Reduces the ability of riparian habitat to trap and filter sediments and pollutants, leading to increased sedimentation and pollution from fecal matter of livestock.
- Increases stream temperatures as a result of lost cover provided by both woody and herbaceous plants.
- Results in loss of nutrient inputs, especially invertebrate food sources, to streams.
- Lowers the water table, with subsequent loss of riparian vegetation and stream flow.
- Increases the magnitude of high and low stream flow events.
- Reduces shrub and ground-nesting habitat for songbirds and other wildlife.
- Causes declines of amphibians, small mammals, and other ground-dwelling animals that need herbaceous and woody vegetation for food and cover.
- Increases songbird nest predation and brown-headed cowbird parasitism due to loss of shielding vegetation.
- Results in loss of structural and compositional diversity of plant communities, thereby reducing overall wildlife diversity.
- Reduces forage available for wild ungulates and other herbivores.

Many of these impacts occur as a consequence of heavy or unmanaged grazing. Unmanaged grazing is usually the result of traditional management practices that allow large numbers of cattle free access to riparian areas on a year-round basis (Kinch 1989, Chaney et al. 1993). However, even light to moderate grazing, in which 50% or greater of potential plant species and biomass remain at the site, results in identifiable changes in riparian habitat quality and fish and wildlife use (Schmidly and Ditton 1978, Thomas et al. 1979, Marlow 1988, Platts 1989).

Heavy livestock grazing adversely affects small mammals, reptiles, amphibians, ungulates, fish, and many birds (particularly shrub and ground-nesting herbivores and granivores) through the loss of cover, forage, and breeding structures and through competition with invading species (Crouch 1981, Kauffman et al. 1982, Mosconi and Hutto 1982, Ohmart and Anderson 1986, Taylor 1986, Medin and Clary 1989). Behnke and Raleigh (1978) found a three to four-fold decrease in the trout biomass in grazed versus ungrazed areas. As an indication that heavy grazing suppresses local wildlife populations, many kinds of animals, including some songbirds, game birds, waterfowl, raptors, deer, and small mammals, experience dramatic population increases when livestock are excluded from riparian areas (Winegar 1977, Duff 1979, Van Velson 1979, Crouch 1981).

Several studies have shown negative impacts on some avian populations in response to the loss of food, nesting structures, and habitat diversity as a result of grazing (Overmire 1963, Owens and Meyers 1973, Buttery and Shields 1975, Evans and Krebs 1977, Behnke and Raleigh 1978, Crouch 1978, Reynolds and Trost 1980). Ammon and Stacey (1997) noted differences in vegetation between a grazed and rested portion of a riparian pasture and documented greater rates of depredation on nests in the grazed pasture. Neotropical migrants, which as a group are highly associated with riparian habitat, are particularly impacted by grazing in riparian areas. Bock et al. (1993) reported that of 43 neotropical migrant species that used riparian woodlands, 17 species (those that nest or forage in heavy shrub or herbaceous ground cover) were negatively affected by grazing, 18 were unresponsive or showed mixed responses, and 8 species were positively affected. Those that benefitted from grazing included aerial foragers associated with open habitats (e.g., Lewis' woodpecker, mountain bluebird), ground foragers that prefer relatively little cover (e.g., American robin, killdeer), and species directly attracted to livestock (e.g., brown-headed cowbird). Other researchers have reported that grazing may improve habitat for avian species better adapted to open environments, particularly in areas with dense vegetation where grazing opens up the canopy (Burgess et al. 1965, Kirch and Higgins 1976, Crouch 1981). Killdeer and some gulls are examples of species better adapted to grazed conditions and that often out-compete local fauna occurring in an area prior to grazing (Crouch 1981).

Grazing Intensity

Degradation of riparian habitat by livestock is related to stocking levels, duration of grazing periods, and timing of grazing relative to plant development. The control of these three factors, regardless of the particular grazing system, is paramount in preventing damage to and facilitating recovery of riparian ecosystems (Van Poolen and Lacey 1979, Clary and Webster 1989, Clary et al. 1996).

Grazing strategies for entire pastures that contain riparian areas must be managed at a level that prevents damage to riparian areas; this may be at a level that is less than can be sustained by upland areas alone. As a general rule, managers should expect that when pastures are managed for an overall moderate grazing intensity (26-50%), riparian areas within pastures will be grazed at a disproportionately higher intensity (51-75%) (Platts and Nelson 1985b). Therefore, the uplands will need to be grazed below 25% in order to maintain grazing in riparian areas at 25-50% use if there is free access to both areas within a pasture. Independent management of riparian habitat (through fencing or herding) would enable greater utilization of uplands.

Platts (1990) recommends that riparian areas should only be grazed lightly. He defines light grazing as "... the amount of grazing that will cause no damage to the riverine-riparian system, and will allow riverine-riparian management objectives to be met" (Platts 1990:II-4). It has been reported that forage utilization above 40% results in unacceptable changes to riparian vegetation, especially browse on woody plants (Elmore and Beschta 1989). Less than 25-30% utilization results in insignificant riparian habitat changes and minimizes stream bank alteration (Platts 1981, Marlow 1988). However, "we must be prepared to acknowledge that on some range types even light grazing is too heavy" (Platts 1990:II-5).

In an evaluation of 34 grazing systems in place for 10-20 years, Myers (1989) found that vigorous woody plant growth and at least 15 cm (6 in) of residual herbaceous plant height at the end of the grazing season typified riparian areas in excellent, good, or rapidly improving condition. Kauffman et al. (1983) reported that a shift to shrub use does not generally occur (except for highly palatable shrubs) if 10 cm (4 in) of herbaceous stubble remains. Clary and Webster (1989), in their review of the literature, recommended retention of 10-15 cm (4-6 in) of stubble to maintain plant vigor, provide stream bank protection, and aid deposition of sediments to rebuild degraded stream banks. Elmore (1988) suggested that 3-4 in of stubble height be retained.

Season of Use

The nature of grazing impacts on riparian habitat is strongly influenced by the season of use. Overall, early-spring grazing shows the greatest promise for alleviating severe and long-lasting grazing impacts on riparian habitats (Platts and Nelson 1985b; Siekert et al. 1985; Crouse 1987; Elmore and Beschta 1987; Kovalchik 1987; Elmore 1988; Medin and Clary 1989; C. Perry, pers. comm; T. Thompson, pers. comm.). During the spring, the succulence of vegetation in the uplands is most similar to that in riparian areas, so cattle distribute their grazing more evenly. Because it is cooler in the spring, there is less tendency for livestock to seek heat shelter in riparian areas. Wet soils in riparian areas during the spring may also discourage livestock use. Spring grazing also allows sufficient time for plant regrowth before the end of the growing season. This regrowth is critical to maintaining plants with adequate root systems and above-ground mass needed to protect stream banks and prevent erosion during the upcoming winter stormy seasons (Clary and Webster 1989, Chaney et al. 1993). However, disturbance to nesting birds may be greater during this time. Spring grazing may also inhibit reproduction of some flowering plants and may be a particular problem if continued for many years (Kauffman et al. 1982). If weather conditions are particularly wet and use by cattle is heavy, stream bank deformation may be severe (Kinch 1989; T. Burke, pers. comm.). These problems can be lessened by controlling stocking levels and the duration of grazing. Because cattle are not as likely to concentrate in riparian areas in the spring, spring grazing in pastures that contain riparian habitat can alleviate the need to fence riparian areas in many situations in order to prevent damage.

Summer grazing, even with low stock levels, has the greatest impact on riparian habitat. Vegetation remains lush in riparian areas while uplands may have already dried out. Relief from summer heat and proximity to water contribute to high livestock concentrations in riparian areas (Clary and Webster 1989, Kinch 1989, Myers 1989, Platts 1989).

Late-season (fall and winter) grazing has variable effects on riparian habitat. In some areas its influence on plant communities and streamside soils is obvious, and in others it is not discernable (Kauffman et al. 1983). Late-season grazing may have less impact on stream channel degradation from trampling if soils and banks are dry or frozen (Marlow 1988, Kinch 1989), but stream bank erosion may also be significant with late-season grazing (Kauffman et al. 1983). Late-season grazing avoids disturbance of spring nesting birds (Kauffman et al. 1982). Utilization of grasses and other herbaceous plants is lower during the fall because of reduced palatability and availability (Kinch 1989). However, utilization of shrubs and tree saplings is greatly increased as cattle switch their feeding preferences to these components late in the growing season (Platts 1989, Grette 1990). Heavy utilization of herbaceous plants that do remain in the fall allows no time for regrowth before winter storms (Elmore 1989). However, removal of dead herbage during winter grazing may help stimulate regrowth in spring (Masters et al. 1996a).

Control of Grazing

Although early-spring grazing has the least detrimental effect on riparian habitat, there are both benefits and detriments to grazing in any season. What determines the success of riparian habitat protection is the control of grazing intensity. Careful supervision of livestock use and the removal of animals before damage occurs can prevent riparian and stream habitat degradation (Elmore 1989, Platts 1989).

Control of livestock use and distribution can be accomplished through diligent efforts on the part of range managers. A number of grazing management tools exist to help control livestock use of riparian areas, including fencing and the establishment of special use riparian pastures, pasture rest, variation of stocking rates, development of alternate water and shade sources, locating stock driveways away from riparian areas, constant herding, control of the kind of livestock (e.g., herded sheep, steers only), salting, and other innovative distribution control practices (Kauffman et al. 1983, Kauffman and Krueger 1984, Clary and Webster 1989, Kinch 1989, Platts 1989, Platts 1990, Winward 1994, Masters et al. 1996b). The use of alternate water and shade sources, providing salt sources away from riparian areas, and varying the stocking rates are all of limited success in drawing livestock away from riparian areas and preventing riparian damage (Platts 1990). Herding, if it is constant, can be very successful (Claire and Storch 1977, Storch 1978), but is not always feasible or affordable. Controlling the kind and class of animal can be very effective but is seldom used (Platts 1990). Sheep have been shown to exert less influence on certain riparian and aquatic areas. Sheep spend more time on slopes and upland areas, whereas unherded cattle prefer the lesser slopes or bottomlands (Platts 1990). More significantly, sheep are more commonly controlled by a herder who can better direct where sheep graze, while cattle are usually unsupervised (Platts 1990).

Although considerable experimentation with the use of various grazing systems (e.g., rest-rotation, deferred-rotation, short duration) to reduce damage to riparian habitat has occurred, no one system has emerged that is effective in all cases (Laycock and Conrad 1981, Blackburn et al. 1982, Dwyer et al. 1984, Pieper and Hietschmidt 1988, Clary and Webster 1989). A grazing strategy that maintains riparian habitat integrity in one situation may be damaging in another, even if it appears closely related (Kauffman et al. 1983). Platts (1989) evaluated various grazing strategies and techniques and rated them according to their compatibility with fish requirements. Systems with the least compatibility were continuous, season-long cattle grazing and short-duration, high-intensity cattle grazing. Those most compatible with fish were grazing by sheep with a carefully controlled seasonal rest-rotation system, and complete rest and closure.

It is difficult to optimize the use of upland areas while protecting riparian areas without the use of fencing. Fencing riparian areas to exclude livestock or to allow carefully controlled management of special-use riparian pastures may be the most effective means of controlling grazing intensity, preventing riparian and stream damage, and reducing soil loss and downstream sedimentation (Winegar 1977; Kauffman 1982; Kauffman et al. 1983; Platts and Wagstaff 1984; Platts and Nelson 1985b; Platts 1989, 1990; Owens et al. 1996). Although fence construction and maintenance can be expensive, it allows grazing in riparian areas while maintaining their condition. The benefits of increased fish and wildlife values as well as some grazing benefits may offset fencing costs (Platts and Nelson 1985b). When faced with the costs of intensive management (e.g., herding), fencing may be a viable alternative. If grazing is completely excluded from riparian areas, the loss of forage may be inconsequential in many areas (Kinch 1989). Although some have claimed that grazing can enhance range conditions, this does not appear to be true in riparian areas. Platts (1990) concluded that it is extremely doubtful that any grazing scheme can improve riverine-riparian systems or local hydrologic conditions over what nature can do in an ungrazed situation.

A variety of grazing management tools used together will have a better potential of yielding beneficial riparian protection results (Platts 1989). Only with a long-term commitment to find the right mix of tools for each situation will livestock use and distribution be controlled enough to prevent severe consequences to riparian habitat.

Recovery Potential

Most riparian ecosystems recover rapidly from the effects of excessive grazing when given a period of complete rest through total livestock exclusion (Platts 1990). Usually within 4-15 years a full complement of riparian vegetation returns to streams, and bank structure and water quality and quantity are much improved (Skovlin 1982, Kinch 1989, Clary and Medin 1990, Chaney et al. 1993). After this restoration period, carefully controlled grazing at low levels can maintain healthy riparian areas (Platts 1990; C. Perry, pers. comm.).

However, other habitat parameters are slower to return to pre-grazing conditions. Channel and bank morphology, instream cover, tree regeneration, snag recruitment, plant species composition, and downed woody debris that have been altered significantly during the period of heavy grazing will take longer to recover (Platts and Raleigh 1984, Evans 1989, Clary and Medin 1990). High-gradient streams with unstable channels, areas with shallow soils and limited sediment transportation needed to rebuild banks, high-elevation glaciated stream basins with little soil building potential, or seriously incised streams may take centuries to fully recover (Chaney et al. 1993).

Well-supervised grazing management of riparian areas, coupled with rest and restoration of severely damaged areas, can result in decreased stream bank erosion and floodplain losses, increased forage production for both livestock and wildlife, and increases in fish and wildlife resources (Kauffman and Krueger 1984).

Urbanization

People have traditionally settled in riverine floodplains and along the banks of major streams and lakes (Goldstein et al. 1983, Nabhan 1985). Modern urban settlement near water and throughout watersheds usually entails large-scale removal of native vegetation and its replacement with buildings, pavement, roads, and manicured plantings, all consisting primarily of impervious surfaces. Unlike the effects of forestry, the loss of natural vegetation and consequences to riparian and stream habitats in urbanized areas are usually permanent (Booth 1991). The effects of urban and industrial developments generally result in:

- changes in basin hydrology;
- loss of riparian habitat;
- loss of woody debris and other instream structures;
- degradation of stream channels;
- reduction in water quality;
- habitat fragmentation;
- introduction of pets and exotic pests.

Changes in Basin Hydrology

The loss of natural vegetation in riparian and upland areas and its replacement with compacted or largely impervious surfaces changes the hydrology of urbanized watersheds. These changes usually result in a loss of fish and wildlife habitat. Overall, hydrologic changes upset the balance of aggradation and degradation processes that are essential in maintaining healthy stream and riparian ecosystems. The most dramatic and well-studied effect is the increase in the maximum discharge associated with floods and storm events; peak flows in urbanized watersheds have been known to increase as much as five-fold over natural conditions (Booth 1991).

To examine the effects of impervious surfaces, Booth and Jackson (1994) compared stream discharge and stream bank and channel stability in forested and urbanized basins. They found that the occurrence of unstable stream banks and channels correlated with basins that had impervious surfaces exceeding 10% of the land cover. Furthermore, Steedman (1988) observed that even with complete retention of streamside buffers, increases in impervious surfaces above 10% resulted in measurable degradation. Klein (1979) found that stream quality impairment is first evidenced when watershed imperviousness reaches 12%, but it does not become severe until imperviousness reaches 30%.

Booth (1991) modeled the effect of a predicted increase in the amount of impervious surfaces from 6-29% on peak stream flow. He found that major peak flows would be amplified and many new peaks associated with small storms would appear, peaks that would not normally appear with natural vegetation cover. He concluded that in a heavily urbanized environment, flood events large enough to cause significant erosion would be more severe and would occur more frequently; such events may increase by nearly two orders of magnitude, from once or twice per decade to several times per year. Booth and Reinelt (1993) determined that a given recurrence interval of floods typically increased by a factor of 2-5 in urbanized watersheds.

The effect of urbanization on basin hydrology is particularly acute in areas that naturally have predominantly subsurface rather than surface water flow. Areas that are wet and well vegetated, as in western Washington, usually receive precipitation in amounts that can normally be absorbed and transported below the surface (Booth 1991). Urbanization with impervious surfaces shifts water transport to largely surface flows, thereby changing natural water flow patterns. These surface flows carry large quantities of water over the land in short periods of time, in contrast to subsurface flows that distribute water and move it slowly.

Planners and municipalities are becoming cognizant of the need to control surface run-off and to retain natural vegetation in the form of greenways and riparian corridors (Ferguson 1990, Wash. Dept. Ecol. 1993). During heavy rains, naturally vegetated land parcels absorb 95% of precipitation, depositing only 5% of relatively silt-free water into nearby streams (King County Planning Division 1980). Many Washington State municipalities now require that stormwater be retained and cleaned of a majority of sediments, nutrients, heavy metals, oils, and other pollutants prior to entering receiving waters (Wash. Dept. Ecol. 1993). One method for doing this is "biofiltration," wherein surface run-off is captured in grass-lined swales or constructed wetlands. This has an added benefit of creating or protecting valuable riparian and wetland habitat (Rea 1983). In addition, vegetation retention and biofiltration conserve aquifer recharge functions and thus help maintain adequate stream flows and high water tables that are important to riparian ecosystems and fish (Wash. Dept. Ecol. 1993). Although these measures are promising, design of retention facilities and estimation of their future needed capacity is still experimental and prone to failure (Booth 1991).

Loss of Riparian Habitat

In an attempt to be close to the water and to "clean up" areas by replacing them with manicured landscapes, riparian vegetation is often cleared when land is developed. Because riparian habitat supports the greatest number of species compared to other habitats, its protection can provide a significant benefit to fish and wildlife in developed landscapes (Noss 1993).

The loss of riparian vegetation due to urbanization: 1) degrades stream conditions through increased erosion of banks that are no longer armored with roots and debris from natural vegetation, 2) removes a source of logs and organic debris that stabilize streams and provide a source of food and nutrients, 3) increases stream temperatures through shade removal, and 4) reduces the capacity of the riparian area to filter incoming sediments and pollutants (Klein 1979).

Booth and Jackson (1994) documented significant erosion as a result of riparian vegetation removal. They found channels widened by erosion an average 0.6 m (2 ft) in areas where native vegetation had been altered or removed. They concluded that there is a positive correlation between riparian corridor condition and habitat quality (defined as pool:riffle ratio, channel roughness and diversity, and fish use).

Problems related to water fluctuations and water quality may lead to extirpation of amphibians in urbanized environments (Richter 1995). Increasing water level fluctuations and watershed urbanization were correlated to low amphibian species richness in Puget Sound wetlands (Richter and Azous 1995). Other variables such as wetland size, vegetation class, and presence of bullfrogs and other fish predators were not as well correlated with amphibian species richness.

Loss of Woody Debris and Other Instream Structures

Woody debris, especially large logs, are lost in urbanized areas through the removal of their source -- riparian vegetation. Logs are flushed through the systems during high peak flows, and they are lost through deliberate removal. Historically, logs were removed in large rivers to improve navigation associated with urban development (Sedell and Luchessa 1982). After the removal of riparian vegetation, remnant logs eventually degrade or are swept downstream during the frequently occurring flooding events in urban areas (Booth 1991). Large woody debris that is removed is rarely replaced in urban areas.

Stream Channel Degradation

Fish-bearing rivers and streams that flow through heavily-developed areas rarely resemble their natural form. Stream beds are replaced with drainpipes and culverts, riparian vegetation is removed, and municipal wastes contribute pollutants, sediments, and excessive nutrients to the water. To accommodate the real estate needs and safety of expanding urban populations, streams and rivers are frequently channelized, diked, or piped underground. For example, 73% of Ravenna Creek in King County now runs through a pipe (Wash. Dept. Ecol. 1981). Loss of riparian vegetation, increased flooding, and stream channel manipulation eliminate large woody debris, pools and riffles, sinuosity, slow flowing side channels, and other essential structural components of fish habitat in urbanized areas. Destruction or severe degradation of fish and wildlife habitat by urbanization is often complete and irreparable (Canning and Stevens 1989).

The combined effects of increased frequency and magnitude of peak flows and the loss of instream structural diversity (e.g., large woody debris, side channels, meanders) result in a widening and deepening of the stream channel (Hammer 1972, Fox 1974, Booth 1991). This increased erosion often occurs during storm events, and at that time substantial sediments are carried through the system. Channel widening reduces existing riparian vegetation and increases the dynamic nature of the riparian area, resulting in younger vegetation that lacks characteristics important to fish and wildlife (e.g., multilayered canopy, large trees and snags).

As a result, urban streams have characteristics that differ from streams in undeveloped areas. "Their beds are uniform, with few pools or developed riffles to break up the planar surface. Channel banks are raw and near-vertical, with incisions of one to many feet. The erosion of adjacent steep banks is constantly adding new sediment. Woody debris is small and sparse, and it is either suspended above the level of the flow or is only weakly anchored in the bed. Finally, the aquatic organisms that thickly populate equivalent drainages in undeveloped settings are nearly absent, reflecting the cumulative impact of physical and chemical changes to the stream and its substrate" (Booth 1991:107). These conditions are often permanent and prevail throughout urbanized watersheds.

Water Quality

Streams and rivers flowing through urban landscapes suffer reductions in water quality that impair their ability to support microorganisms, fish, and wildlife. Water quality is reduced through increased sedimentation, chemical pollution, and increases in water temperature. Higher than normal surface flows carry pollution, nutrients, and sediment to streams in large quantities. Surface flows also deliver warmer water to streams than do subsurface flows. Urban stormwater run-off is commonly borne in storm sewers or surface channels and deposited directly into the waterway, with little opportunity to be absorbed, cooled, and cleansed by passing through natural vegetation and soils (King County Planning Division 1980).

The combined effects of shade reduction, stream widening, and the input of warm surface flows cause stream temperatures to increase in the summer and decrease in the winter, thereby altering natural temperature regimes (Klein 1979, LeBlanc et al. 1997). Stream temperatures in urbanized areas have been observed to be higher than in less-developed landscapes (Klein 1979, Griggs 1984, Scott et al. 1986).

Construction of buildings and other developments clears the land of protective vegetation and often denudes the soil. Erosion and consequent stream sedimentation resulting from construction can be considerably greater than that produced by farming or timber harvest (Klein 1979). Sedimentation from construction sites can be 20,000 to 40,000 times the amount eroded from farms and woodlots (Wolman 1964), and urbanizing watersheds can generate 9 times the sediment as rural or natural drainage areas (Fox 1974). The volume of sand in sediments may be 15 times that found in nearby rural watercourses, and sand, if it is an unstable variety, provides one of the poorest substrates for benthic life (Fox 1974).

The input of heavy metals to aquatic systems is high in urban areas (Klein 1979). Lead and zinc have been found to increase in proportion to impervious surfaces in a watershed (Northern Virginia Planning District Commission 1977). Laxen and Harrison (1977) reported that lead concentrations in highway run-off were 10^3 to 10^4 times that of background levels. Berger (1976) reported that urban run-off yielded unexpectedly high and normally acute toxic concentrations of several metals in sediment, detritus, and benthic macroinvertebrates.

Habitat Fragmentation

One of the greatest impacts of urbanization on wildlife comes from habitat fragmentation (Stenberg et al. 1997). Remaining natural habitat in urban areas typically consists of small, infrequently encountered remnant patches that are isolated from each other (Carleton and Taylor 1983, Goldstein et al. 1983). Wildlife in such settings is limited to highly-adaptive and mobile species with small area or generalized habitat requirements; examples include the American robin, European starling, house sparrow, raccoon, and coyote (Aldrich and Coffin 1980, Quinn 1992). Animals that require large areas of intact natural vegetation, such as some forest interior songbirds and elk, are lost during habitat fragmentation associated with urbanization (Aldrich and Coffin 1980, Bryant and Maser 1982).

The isolation of remnant habitat parcels makes utilization and recolonization difficult or impossible. Areas that may have once supported wildlife but whose populations were eliminated may stay impoverished because of isolation even though habitat conditions may be healthy. This is of particular concern for species with low mobility such as amphibians (Richter 1995). Intact riparian habitat with its dense, protective vegetation can serve as a safe corridor linking remnant habitat parcels, enabling wildlife dispersal and use of separated patches (Harris 1984, Noss 1993).

In the face of heavy development pressures in one rapidly urbanizing community (Lake Sammamish), King County developed a plan to link remaining pockets of natural habitat with protected riparian corridors (Stenberg et al. 1997). In this plan, major riparian networks were used as linear landscape connectors, providing contiguous travel routes between refuges for wildlife. Creative urban landscape design is a promising way in which to provide for the needs of expanding human populations while protecting many natural habitat functions and values (Goldstein et al. 1983).

Introduction of Pets and Exotic Plants

Exotic plants can out-compete native plants in urban riparian areas. Dominance by exotic plants can cause habitat simplification and reduce the value of those areas to wildlife (Noss 1993).

Significant predation on native fauna by pets, particularly free-ranging cats, occurs in rural and urban areas (Churcher and Lawton 1987, Mitchell and Beck 1992, Coleman and Temple 1993). Cats compete with native predators such as raptors (e.g., red-tailed hawks, American kestrels, northern harriers) and weasels, thereby reducing their populations in rural and urban areas (George 1974). Because domestic cats are supported by people, they can occur in very high densities (Coleman and Temple 1993). This creates a potential to remove a significant portion of prey, thereby impacting prey populations and reducing their availability to native predators. Free-ranging cats can also transmit new diseases to wild animals. For example, the feline leukemia virus has spread to mountain lions (Jessup et al. 1993).

Domestic cats eat small mammals, birds, reptiles, and amphibians (Hubbs 1951, Coman and Brunner 1972). Mitchell and Beck (1992) found that small mammals (rodents, rabbits, shrews) make up the largest portion of the diets of domestic cats. Birds, particularly songbirds that nest or feed on the ground, constituted the second most significant prey item. They estimated that 3-26 million songbirds were killed annually in both rural and urban Virginia by cats. They also estimated that 27-79 million small mammals and 3-9 million reptiles were killed annually by cats. It has been estimated that cats in rural Wisconsin kill 19 million songbirds and 140,000 game birds annually (Harrison 1992). Probably because of greater prey availability, rural cats kill greater numbers of wildlife than do urban cats (Mitchell and Beck 1992). While cats may play a helpful role in controlling undesirable rodents, this domestic predator can also deplete native wildlife populations.

Dams

An effect of dams is inundation of riparian habitat. The amount of habitat affected depends on the level of water rise and the geomorphic shape of the riparian channel. Steep-sided, forested canyons that are dominated by upland vegetation will lose less functional riparian habitat than broad river floodplains featuring extensive deciduous stands, gravel bars, and side channels. Water impoundment by dams has a way of “smoothing out” riparian features and irregularities that are important to the diversity of fish and wildlife (Sauve 1977).

The following are ways in which dams can affect riparian and aquatic habitats (Johnson et al. 1977, Sauve 1977, Hildebrand and Goss 1981, Turbak et al. 1981, Strahan 1984, Brown and Johnson 1985, Carson and Peek 1987, Junk et al. 1989, Columbia Basin Fish and Wildlife Authority 1991, Hunter 1992, McComas et al. 1994).

Riparian Habitat

- continual rise and fall in water levels creates a zone of unnatural disturbance at the aquatic/riparian interface that usually cannot support the original vegetation;
- changes in the plant species occupying the relocated riparian zone, with reductions in maturity and structural diversity of plant communities;
- loss of level streamside habitat as banks become steeper;
- loss of snow-free wintering habitat for deer, elk, and other species due to a net increase in riparian zone elevation.

Instream Structure

- sharply reduced recruitment of LWD and gravel downstream from the dam;
- decreased stability of bank and bed;
- altered sedimentation patterns.

Water Quality

- changes in nutrient transport and cycling;
- gas supersaturation;
- loss of water quality from dredging;
- wide fluctuations in stream and reservoir water temperatures;
- colder stream temperatures downstream from the dam;
- increased water surface area above the dam, resulting in less shading by bank-side vegetation and increased absorption of heat-producing solar radiation, thereby increasing the water temperature;
- reduced levels of dissolved oxygen concentrations downstream from reservoirs;
- elimination of flood pulses that bring nutrients from the floodplain into the river system.

Water Quantity

- wide fluctuations in water levels above and below the dam causing the stranding of fish and alternating desiccation and inundation of fish and wildlife breeding habitat;
- changes in the timing of high flows and water velocity from natural conditions, negatively affecting salmon migration and survivability.

Fish Habitat

- changes in fish numbers, species composition, and distribution;
- inundation of feeder streams, with loss of spawning habitat;
- loss of spawning and rearing habitat;
- blocked or impeded upstream and downstream fish passage;
- stranded juvenile fish and dewatered redds during flow fluctuations;
- turbine mortality.

An indirect effect of dams is the encouragement of agricultural, commercial, residential, and recreational development in previously undeveloped areas, particularly adjacent to water bodies. Roads are often built into relatively remote areas to construct and service the dams, and also to accommodate human developments that are created adjacent to the reservoirs created by the dams. In the Columbia Basin, extensive conversion of shrub-steppe riparian habitat into agricultural lands has occurred as a result of new irrigation capability afforded by water impoundment behind dams. These shrub-steppe riparian habitats formerly supported a great variety of wildlife species and provided critical mule-deer fawning grounds (Tabor 1976, Carson and Peek 1987).

Dams are major projects that are obligated to undergo full environmental and public review, as provided through the State Environmental Protection Act/National Environmental Protection Act, Federal Energy Regulatory Commission, and Fish and Wildlife Coordination Act. Mitigation and management prescriptions are thoroughly covered during these processes; therefore, management recommendations concerning dams would be redundant in this document and are not given. However, an understanding of the impacts of dams is important in assessing the quality and availability of fish and wildlife habitat on a regional basis. Also see Hunter (1992) for further information regarding dams and salmonids.

Recreation

Recreation is an important cultural activity that may take place within riparian areas. Recreational use of the riparian zone is many times that of other habitats, particularly in suburban and urban areas (North Central Forest Experiment Station 1977, Sachet 1988). In Oregon, up to 80% of the Willamette National Forest's dispersed recreation occurs in riparian areas (Gregory and Ashkenas 1990).

Vegetation alteration at recreation sites occurs as a result of trampling, firewood gathering, off-road-vehicle (ORV) use, dispersed camp sites, landscaping, and the construction of roads, launches, and other structures. Herbaceous and shrub layers are usually most affected (Settergren 1977, Reese and Blakesley 1987). These layers are particularly important to nesting songbirds, amphibians, small mammals, and other species that require thick and multi-layered vegetation for protective cover, food gathering, and microclimate control (Weaver et al. 1979, Bull and Skovlin 1982, Doyle 1990). Shrub-oriented species such as Macgillivray's warbler and lazuli bunting may be fewer in number or absent at recreational sites. But species that nest and feed within tree canopies, such as Douglas squirrel and warbling vireo, may be unaffected by recreational development because mature trees are often spared at recreation sites (Reese and Blakesley 1987).

Although information found in a literature review provided by Sachet (1988) was not specific to riparian areas, it does provide some insight to potential impacts in riparian areas as a consequence of ORV, pedestrian, and equestrian recreation in back country areas. General conclusions of wildlife habitat impacts by those forms of recreation have been summarized by Sachet (1988).

Indirect Effects

- increased bare ground, trail width, trail depth, soil compaction, and soil bulk density;
- increased potential for soil erosion;
- reduced trailside vegetation, vegetative cover, and organic matter in the soil;
- tree damage.

Direct Effects

- disruption of normal activity patterns and habitat selection of big game because of ORV activity;
- human disturbance of all wildlife.

Trails, roads, and other openings in forested riparian habitat may encourage the penetration of new plant and animal species into formerly protected interior forest ecosystems (Gashwiler 1970, Harris 1988, Gates and Giffen 1991). Nest predators such as jays and crows are attracted to recreation areas by the availability of garbage and other foodstuffs. For example, researchers studying marbled murrelet nests in northern California observed predation of murrelet chicks by crows and jays that had apparently flown in from nearby campgrounds (Singer et al. 1991).

Aquatic and near-shore riparian habitats are especially vulnerable to physical disturbance. Trampling, removal of emergent vegetation and woody debris, and pollution by fecal waste or chemical compounds all contribute to the degradation of these habitats (Aitchison et al. 1977). Where these factors are widespread, as might occur along popular lake and river fronts, there are observable impacts on fish and aquatic ecotone-dependent wildlife such as red-winged blackbird, water shrew, common loon, and beaver (Ehrlich et al. 1988).

The presence of human beings in a natural area may also affect sensitive fish and wildlife. Noise and the approach of human beings to breeding sites, spawning reaches, feeding areas, or resting cover is distressing to most wild animals (Beam 1978, Skagen 1980). Abandonment of the habitat due to human disturbance may occur even in the presence of suitable vegetative conditions (Taylor 1986). Negative reactions to disturbance are heightened when animals are also stressed by malnutrition, parasites, or inclement weather, and also when suitable habitat is fragmented and/or limited in size (Harris 1988).

Table 1 summarizes impacts of land use on riparian and stream systems. This information provides the rationale for management recommendations provided in the next section.

Table 1. Summary of potential effects of various land uses on riparian habitat elements needed by fish and wildlife.

Potential changes in riparian elements needed by fish and wildlife	Land use						
	Forest practices	Agriculture	Unmanaged grazing	Urbanization	Dams	Recreation	Roads
Riparian Habitat:							
altered microclimate	X	X	X	X		X	X
reduction of large woody debris	X	X	X	X	X	X	X
habitat loss/fragmentation	X	X	X	X	X	X	X
removal of riparian vegetation	X	X	X	X	X	X	X
reduction of vegetation regeneration	X	X	X	X	X	X	X
soil compaction/deformation	X	X	X	X		X	X
loss of habitat connectivity	X	X	X	X		X	X
reduction of structural and functional diversity	X	X	X	X		X	X
Stream Banks and Channel:							
stream channel scouring	X	X	X	X		X	X
increased stream bank erosion	X	X	X	X	X	X	X
stream channel changes (e.g., width and depth)	X	X	X	X	X	X	X
stream channelization (straightening)	X	X		X			
loss of fish passage	X	X	X	X	X		X
loss of large woody debris	X	X	X	X	X	X	X
reduction of structural and functional diversity	X	X	X	X	X		X
Hydrology and Water Quality:							
changes in basin hydrology	X	X		X	X		X
reduced water velocity	X	X	X	X	X		
increased surface water flows	X	X	X	X		X	X
reduction of water storage capacity	X	X	X	X			X
water withdrawal		X		X	X	X	
increased sedimentation	X	X	X	X	X	X	X
increased stream temperatures	X	X	X	X	X	X	X
water contamination	X	X	X	X		X	X

MANAGEMENT RECOMMENDATIONS

Goal

Management recommendations for riparian habitat are intended to meet the following goal:

> *Maintain or enhance the structural and functional integrity of riparian habitat and associated aquatic systems needed to perpetually support fish and wildlife populations on both site and landscape levels.*

Management recommendations from WDFW are not intended to address the wide diversity of habitats, existing land uses, and landowner/manager objectives. They have been written to meet the general needs of fish and wildlife. These management recommendations are provided to guide rather than dictate site-specific activities. For these reasons and because they are generalized to cover the entire state, fine-tuning may be necessary to adapt these recommendations to local conditions and landowner/manager objectives. Specific recommendations are provided, not necessarily as site prescriptions, but to offer clear, implementable guidelines that would result in the protection of fish and wildlife in most cases.

It is expected that these management recommendations will contribute to the scientific component of planning, protection, and restoration efforts for fish and wildlife. These efforts include the Growth Management Act; habitat conservation plans (e.g., the Department of Natural Resources Habitat Conservation Plan); the WDFW Hydraulic Code; the Puget Sound Action Plan; the Timber, Fish, and Wildlife Agreement; individual landowner farm and forest plans; and restoration projects conducted through the Jobs for the Environment Program, Regional Fisheries Enhancement Groups, State Conservation Commission, For the Sake of the Salmon, and other efforts. Habitat requirements for salmon recovery outlined in WDFW's draft Wild Salmonid Policy were derived, in part, from these management recommendations. These recommendations may provide a basis for WDFW participation in other planning processes that address riparian management strategies; however, WDFW will defer to negotiated agreements (e.g., the TFW Forestry Module) regarding riparian management that may result from those planning processes.

Landowners and managers may have to make modifications or compromises to these recommendations in order to consider site-specific factors. Site-specific study and examination of alternative solutions that would meet the needs of fish and wildlife may be necessary if landowners and managers desire to implement practices other than those recommended here. These management recommendations have not provided guidance to address all alternative solutions because the variables are too numerous and complex and should be evaluated on a site-by-site basis. Landowners and managers should consult with professional fish and wildlife biologists when making substantial modifications to these recommendations. Biologists can help to develop more specific and innovative means of meeting the needs of fish and wildlife.

Because riparian habitat affects and is affected by management activities in adjacent riparian areas and in uplands, the health of the entire watershed should be considered when planning and conducting specific land use activities. Implementation of these management recommendations should ideally be part of watershed-level analysis and planning in order to best meet the needs of fish and wildlife across the landscape. Small landowners should consult with adjacent landowners and government agencies that manage land (e.g., Washington State Department of Natural Resources) to determine if watershed-level work is in progress.

These recommendations are designed to provide riparian habitat characteristics that are required by fish and wildlife. These same characteristics should serve as a guide if alternative management activities are pursued for a particular site. The characteristics of functioning riparian habitats are described below.

Habitat Characteristics Important to Fish and Wildlife

Site-specific activities should strive to retain or restore fully functioning riparian habitat and habitat characteristics that are required by fish and wildlife. Below is a summary of required habitat characteristics based on natural systems (discussed in greater detail in the *Fish and Wildlife Use* section, p. 19).

Connectivity. Connectivity provides a protected corridor for fish and wildlife travel between seasonal ranges and remnant habitat parcels. Because stream networks are interconnected, and because degradation in one area affects other areas downstream, continuous riparian habitat also helps to ensure the health of entire watersheds.

Vegetation Composition. A mosaic of successional stages and plant communities exists along undisturbed stream courses. This mosaic provides high habitat diversity important to supporting diverse fish and wildlife populations. In naturally forested areas, a mixture of conifer and deciduous trees exists. Deciduous trees are more abundant in very dynamic riparian areas (because of flooding and bank erosion) and/or on gravelly soils such as river bars. Conifers are generally more abundant adjacent to small streams where disturbance and flooding is less frequent and where the small size of the stream exerts less influence on the vegetation. Conifers are of mixed age classes with relatively abundant large mature trees that are key contributors of large woody debris to the stream system. Herbaceous and shrub layers are well-developed, leaving little bare ground. They consist of a diversity of both upland and riparian plant species. In naturally non-forested areas, the dominant vegetation may be coniferous or deciduous trees, shrubs, or grasses and forbs which all occur in an irregular mosaic across the non-forested areas of eastern Washington. A diversity of tree, shrub, and herbaceous species exists and covers a large portion of the ground. Native plant species predominate.

Multiple Canopy Layers. In naturally forested areas, at least three and sometimes all of the following canopy layers are present: humus, grass/forb, short shrubs, tall shrubs, small trees, and large trees. In naturally non-forested areas, the number of canopy layers is often less than in forested areas and consist of any combination of the above layers. Multi-layered canopies, whether in forested or non-forested environments, provide varied habitat niches to support diverse wildlife populations. A multi-layered canopy is also important in providing thermal and disturbance cover for all species. Each layer of vegetation should show evidence of reproduction (e.g., there should be more seedlings than decadent individuals and more young plants than mature plants).

Natural Disturbance. It is important to fish and wildlife that natural disturbances (e.g., flooding, channel meandering) occur unimpeded and that human-induced disturbances are minimized. Fish and wildlife that use riparian and associated aquatic systems have evolved with continual yet generally low-level natural disturbances. Natural frequencies and magnitudes of disturbances enhance habitat diversity and provide key resources to riparian and aquatic areas (e.g., woody debris, nutrients). Disturbances caused by human activities often occur more frequently and are of greater magnitude than natural disturbances.

Snags. Snags, particularly those greater than 51 cm (20 in) dbh, are valuable to wildlife and should be present or abundant in forested riparian areas. Snags are especially critical to pileated woodpeckers, many species of bats, cavity-nesting species (particularly those that nest near water such as wood ducks and hooded mergansers), and snag-using species like osprey and bald eagles.

Woody Debris. Abundant woody debris, including large logs, stumps, root wads and branches, are present in forested riparian areas and in adjacent aquatic and upland areas. Woody debris plays a critical function in providing stream bank stability, instream habitat structure, and nutrients and organic matter needed by fish, particularly salmonids. Large woody debris in riparian and instream areas is also important for small mammals, amphibians, and invertebrates. In non-forested areas, woody debris will only occur in riparian and stream habitat if trees are present.

Shape. Riparian habitat has a characteristic curvilinear shape with irregular edges. It incorporates various land forms and related plant communities (e.g., connected wetlands). Its irregular edge provides a diverse interface between riparian areas and adjacent habitat types, which further increases habitat diversity.

Width. The actual width of riparian habitat is variable from site to site. No figures exist on average riparian habitat widths for various plant communities across Washington. However, information exists on riparian habitat functions and the widths needed to retain those functions (Appendix C). Management recommendations and any modifications to them are based on the best available information on the width needed to retain wildlife habitat functions (e.g., travel corridors, protection from disturbance and predation), stream temperature and microclimate control, provisioning of large woody debris, pollution and sediment filtration, and erosion control. Site-specific variables will affect this width and may be modified accordingly if adequate local information exists.

Stream Bank. The stream bank is stabilized with deeply rooted riparian vegetation, large woody debris, or coarse-grained alluvial debris. Undercut banks and vegetation overhanging into the stream are common. Apparent stream bank erosion is uncommon.

Associated Wetlands. Attached wetlands (e.g., oxbows, beaver ponds) are frequently present, and their management strategies will be addressed in a future WDFW publication.

Specific Management Recommendations

Below are management recommendations for riparian habitat in Washington. The rationale for each recommendation or group of similar recommendations is synopsized. The rationale and other supporting statements are based on previously cited literature; however, statements based on new information are referenced by citations. If the goal to maintain or enhance the structural and functional integrity of riparian habitat and associated aquatic systems is neglected and the resulting land use practice does not accommodate all riparian habitat functions, there will likely be negative consequences to fish and wildlife. These expected consequences are discussed after each recommendation. Because these consequences may not have been specifically documented in scientific studies, they may be based on a logical extension of habitat requirements and existing studies. Because there are few studies that examine the specific effects of incremental variation in management recommendations (e.g., reduction or expansion of recommended riparian habitat area widths), the consequences are general and qualitative in nature.

Riparian Habitat Areas

Specific management recommendations in this section are based on the protection of *riparian habitat areas* (RHAs) as a means of maintaining and enhancing riparian habitat structure and function. This strategy is one that will also assist in maintaining or enhancing the structure and function of instream habitat.

Riparian habitat areas are standard width areas adjacent to streams and rivers. These areas exhibit the full range of habitat functions necessary to support riparian-associated fish and wildlife. Riparian habitat areas differ somewhat from riparian “buffers.” The concept of riparian buffers is usually applied to the buffering of streams from the effects of adjacent, more upland activities. As such, buffers typically only address the retention of functions needed by fish and stream-dwelling wildlife (e.g., some amphibians). They often fail to adequately accommodate the needs of other wildlife species, especially those upland species that use riparian areas to varying degrees. Examples of riparian functions that may not be addressed through the traditional notion of a “buffer” include sufficient space within riparian areas for feeding, breeding, and resting for riparian and upland wildlife species; sufficient travel corridors for the movement of individual animals; microclimate effects, including temperature moderation during periods of heat or cold; and sufficient cover and refuge from disturbance. Riparian habitat areas include the concept of buffering streams to retain important stream functions, but they also encompass the functional aspects of riparian areas relative to uplands. Therefore, RHAs present the opportunity to manage riparian habitat as a more completely functioning system in which streams and uplands mutually influence each other.

Riparian areas should be sufficiently wide to achieve the full gamut of riparian and aquatic ecosystem functions, which include but are not limited to: 1) protection of instream fish habitat through control of temperature and sedimentation in streams; 2) preservation of fish and wildlife habitat; and 3) connection of riparian wildlife habitat to other habitats (Steinblums et al. 1984, Harris 1988, Schaefer and Brown 1992).

A variety of studies demonstrate that the retention and protection of riparian habitat is successful in:

- supporting greater species diversity (Stauffer and Best 1980, Dobkin and Wilcox 1986, Rudolph and Dickson 1990);
- retaining macroinvertebrate populations (Erman et al. 1977, Roby et al. 1977, Newbold et al. 1980);
- retaining small mammal populations (Cross 1985);
- moderating stream temperatures (Beschta et al. 1987, Johnson and Ryba 1992, Moring et al. 1994);
- improving infiltration and minimizing surface flows, thereby assisting in stream flow regulation (Budd et al. 1987, Debano and Schmidt 1990, Chamberlin et al. 1991);
- reducing sediments and pollutants that reach water supplies (Aubertin and Patrick 1974, Moring 1975, Lowrance et al. 1984, Terrell and Perfetti 1989, Johnson and Ryba 1992, Moring et al. 1994, Schultz et al. 1995);
- recruiting large downed logs into the stream and riparian habitat (Harmon et al. 1986, Murphy and Koski 1989);
- providing large diameter snags for fish and wildlife use (Cline et al. 1980, Andrus and Froehlich 1988);
- providing breeding, feeding, and movement habitat for fish and wildlife species (Allen 1983, Rudolph and Dickson 1990, Johnson and Ryba 1992, Croonquist and Brooks 1993);
- providing critical refuge and continuous corridors in developed landscapes, linking remaining wildlife habitat that would otherwise be fragmented (Gregory and Ashkenas 1990).

It is important to recognize that the retention of riparian habitat alone will not mitigate all impacts of upland activities on riparian and aquatic ecosystems. Nor will riparian habitat alone meet all the needs of upland species that seek refuge in intact riparian areas when upland habitat is lost (McGarigal and McComb 1992). An integration of riparian habitat protection with watershed management is essential in maintaining diverse fish and wildlife in perpetuity.

There is agreement in the literature that restricted use of riparian habitat is needed to retain the functions of aquatic and riparian ecosystems. Schaefer and Brown (1992) stated that width is one of the most important variables affecting riparian corridor functions. However, there is less agreement on the specific width needed to protect riparian and stream habitat (O'Connell et al. 1993). Nor is there agreement on which land use activities might be compatible with fish and wildlife in riparian habitat. Recommendations to retain riparian areas are usually designed to retain specific functions (e.g., water quality and temperature) and rarely address the full range of ecological functions necessary to support fish and wildlife, as is the goal of these management recommendations.

Many authors have investigated the retention of riparian habitat areas and have recommended various widths to maintain fully functional riparian and aquatic ecosystems. Table 2 summarizes some of these riparian buffer recommendations; only those that were designed to maintain riparian habitat for fish and wildlife in general (as opposed to retaining specific riparian functions such as water quality) are included. Appendices C and D provide a more extensive list of reported riparian habitat widths needed to maintain various functions of riparian habitat.

Standard versus Variable Width Riparian Habitat Areas. While variable riparian habitat widths may allow landowners greater flexibility, sufficient information does not currently exist to provide variable width recommendations that adequately accommodate the extreme variability of riparian widths, land uses, and fish and wildlife communities across the Washington landscape. Therefore, any application of variable riparian widths must first include additional site-specific and watershed-level studies.

The Washington Department of Fish and Wildlife provides standard RHA widths to serve as the basis for planning and as a benchmark for evaluating specific site conditions. Recommended RHA widths are derived by WDFW from known fish and wildlife needs and riparian habitat functions demonstrated in scientific literature.

Table 2. Examples of riparian habitat buffer recommendations found in the literature. Widths apply to each side of the stream.

Source	Recommended riparian buffer widths	Notes
Washington Department of Ecology (1985)	60 m (200 ft) buffer on all streams	Buffer to protect riparian ecosystem.
Gregory and Ashkenas (1990)	Class I Streams: 61 m (200 ft) ave., 46-122 m (150-400 ft) range Class II Streams: 30 m (100 ft) ave., 30-61 m (100-200 ft) range Class III Streams (stable): 23 m (75 ft) ave., 15-30 m (50-100 ft) range Class III Streams (unstable): 30 m (100 ft) ave., 23-38 m (75-125 ft) range	Recommendations for the Willamette National Forest, Oregon.
Johnson and Ryba (1992)	Recommends 15-30 m (50-100 ft) buffer to protect most stream functions. Reports buffer recommendations from the literature ranging from 3-200 m (10-656 ft).	Based on a literature review of buffer recommendations. Recommendations do not include wildlife habitat, only riparian functions to maintain instream habitat.
U.S. For. Serv. et al. (1993), Reeves and Sedell (1992)	Fish-bearing streams: outer edge of the 100-year floodplain, or the outer edge of riparian vegetation, or the distance equal to the height of 2 site-potential trees, or 92 m (300 ft), whichever is greatest. Permanently flowing non-fish-bearing streams: outer edge of the 100-year floodplain, or the outer edge of the riparian vegetation, or the distance equal to the height of 1 site-potential tree, or 46 m (150 ft), whichever is greatest. Intermittent streams: the extent of unstable or potentially unstable area, or the outer edge of riparian vegetation, or 30 m (100 ft), whichever is greatest.	Buffers are part of an Aquatic and Riparian Conservation Strategy. Buffers are recommended for areas within the range of the northern spotted owl, including western Washington and the east slope of the Cascades.

Table 2. Continued.

Source	Recommended riparian buffer widths	Notes
Washington State Forest Practices Board (1992)	Riparian Management Zones for western Washington: Type 1 and 2 water (≥23 m): 30 m (100 ft) Type 1 and 2 water (<23 m): 23 m (75 ft) Type 3 water (≥2 m): 15 m (50 ft) Type 3 water (<2 m): 8 m (25 ft) Riparian Management Zones for eastern Washington: Partial harvest units: 9-15 m (30-50 ft) Other harvest types: 9-91 m (30-300 ft)	These Riparian Management Zones are not 'no entry' zones as are most others reported in this table. Specific restrictions regarding the number of trees to leave during timber harvest are set forth in the Forest Practice Rules.
Cederholm (1994)	Based on Forest Practices Water Types: Types 1 and 2: 76 m (250 ft) Type 3 [2-6 m (5-20 ft) stream width]: 61 m (200 ft) Type 3 [<2 m (5 ft) stream width]: 46 m (150 ft) Types 4 and 5 (low mass wasting potential): 46 m (150 ft) Types 4 and 5 (high mass wasting potential): 69 m (225 ft)	Buffers designed for western Washington riparian ecosystems. Add 50 ft buffer on windward side in area of high blowdown potential. Provide additional buffers to include entire unstable slope on Type 4 and 5 streams.
Ecosystem Standards Advisory Committee (1994)	Riparian Management Zones, defined as: Type 1-4 waters - 30 m (100 ft) Type 5 waters - 15 m (50 ft)	Developed as ecosystem standards for state-owned agricultural and grazing land under HB1309. These recommendations were based on an earlier draft of this PHS Management Recommendation document.

Recommendation. **Protect Riparian Habitat Areas** - The protection of RHAs is recommended to maintain fully functional riparian ecosystems and to provide sufficient habitat to meet the needs of fish and wildlife. Recommended RHA widths are designed first to retain riparian habitat functions necessary to maintain instream habitat for fish and aquatic wildlife. These functions include control of stream temperature, provision of large woody debris and other organic material to the stream system, regulation of stream flow, filtration of sediments and pollutants, and erosion control. Secondly, RHAs are designed to provide sufficient riparian habitat for terrestrial species, including sufficient travel corridor widths, sufficient buffers to adjacent disturbance during critical times (e.g., breeding), and sufficient area to provide cover and foraging habitat.

Recommended RHA widths are derived from a review of the scientific literature. This literature is summarized in Appendices C, D, and E. With the primary goal of maintaining riparian habitat and stream functions, and with an interest in producing a coordinated approach to riparian habitat management by aligning with other recommendations if possible, WDFW found that the riparian habitat buffer recommendations presented by Cederholm (1994) most closely agreed with WDFW's synthesis of the literature. However, WDFW's recommendations also provide additional riparian habitat area to meet the needs of specific wildlife species that occur in particular areas.

Recommended RHA widths are intended to encompass the full extent of riparian habitat associated with streams and rivers. Where appropriate, the RHA widths also include an additional area necessary to protect the RHA from windthrow or unstable slopes. In developed areas or areas where natural resources have been extensively modified, there may be man-made features or vegetation that do not resemble natural conditions within the recommended RHA. In these areas, the RHA width still provides an indication of the area that is influencing the stream system and the area that could potentially serve as fish and wildlife habitat, if it were restored.

Recommended RHA widths generally include a zone of riparian vegetation plus a transition zone dominated by upland vegetation. Even though it may not be obvious that upland vegetation is part of riparian habitat, scientific studies clearly describe the critical function of transitional areas in maintaining riparian and aquatic systems (e.g., Gregory and Ashkenas 1990, Gregory et al. 1991).

Recommended RHA widths in this document only apply to riparian areas associated with streams and rivers. The widths should be applied to both sides of a stream or river, and width measurements should begin at the ordinary high water mark. The channels of some streams, particularly larger streams and rivers in broad, alluvial valleys, may migrate across the valley as a result of natural erosional and depositional processes; the area over which the channel is expected to migrate is called the channel migration zone. For these streams and rivers, RHA width measurements should begin at the edge of the channel migration zone.

For existing or previously forested areas of the state, RHA widths are recommended for each stream type as defined in WAC 222-16-030. For non-forested areas in eastern Washington that are not covered in this stream typing system, RHA widths are recommended for streams comparable to the Forest Practices Water Types. Table 3 presents recommended RHA widths for these two areas.

Table 3. Standard recommended Riparian Habitat Area (RHA) widths for areas with typed and non-typed streams. If the 100-year floodplain exceeds these widths, the RHA width should extend to the outer edge of the 100-year floodplain.

Stream Type	Recommended RHA widths in meters (feet)
Type 1 and 2 streams; or Shorelines of the State, Shorelines of Statewide Significance	76 (250)
Type 3 streams; or other perennial or fish bearing streams 1.5-6.1 m (5-20 ft) wide	61 (200)
Type 3 streams; or other perennial or fish bearing streams <1.5 m (5 ft) wide	46 (150)
Type 4 and 5 streams; or intermittent streams and washes with low mass wasting* potential	46 (150)
Type 4 and 5 streams; or intermittent streams and washes with high mass wasting* potential	69 (225)

*Mass wasting is a general term for a variety of processes by which large masses of rock or earth material are moved downslope by gravity, either slowly or quickly.

The following are important additions to the recommended RHA widths in Table 3:

- Larger RHA widths may be required where priority species occur; consult Appendix D for these widths.
- Add 30 m (100 ft) to the RHA's outer edge on the windward side of riparian areas with high blowdown potential.
- Extend RHA widths at least to the outer edge of unstable slopes along Type 4 and 5 waters in soils of high mass wasting potential.

Activities Within RHAs. The scientific literature supports the maintenance of riparian habitat areas as restricted-use zones. The restricted-use area should apply to all future developments that affect riparian habitat, and it should guide restoration of degraded areas. Activities that may affect riparian habitat features important to fish and wildlife should be carefully conducted within the RHA. Activities that degrade the structural and functional integrity of riparian habitat and associated aquatic systems should be minimized. Examples of activities that may affect riparian habitat features include tree cutting, road building, agriculture, grazing, clearing, earth moving, mining, filling, burning, or construction of buildings or other facilities.

Because specific information on the level of each activity that riparian and stream systems can withstand without habitat degradation is generally absent, WDFW recommends a conservative approach when considering such activities. Where scientific information indicates that some level of each activity can occur without any damage to riparian and stream ecosystems, that level may be appropriate. While compromises may be necessary in some situations, modifications to these recommendations should be based on a consideration of the habitat characteristics required by fish and wildlife.

It is acknowledged that in some specific situations, management activities (e.g., vegetation thinning) may assist in the restoration of riparian characteristics required by fish and wildlife. Such activities may be an option if they are part of a well-researched and planned riparian habitat restoration effort and if adequate consultation with fish or wildlife biologists has occurred.

RHA Width Measurements. Riparian habitat area widths are measured on the horizontal plane. They begin at the change in topography or vegetation that marks the ordinary high water line on each side of the active channel. "Ordinary high water line" is defined as the mark on the shores of all waters that will be found by examining the bed and banks and ascertaining where the presence and action of waters are so common and usual and so long continued in ordinary years, as to mark upon the soil or vegetation a character distinct from that of the abutting upland, provided that in any area where the ordinary high water line cannot be found, the ordinary high water line is the line of mean annual high water (approximated by a flood recurrence interval of 2.33 years) (WAC 220-110-020). The "active channel" is defined as "all portions of the stream channel carrying water at bankfull flows" (Thomas et al. 1993:279). The active channel will generally encompass meanderings, braids, and irregularities characteristic of larger streams and rivers (Gregory and Ashkenas 1990). For streams and rivers in channel migration zones, RHA width measurements should begin at the edge of the channel migration zone.

RHAs Apply to Each Side of the Stream. Recommended RHA widths are to be applied to both sides of a stream.

RHAs are Neither Minimums nor Maximums. Recommended RHA widths are designed to retain fully functional riparian habitat. The Washington Department of Fish and Wildlife has not identified minimum widths because minimal conditions do not offer adequate habitat to support healthy fish and wildlife in the long run. With the current state of knowledge, no one can definitively say at what point each riparian function is lost. At the same time, WDFW recommendations are not to be considered maximums. Maximum protection from a fish and wildlife perspective would likely involve no development anywhere.

Beyond the standard recommended RHAs, it must be recognized that larger areas are needed by some wildlife species, including yellow-billed cuckoo, great blue heron, mule deer, elk, marten, osprey, and bald eagle (Gaines 1974, Thomas et al. 1979, Knight 1988, Freel 1991, Rodrick and Milner 1991) (Appendix D). Larger RHA widths should be added to standard RHAs where these and other priority species require such increases.

Applied Across the Landscape. For RHAs to be effective in maintaining quality riparian and aquatic habitat, they should be applied in all areas throughout Washington to the greatest extent possible. The implementation of RHA protection should be combined with watershed analysis and planning to comprehensively address problems and solutions at the ecosystem level.

Modifications to Recommended RHAs. Site-specific modifications to recommended RHAs can be made using *Habitat Characteristics Important to Fish and Wildlife* (p. 79) as a guide. Important characteristics should be retained or restored in all riparian areas in order to provide suitable habitat for fish and wildlife.

Rationale. The recommended RHA widths were developed by synthesizing studies that examined riparian habitat functions and the widths necessary to maintain these functions (Appendix B). This information was then grouped by riparian habitat function, and averages and ranges of reported distances were calculated (Appendix C and Table 4). Literature containing recommended riparian habitat buffer schemes was compared to the information in Appendix C. The WDFW recommended RHA widths are based in large part on this synthesis and evaluation, with a provision for variable RHA widths to accommodate the specific needs of priority species.

Table 4. Range and average widths to retain riparian function as reported in the literature (summarized in Appendix C).

Riparian habitat function	Range of reported widths in meters (feet)	Average of reported widths in meters (feet)
Temperature control	11-46 (35-151)	27 (90)
Large woody debris	30-61 (100-200)	45 (147)
Sediment filtration	8-91 (26-300)	42 (138)
Pollution filtration	4-183 (13-600)	24 (78)
Erosion control	30-38 (100-125)	34 (112)
Microclimate maintenance	61-160 (200-525)	126 (412)
Wildlife habitat	8-300 (25-984)	88 (287)

Recommended RHA widths will generally encompass the extent of riparian habitat and provide sufficient distances to retain riparian habitat functions. Recommended RHA widths are wider for larger rivers and streams to encompass the wider riparian habitat. It is recommended that RHAs be protected across the entire landscape because maintaining the connectivity of all parts of the aquatic and riparian ecosystem is necessary for healthy watersheds and fish and wildlife habitat (Naiman et al. 1992). In addition, within a watershed all flowing water is connected; impacts in a localized area can have far-reaching consequences.

Because floodplains strongly influence the aquatic system and support a combination of riparian and upland vegetation used by wildlife, their entire extent is included in the RHA. Floodplains also assist in the control of flooding downstream. The entire floodplain accumulates tremendous quantities of organic matter. During floods, this organic matter along with dissolved nutrients is flushed into the river, supplying fish and aquatic invertebrates with a rich source of food that enhances fish production (Junk et al. 1989, Gregory and Ashkenas 1990).

A frequent argument against retaining riparian corridors is that they will succumb to wind (Steinblums et al. 1984). In actuality, under most circumstances only about 2-17% of buffer trees succumb to blowdown, and this is generally restricted to specific high-wind areas (Wash. Dept. Ecol. 1985, Carlson 1991, Mobbs and Jones 1995). Although few scientific studies have examined windthrow on riparian habitat, it appears that some uncut areas are prone to substantial blowdown (Steinblums et al. 1984, Andrus and Froehlich 1986, Sherwood 1993). Mobbs and Jones (1995) found that almost half of the trees that do blow down are smaller than 28 cm (11 in) dbh, less than 1% are larger than 91 cm (36 in) dbh, and the average diameter is 33 cm (13 in). Most blowdown occurs in the first few years after timber harvest, after which the stands assume a more wind-resistant shape due to the development of shrubs along edges and changes in canopy structure (Steinblums et al. 1984, Forman and Godron 1986). The downed logs that result from blowdown contribute to woody debris requirements of riparian and stream habitat. A significant portion of instream LWD, for instance, is contributed by blowdown trees (Heede 1985, Bisson et al. 1987, Robison and Beschta 1990). Windthrow naturally contributes about 70% of terrestrial downed woody debris (Harmon et al. 1986). However, other fish and wildlife requirements involving cover, microclimate, and stream shading are lost or reduced as a result of windthrow. Therefore, additional widths are recommended in areas where high winds may jeopardize a RHA. As the width of the uncut area increases, the percent of windthrow decreases and is minimal with a width of 30 m (100 ft) (Mobbs and Jones 1995). Unfortunately, the identification of areas that are prone to wind damage may be difficult. Steinblums (1978), Andrus and Froehlich (1986), Harris (1989), and Sherwood (1993) discuss various factors that affect blowdown potential; however, a clear means of identifying such areas on the ground is still lacking. These areas must be identified using evidence on the site of past wind damage (e.g., mound and pit topography) and professional judgement.

Mass wasting of unstable slopes is a major factor in reducing water and instream habitat quality. An extra width of protected riparian habitat is recommended to assist in reducing mass wasting and to provide additional area for trapping and filtering sediments that are produced by unstable slopes. These distances are based on recommendations made by Cederholm (1994).

If sufficient width is retained, riparian areas can serve as habitat within altered landscapes. In areas with substantial early successional forest due to timber harvest, agriculture, or urbanization, riparian habitat can support a variety of animals. However, sufficient width must be retained for the riparian corridor to support more sensitive species. For example, forest interior birds avoid edge habitats. If riparian habitat is to function as a reserve for interior species, the width of the riparian area must be sufficient to provide an interior area. Tassone (1981) found that interior forest birds only occurred in corridors of at least 50 m (164 ft) in width. The WDFW species management recommendations provide information regarding the riparian needs of special species (see Appendix D).

Information on the effects of selective timber harvest in riparian habitat in Washington is limited. The few existing studies in other parts of the country are not specific to riparian habitat. Because of variability in selective harvest methods in terms of the number, size, spacing, and species of trees removed, the type and extent of effects may vary significantly. Based on existing studies, WDFW would expect selective harvest in riparian habitat to benefit some species (e.g., black bear, dusky flycatcher, ruby-crowned kinglet, chipping sparrow, dark-eyed junco) associated with early-successional forests (Mannan and Meslow 1984, Brawn and Balda 1988, Unsworth et al. 1989). However, indications from existing studies suggest other negative effects to local resident fish and wildlife. These effects are:

- decreased LWD (Morman, 1993);
- loss of neotropical migrant songbirds (Whitcomb et al. 1977, Franzreb and Ohmart 1978, Medin 1985, Gates and Giffen 1991);
- substantial reduction in breeding birds (Carothers et al. 1974);
- loss of accipiter hawks (Reynolds et al. 1982, Crocker-Bedford 1990);
- loss of snags and resultant reduced use by cavity-nesting birds and other snag-dependent species (Cline 1980, Medin 1985, Bull and Holtahausen 1993, Morman 1993);
- reduced use by elk for hiding and thermal cover (Skovlin et al. 1989);
- reduced water quality where ground-based skidding instead of suspension logging techniques occur (P. Harvester, pers. comm.).

Consequences. Significant reductions to the recommended standard widths for retaining riparian habitat functions may result in short- and long-term loss of both riparian and instream habitat quality for fish and wildlife. The loss of habitat quality will depend on the degree to which recommended RHAs are compromised within a watershed and on a specific site. In a cumulative fashion, riparian habitat functions may diminish at a site and throughout the watershed as recommended standard widths are reduced. The point at which the loss of function results in significant problems is variable and unknown.

Although trends of declining fish populations have been demonstrated in response to reductions in instream habitat quality, no clear predictor of specific population declines exists. Reductions of riparian habitat of all stream types, not just large rivers, will reduce overall habitat quality.

Reductions to specific RHA widths needed to accommodate special terrestrial wildlife species may lead to reductions in the number and distribution of those species. The standard recommended RHA widths will retain intact riparian ecosystems and accommodate the needs of many fish and wildlife species. However, the needs of specialized species (e.g., bald eagle, cavity-nesting ducks, snag-dependent species, marten, mink, fisher) may not be met with standard functional widths. Those species that are uniquely suited to riparian habitats and those with large area requirements are most vulnerable to the effects of fragmentation and habitat loss. If RHAs do not accommodate their needs where they occur, they may increasingly be adversely affected.

Watershed and Landscape Planning

Fish and wildlife are public resources. Fish and wildlife populations depend on the presence of adequate habitat, including the essential quantity, quality, and placement of habitat in a landscape. Landowners, agencies, and members of the public have a shared responsibility to protect and maintain these resources.

The most significant mitigation measure to protect riparian areas in developed landscapes is to limit the amount of impervious surfaces to approximately 10% of the watershed. The combined efforts of riparian habitat protection and stormwater retention in ponds will help mitigate the impacts of heavy urbanization and should be emphasized in already heavily developed areas. But these two measures alone cannot offset the impacts on basin hydrology caused by large areas of impervious surfaces.

Justifying the increased expense of additional mitigation is often difficult, because the tangible costs purchase only an intangible, often far-removed benefit of avoiding potential incremental damage to an off-site downstream system, perhaps at some time in the far-off future (Booth 1991). In spite of the lack of immediate payoff for efforts to prevent cumulative impacts of urbanization, such efforts are important to prevent future damage to riparian and stream systems and to rebuild degraded areas.

A key to fish and wildlife protection is to integrate fish and wildlife management considerations in all land use decisions. High impact development should be focused away from priority fish and wildlife habitats. Lands outside critical areas are also important to fish and wildlife as they help protect critical areas from surrounding urban development.

Successfully retaining and maintaining healthy riparian and stream habitat depends on thoughtful and knowledgeable planning to direct present and future land use activities. The following are recommendations to planners and elected officials when developing and implementing comprehensive land use plans.

<u>Recommendation</u>. **Retain natural areas in developed landscapes -** Retain undeveloped publicly-owned land, especially that which contains priority habitats or species, in a natural state as much as possible. Adequate protection of RHAs should be provided. A network of undeveloped corridors that connect existing natural areas should be planned and provided. RHAs provide an excellent opportunity to maintain both a priority habitat and a naturally interconnected corridor.

Rationale and Consequences. Undeveloped parcels play an important role in maintaining a diversity of wildlife species within developed landscapes. They also serve as naturally-vegetated "stepping stones" and travel corridors for wildlife in transit to better-suited habitat. Consequently, these parcels should receive high levels of environmental protection. This protection is best afforded by coordinated planning between county and city governments, with assistance from state agencies, using ideas and tools provided by the Growth Management Act, the Planning Enabling Act, and other legislation. Riparian areas and naturally-vegetated uplands should be treated as a continuum in developed landscapes for the reason that, in general, neither has sufficient remaining area to be ecologically functional on its own. Each must depend on the continued existence of other natural areas interspersed throughout a human-transformed landscape (Beissinger and Osborne 1982, Dickman 1987).

<u>Recommendation</u>. **Maintain rural lands -** In rural areas, discourage land conversions that are ecologically harmful, such as:

- conversions from forested or shrub-steppe land to agriculture;
- conversions from agriculture to housing or commercial development;
- conversions from low-density housing with greenery and largely pervious surfaces to higher density development with attendant obliteration of natural vegetation and construction of impervious surfaces.

Rationale and Consequences. Rural lands have a greater capacity to support native wildlife than heavily urbanized areas. In general, more intense development results in greater loss of habitat features needed to support fish and wildlife.

<u>Recommendation</u>. **Reduce urban sprawl -** Urban growth areas should be designed to concentrate residential, commercial, and industrial areas. In rural areas, zoning should not encourage a pattern of settlement that promotes road building and clearing of natural habitats to the detriment of fish and wildlife (Levenson 1981, Blake 1986, Dickman 1987).

Rationale and Consequences. In a cumulative process, urban and suburban developments convert natural areas to developed areas with less habitat value and greater amounts of impervious surfaces. Planned growth that concentrates the effects of urbanization in as few areas as possible will lessen the continued piecemeal loss of upland and riparian habitats.

Recommendation. **Compensate for lost habitat -** Full mitigation for projects that will impact significant portions or functions of riparian habitat should be required. This includes projects in upland areas that will negatively influence basin hydrology or fish and wildlife use in riparian and stream habitats.

Rationale and Consequences. When riparian habitat is lost or severely altered without mitigation, the downward trend of fish and wildlife populations continues. Only by retaining existing habitat and restoring degraded areas will the trend of reduced habitat quality for fish and wildlife be slowed or reversed.

Recommendation. **Consult with fish and wildlife professionals -** WDFW biologists should be included when developing comprehensive plans or development regulations and on projects involving fish and wildlife resources.

Rationale and Consequences. Working closely with WDFW fish and wildlife professionals will ensure that innovative techniques and best available science are considered in the search for possible solutions.

Recommendation. **Develop coordinated plans -** Coordinate land use planning for fish and wildlife across jurisdictional boundaries.

Rationale and Consequences. Fish and wildlife do not recognize political and ownership boundaries. Coordinated work with landowners and government jurisdictions must occur to develop a landscape that provides fish and wildlife habitat rather than a series of disjointed and potentially dysfunctional refuges. Because of intricate interdependencies, the condition of riparian and stream habitat depends on the health of local areas as well as entire watersheds.

Agriculture

Agricultural activities may contribute significantly to riparian and instream habitat degradation locally and across the landscape. A shift from conventional to sustainable agricultural practices would reduce or eliminate impacts to riparian and aquatic habitats and their fish and wildlife communities. Protection of RHAs, conservation tillage, use of cover crops, integrated pest management, use of non-chemical alternatives to pesticides, and alternative irrigation systems that reduce water use, erosion, and return flows are all techniques that should be explored and implemented across the landscape (Grue et al. 1989).

Below are recommendations for protecting riparian and stream habitat in agricultural areas. Also, see the recommendations regarding grazing (p. 97) and chemical treatments (p. 104). The Washington Department of Fish and Wildlife recommends that farmers seek further assistance from local soil scientists, fish and wildlife biologists, and agricultural professionals in order to develop more specific agricultural activity plans using the guidelines presented here.

Recommendation. **Protect riparian habitat -** Provide a buffer of natural vegetation between perennial or intermittent stream courses and cropland of 61 m (200 ft) or the above recommended RHA width (Table 3), whichever is greatest. If cropland currently exists within riparian areas, explore ways to cease farming in that area and pursue restoration and revegetation with native riparian plants. See the section on *Restoration and Enhancement* (p. 113) and seek assistance from the Natural Resources Conservation Service or the Washington Department of Fish and Wildlife.

Rationale. The soils and natural vegetation of riparian habitat can hold and filter significant amounts of sediments, pesticides, and nutrients generated in cropland. This filtering capacity will reduce the quantities of these substances that enter aquatic systems to the detriment of fish, wildlife, and water quality. Adequate areas of intact riparian vegetation will also provide critical cover and foraging habitat for terrestrial wildlife, enabling many species to exist in an agricultural landscape.

Consequences. Without intact RHAs in farmed landscapes, water quality is likely to continue to decline, further reducing anadromous and resident fish production. Populations of amphibians, birds, and mammals that use aquatic areas would continue to decrease because of poor water quality and loss of habitat.

Recommendation. **Minimize soil erosion -** In all agricultural areas, use techniques to eliminate or minimize soil erosion. Such techniques include: 1) conservation cropping systems (e.g., cover crops and conservation tillage); 2) selection of crops that hold soil and have high ground cover; 3) harvest techniques that minimize soil disturbance; 4) maintenance of continuous plant cover to the greatest extent possible; and 5) cultivation and harvest techniques that reduce the time that the soil is bare. Use drip irrigation or lateral piping rather than sheet or rill irrigation to reduce sedimentation and water consumption (P. Harvester, pers. comm.).

Rationale. Erosion of cropland topsoil and its subsequent deposition into stream systems is one of the most significant impacts of agricultural practices. Careful consideration of the erosion potential of various farming practices and adoption of techniques that reduce erosion can help limit stream sedimentation and preserve valuable fish resources. Conservation cropping systems (e.g., cover crops and conservation tillage) generally yield much less sedimentation than conventional systems (Terrell and Perfetti 1989). Using cultivation and harvest techniques that reduce the time that the soil is bare will not only protect riparian and stream systems but also help retain topsoil. When cropland is located in riparian areas, the loss of herbaceous, shrub, and tree cover can increase bank erosion and reduce the ability of riparian vegetation to keep sediments from entering the stream system. The retention of riparian vegetation will help reduce stream bank erosion, moderate upland erosion, and lessen sediments in streams.

Sheet and rill irrigation systems exacerbate erosion problems; alternative irrigation methods can facilitate the retention of topsoil. Intact RHAs can hold and filter much of the sedimentation produced in agricultural uplands, but these areas cannot control excessive sedimentation. By reducing topsoil loss and general upland and stream bank erosion, fish, wildlife, and farmers will benefit in the long run.

Consequences. The extent of fish and aquatic wildlife losses as a result of increased sedimentation is related to the duration and degree of sedimentation. Because of this, it is difficult to predict the degree of population declines; however, general trends of losses of aquatic resources with increasing soil erosion have been observed.

Recommendation. **Pursue alternatives to harmful fertilizers in uplands** - When fertilizers (including animal wastes) are used, apply them only in amounts and at times that match crop requirements in order to reduce excess nutrients that are eventually deposited in stream systems.

Rationale and Consequences. Fertilizers applied in excess of crop uptake eventually get into water systems. These fertilizers change the water chemistry, resulting in excessive aquatic plant and algal growth. Although this increased productivity may be immediately beneficial, it is detrimental over time. Oxygen depletion occurs and water acidity increases, thereby altering survival of some fish and aquatic invertebrates and causing a shift in the abundance and composition of the native fish community.

Recommendation. **Increase efficiency of water-use -** Implement water-use efficiency measures and reduce water requirements of crops as much as possible. For example, use drip irrigation and piped laterals.

Rationale and Consequences. Water withdrawal for crop irrigation reduces the availability of suitable fish habitat, especially spawning and rearing areas. Low flows can also block fish migration. Reducing the amount of water in the stream channel increases water temperature that may be detrimental to fish populations. The reduction of stream flows may reduce existing riparian vegetation. Water fluctuations between the irrigation and non-irrigation seasons also reduces the area that can support riparian vegetation. The loss of riparian vegetation not only reduces riparian-associated wildlife but further reduces the quality of instream habitat in terms of woody and organic debris, stream temperature, and filtration of sediments and artificial chemicals.

Recommendation. **Treat agricultural waste-water** - Support enhancements that treat agricultural waste-water (e.g., settling ponds) before water re-enters natural stream systems.

Rationale and Consequences. Water that flows over and through agricultural areas, especially irrigation water, is a vehicle that carries sediments, excessive nutrients, and pesticides to stream courses, thereby degrading water quality in natural systems. The capture and treatment of agricultural waste water will help reduce water quality problems that adversely affect fish and wildlife.

Recommendation. **Limit accumulations of animal waste near riparian habitat** - Avoid locating feedlots, stockyards, and waste treatment and control facilities (e.g., manure lagoons) within 183 m (600 ft) of water courses (Terrell and Perfetti 1989). In heavily-used pastures, maintain a 61 m (200 ft) stream buffer of intact vegetation (e.g., ungrazed) to filter animal wastes (Terrell and Perfetti 1989).

Rationale and Consequences. These significant sources of animal waste alter stream chemistry that adversely affect fish. In addition, large quantities of animal waste can create ammonia during the decomposition process in amounts that are fatal to fish. Intact vegetation and soils in riparian areas can serve a key role in filtering bacteria, nutrients, and salts from animal waste.

Grazing

Improper management of livestock grazing in riparian habitat will likely have significant negative consequences for fish and wildlife. However, careful management and an understanding of the unique conditions that occur in riparian habitat can minimize or eliminate damage to riparian areas from grazing.

Because each riparian area is unique, no one grazing strategy fits all conditions. A successful riparian grazing strategy will: 1) incorporate sufficient rest periods to allow plant regrowth, vigor, and energy storage; 2) retain sufficient vegetation during high flow periods to protect stream banks, dissipate stream energy, and trap sediments; and 3) control grazing times and intensity to prevent damage to stream banks from trampling and over-utilization of vegetation. With carefully supervised management, a variety of grazing systems can accomplish this. Following are specific recommendations to guide the development of a grazing strategy for pastures that contain riparian habitat.

Recommendation. **Exclude livestock grazing from riparian areas or manage them as special use pastures** - In grazed areas, fences can be used to exclude livestock or to create special-use riparian habitat pastures. Fencing is particularly important when careful management of pastures with riparian habitat is not feasible or when pastures with riparian habitat are small and use is heavy. If they are not in a degraded condition, fenced riparian pastures (which may include upland areas) may be managed as special-use pastures with carefully controlled grazing. If they are in a degraded condition, fenced riparian areas should be rested for the period necessary to restore herbaceous and woody vegetation and to restabilize stream banks and channels. Fence maintenance is key; a fence break can quickly negate any gains. Financial assistance for fencing may be pursued through the USDA Natural Resources Conservation Service.

Smooth wire (New Zealand type) is preferred for fencing in order to allow easier and safer access to and from the riparian area by wild animals such as elk and deer. The top wire of the fence should be no higher than 107 cm (42 in), the next wire should be at least 41 cm (16 in) below the top wire (to prevent entanglement of animals jumping the fence), and the bottom wire should be at least 41-46 cm (16-18 in) above the ground. Use fence stays for spans of greater than 2.4 m (8 ft) between posts (Karsky 1988, T. Thompson, pers. comm.).

Rationale. Livestock exclusion provides the best assurance of riparian protection in grazed areas. Although not impossible, it may be difficult to maintain healthy riparian conditions without fencing because livestock tend to concentrate in riparian habitat regardless of stocking rates and grazing system. While some have claimed that grazing can enhance range conditions, the scientific literature does not support this in riparian areas.

Consequences. In riparian areas where intensive management or fencing does not occur and grazing use is high, small mammals, reptiles, amphibians, ungulates, fish, and shrub- and ground-nesting or foraging birds are likely to suffer severe reductions through loss of cover, forage, and breeding structures. The vegetation composition is likely to change, perhaps simplifying the plant community, and there may be a loss in the number of canopy layers. The condition of stream banks, channels and riparian soils will deteriorate under unmanaged or heavy grazing in riparian habitat. Overall, riparian and stream habitat quality and diversity will probably decline, resulting in local fish and wildlife losses.

Recommendation. **Intensively manage pastures with riparian habitat -** If fencing is not feasible, use intensive grazing management techniques (e.g., special grazing systems, herding, pasture rest, controlling the kind of animal, alternative water and shade sources) to control timing, distribution, and intensity of grazing in pastures with riparian habitat. Livestock use of riparian areas must be carefully and regularly supervised over time. Inadequate supervision and resultant heavy livestock use even for a short time can set back years of progress in riparian habitat improvement.

Grazing management should strive to meet the following performance objectives in riparian areas in order to provide adequate habitat for fish and wildlife:

- Maintain vegetative cover and composition very close to what would occur naturally without grazing (Platts and Nelson 1985a).

- Remove no more than one-half of one year's growth of woody vegetation in a given year (Behnke and Raleigh 1978; C. Perry, pers. comm.).

- Retain a 10-15 cm (4-6 in) average stubble height of herbaceous vegetation at the end of the grazing period, regardless of when grazing occurs. Alternatively, remove no more than 25% of the herbaceous vegetation by weight in riparian areas (Platts 1981). Greater use may be appropriate if it can be demonstrated that a greater amount of grazing will not damage the stream or riparian area, including the vegetation, stream banks and channels. Conversely, lesser utilization may be needed to maintain or restore some particularly sensitive riparian areas. Refer to *Habitat Characteristics Important to Fish and Wildlife* (p. 80) to guide the maintenance or restoration of healthy riparian habitat.

- Emphasize short duration, early-season (March-June) grazing. The duration of grazing to meet the performance objectives is probably less than one-half of the spring season and preferably occurs in the earliest part of spring. Summer grazing should not occur, and fall and winter grazing are also not preferable because livestock concentrate in riparian areas during these seasons and over-utilize the woody vegetation. Fall and winter grazing may be an option for riparian areas if the extent of use, particularly of woody vegetation, is carefully controlled. Monitoring the condition of stream banks and removal of livestock when any erosion occurs is also important.

- Diligently monitor pastures to detect damage to riparian vegetation or stream banks; adjust management schemes accordingly. The Rangeland Health Evaluation Matrix and Surface Soil Characteristics tables presented in HB 1309 Ecosystem Standards report (Ecosystem Standards Advisory Committee 1994) provide a simple tool to evaluate rangeland health.

- Utilize pasture rest if needed to regain plant vigor and to repair or stabilize stream banks.

Seek further assistance in developing specific livestock management plans from sources such as Platts (1990) and from local Natural Resources Conservation Service staff. Platts (1990) presents information on many common management schemes and their specific effects on riparian habitat.

Rationale. Because livestock concentrate in riparian areas, grazing that occurs there must be managed differently than in uplands. The vegetation, soils, and topography are also inherently different, necessitating alternative management strategies. For this reason, standard rangeland guidelines are not suitable for riparian habitat.

Riparian vegetation is more affected by grazing intensity and distribution rather than by a specific grazing system. With careful supervision and management, many systems can maintain required characteristics of riparian vegetation. For that reason, desired riparian habitat conditions are recommended rather than any one grazing system.

The Washington Department of Fish and Wildlife recommends the retention of a particular stubble height of herbaceous vegetation rather than a percent utilization. A primary objective of riparian management is to retain sufficient vegetative cover to protect soils from erosion and to maintain healthy plant growth. By retaining sufficient herbaceous and woody vegetation at all times of the year, erosion can be minimized and adequate vegetation will remain to provide fish and wildlife with necessary cover and forage.

The retention of adequate stubble height and proper timing of grazing will produce the best conditions for riparian and stream habitat as well as for fish and wildlife. During the spring, green herbaceous vegetation is generally abundant in uplands as well as riparian areas, reducing livestock concentration in riparian habitat. Because herbaceous vegetation is abundant, consumption of shrubs by livestock during the spring is minimal. Mild temperatures also reduce livestock concentration in riparian areas. These conditions reduce livestock damage in riparian habitat during spring. By restricting the spring utilization of grazing in riparian areas [i.e., retaining a 10-15 cm (4-6 in) stubble height], regrowth of vegetation can occur during the summer to provide good cover for soil stabilization and fish and wildlife habitat during the winter.

Consequences. If neither riparian fencing nor careful management of pastures with riparian habitat occur, then decline of riparian ecosystems, associated aquatic systems, and fish and wildlife inhabitants are likely to continue as they have over the past 100 years. If compromises occur even for short periods, any gains can be quickly lost. Water quality and the general aesthetic quality of stream systems will also continue to suffer with inadequate grazing management.

Recommendation. **Use additional methods to reduce impact on riparian habitat -** Include the following management practices to reduce or eliminate impacts from livestock and to restore riparian habitat:

- Armor banks to lessen erosion and sedimentation in riparian areas where livestock concentrate for watering or stream crossing.

- When designing pastures, include as much of a stream inside a pasture rather than along a pasture boundary. Cattle tend to concentrate along fence lines. Fences that cross streams, are on either boundary, or are in the middle of streams will encourage heavy livestock use and consequent damage (Myers 1981).

- Move livestock from one pasture to another rather than depend on passive livestock drifting (Myers 1981, Winward 1994).

Recommendation. **Do not graze damaged or sensitive riparian habitat -** Significant loss of vegetation has occurred when any of the following conditions are noted: 1) use of streamside vegetation is high and only a short stubble remains; 2) more than half of the potential vegetative biomass has been used; and 3) only the root system and part of the stem remains on many plants (Platts et al. 1987). Stream and riparian habitat degradation is indicated by stream bank deformation, erosion or excessive sedimentation, lack of mature woody vegetation, lack of reproduction of woody vegetation, lack of vigorous herbaceous vegetation, and other vegetative changes. It may be necessary to eliminate all grazing from degraded or highly sensitive riparian areas through fencing and herding techniques on a temporary or permanent basis to restore or protect riparian vegetation and stream bank conditions. The exact period of rest must be determined on a site-by-site basis. When and if grazing is resumed, an intensive system of grazing management should be instituted.

Recommendation. **Restore damaged streams -** Stream restoration or channel and bank stabilization structures may be necessary in severe situations. Any restoration efforts must be accompanied by sound riparian grazing strategies (Kaufman and Krueger 1984). Consultation with fish and wildlife biologists for specific restoration prescriptions is encouraged.

Rationale and Consequences. In areas where riparian and stream habitat have been damaged from overgrazing, conditions are not likely to improve unless the vegetation and soils have a period of rest to stabilize and regain vigor. The length of this period will vary depending on the extent of damage, plant communities involved, soil conditions, and other site-specific variables. If damage to degraded or particularly sensitive riparian areas continues, the restoration time will increase and fish and wildlife habitat will continue to decline. The cumulative effect of riparian habitat degradation by grazing can also increase sedimentation and erosion in downstream areas.

Watershed Management

Because riparian habitat affects and is affected by management activities in adjacent riparian areas and in uplands, the health of entire watersheds should be considered when planning and conducting land use activities. Wildlife use of riparian habitat is related to and may be dependent on the retention of upland native vegetation near the riparian area. Riparian and upland habitats are functionally intertwined; hence, spatial connectivity should be maintained between them to the greatest extent possible. To focus habitat management efforts on riparian areas alone will provide significant gains, but riparian habitat cannot ameliorate all adverse impacts on uplands (e.g., sedimentation, habitat fragmentation). The importance of adjacent uplands with natural vegetation is particularly critical in non-forested areas in arid eastern Washington where riparian vegetation is especially thin and fragile.

Recommendation. **Manage forested watersheds to maintain an appropriate mix of successional stages -** To reduce erosion and stream sedimentation, a balanced hydrologic system that resembles natural conditions should be maintained. To provide connectivity of riparian and upland vegetation, strive to develop watershed-specific forest practices prescriptions that direct cutting patterns that establish an appropriate mix of successional stages for a particular area. This watershed-level analysis should be based on methods developed by state or federal agencies (e.g., Department of Natural Resources, Department of Fish and Wildlife, U.S. Forest Service), habitat conservation planning (Department of Natural Resources), or other watershed-level tools for evaluating cumulative effects (e.g., Natl. Council of the Pap. Indust. for Air and Stream Improv. 1992). Such analysis should include the habitat needs of both fish and wildlife.

Where watershed level analysis and planning cannot be conducted, forest management should reflect the general guideline of having no more than 25% of a watershed in the clear-cut/small sapling successional stage (open canopy) at any given time (see the following for related discussions: Franklin and Forman 1987, U.S. For. Serv. 1990, Chamberlin et al. 1991).

Rationale. Vegetation removal and the associated soil disturbance and compaction in upland areas has negative effects on riparian and aquatic habitats. These effects decline as forest stands develop a closed canopy and mature vegetation. Negative impacts can be moderated by controlling the extent of vegetation removal and soil disturbance in uplands.

Consequences. Basin hydrology will begin to change if the extent of early-successional forests increases beyond that which is recommended through a watershed-level analysis. Changes affecting riparian and stream habitat will usually involve increased run-off and increased peak flows. As a result, erosion and stream sedimentation are likely to escalate beyond natural levels, thereby reducing habitat stability, diversity, and quality. These effects will primarily affect fish and aquatic wildlife.

If forest practices yield early-successional stands that are proportionately greater in extent than that which occurs in a natural disturbance regime, early-successional species and habitat generalists will increase, while species associated with forest interiors and with late-successional conditions will decline.

Recommendation. **Implement long rotation cycles of timber harvest** - Rotation periods of greater than 120 years are recommended to retain mature forests, snags, large woody debris, and other features of high value to wildlife in proximity to riparian habitat (Bull 1980, Cline et al. 1980, Cline and Phillips 1983, Chamberlin et al. 1991).

Rationale and Consequences. The frequency of forest harvest may affect the rate of erosion on the time scale of several rotations. Shorter rotation intervals result in a greater portion of a drainage basin being in a sensitive condition because of reduced root strength while stands are in early stages of development. Longer rotation intervals will ensure a supply of essential large logs to stream and riparian areas. Large trees have been shown to be necessary for the maintenance of channel integrity and productivity in most forest streams. Mature forest fauna will continue to be replaced by early-successional and habitat generalist species if short forest rotation intervals are prevalent. Large woody debris, critical to the function of both riparian and stream habitat, will also continue to decline, thereby reducing habitat and species diversity.

Recommendation. **Avoid timber harvest on unstable slopes -** Avoid timber harvest and road building on slopes prone to instability and accelerated erosion. Potentially unstable slopes are generally those greater than 31° (60%) and exhibit one or more of the following characteristics (K. Lautz, pers. comm.):

- concave slope profile;
- wet areas such as springs, seeps, and ponds;
- presence of hydrophytic (water-loving) plants;
- hummocky terrain;
- jackstrawed (trees tilted in various directions) or pistol-butted (curved tree trunks bent down slope) conifers;
- evidence of current or previous instability (landslide tracks, debris jams or fans);
- tension cracks.

Stream banks that have been oversteepened (gradient >50%) due to erosion of the toe of the bank are especially prone to instability and are of special concern because of the very high likelihood of sediment delivery. Timber harvest and road building should be avoided on these features.

The following references contain additional methods for identifying areas that are susceptible to mass wasting or erosion: Sidle et al. 1985, Swanston 1985, Hammond et al. 1992, Chewin et al. 1994, Prellwitz et al. 1994, Shaw and Johnson 1995.

Rationale. Vegetation removal or soil disturbance on unstable slopes greatly increases the likelihood of mass wasting or chronic erosion problems. To protect water quality, stream banks and channels, and riparian habitat from excessive erosion rates, unstable slopes should not be disturbed. Swanson et al. (1987) concluded that steep basins tend to produce more sediment and have a greater response to management activities than areas with gentler topography. As a general indication, Bennett (1982) found erosion to be ten times greater in basins with average slopes of 60% than in areas with gentler slopes.

Consequences. Fish, aquatic invertebrates, and amphibians are most affected by the increases in erosion and sedimentation that eventually reach stream systems when unstable slopes fail at unnaturally high rates. Their populations may decline as a result of stream siltation, loss of spawning habitat, scouring of stream channels, and a general increase in the instability of stream banks and beds.

Recommendation. **Carefully manage grazed uplands -** To prevent excessive erosion and stream sedimentation, grazing in all areas should not exceed moderate levels of plant usage (i.e., more than half of plant biomass should be retained). Vegetative cover and composition very close to what would occur naturally without grazing should be retained. No more than one-half of one year's growth of woody vegetation should be removed.

Rationale and Consequences. Sediment is eventually delivered to streams when upland erosion occurs. Unmanaged livestock grazing in uplands can cause rates of erosion that exceed natural levels. Stream sedimentation can directly alter fish survival and reduce instream habitat diversity necessary to support healthy and productive fish populations. In addition, when upland ranges are in good condition, grazing pressure and damage to riparian areas are likely to be less.

Recommendation. **Provide corridors connecting riparian and upland habitats -** Natural vegetation connectors between riparian and upland areas should be retained to provide protected travel corridors between riparian and other habitats.

Rationale and Consequences. Riparian and upland habitats are functionally intertwined; hence, spatial connectivity should be maintained between them to the greatest extent possible. Many species that use riparian habitat also depend on other upland habitats to meet their life requisites. They also must disperse when an area is beyond its carrying capacity. This dispersal helps to maintain genetic variability and viability within populations. Without protected corridors connecting riparian habitat with adjacent natural areas, species that are vulnerable to predation, sensitive to human disturbance, or that have mobility limitations may be restricted to riparian areas. This isolation may eventually cause population problems as a result of genetic isolation.

Chemical Treatments

Some pesticides (including insecticides, fungicides, rodenticides, herbicides) and fertilizers (including animal wastes) can directly kill fish and wildlife and indirectly affect habitat quality when used inappropriately. Because information on the toxicity and effects of specific chemical treatments to fish and wildlife is scarce, a conservative approach to chemical treatments is recommended and alternatives to chemicals are encouraged. Appendix E lists contacts helpful when assessing pesticides and their alternatives.

Recommendation. **Restrict chemical treatments -** Unless it is certain that a chemical treatment has no deleterious effects on fish, wildlife, or their habitats, it is recommended that the application of pesticides and fertilizers, including drift from aerial and ground applications, be restricted within RHAs. The soils and vegetation present in intact riparian areas are uniquely suited to trap and filter pesticides and fertilizers before they reach the water. Suggested widths of buffers to filter and sequester the majority of these chemicals vary considerably in the literature because of the variable conditions among the studies. Reported buffer distances range from 4-183 m (13-600 ft) and average 24 m (78 ft) (Appendix C). Terrell and Perfetti (1989) suggest a buffer of 61 m (200 ft) adjacent to irrigation ditches and water courses when applying chemicals. Additional RHA widths may be required for compounds with known toxicity to wildlife, fish, and aquatic organisms (Payne et al. 1988, Terrell and Perfetti 1988, Driver 1994).

Near riparian areas, avoid application of fertilizer on frozen ground or in areas with an immature crop or bare ground. Higher than usual runoff occurs in these situations; this runoff can carry large quantities of fertilizers to water bodies (Terrell and Perfetti 1989).

Aerial application of pesticides and fertilizers increases overspray to adjacent areas and increases the likelihood that these chemicals will reach stream systems. Ground and spot-application methods reduce such overspray. Appendix E lists contacts that may be helpful when assessing pesticides and other chemical applications.

The control of noxious weeds may be an exception to these recommendations because it is required by law (RCW 17.10 and WAC 16.75) and because noxious weeds can degrade the quality of fish and wildlife habitat. Weed control within riparian habitat (as well as in uplands) should be done through diligent monitoring and by early detection and treatment. When noxious weeds are first detected, the situation should be evaluated to determine the most effective yet least environmentally damaging technique to employ. Examine the use of mechanical or biological means of controlling weeds. Sources listed in Appendix E may assist in this examination.

Rationale and Consequences. Deposition of fertilizers into water bodies will alter the water's natural chemical balance, resulting in unusually high aquatic plant and algal growth. Long-term consequences of this excessive growth are detrimental and can kill fish. Decaying plants deplete oxygen available for fish and increase nitrate levels which in turn increase the water's acidity. Excess acidity may slow fish growth and negatively affect reproduction in some species. In addition, the abundance and composition of bottom-dwelling organisms in waters receiving excess nutrients can change. Species diversity may significantly decreases and the abundance of a few nutrient-tolerant species may increase. These changes may bring about changes in the composition of fish species that depend on bottom-dwelling organisms.

Pesticide-free areas adjacent to irrigation ditches and RHAs will help hold and filter pesticides applied to upland areas and prevent large quantities of pesticides from entering ditch water and natural stream systems.

Recommendation. **Select sound pest control methods** - Sound methods of pest control include those with few or no toxic effects on non-target fish, wildlife, or invertebrates; methods that do not alter native plant abundance and composition; and methods that apply chemicals during those select periods when wildlife is either absent or not at a critical stage in their life cycles (e.g., reproduction). When chemical treatments cannot be avoided, careful use of pesticides and fertilizers, in strict accordance with their labeling, can help keep them out of water courses and minimize impacts to fish, wildlife, and habitat.

Roads, Stream Crossings, and Utility Lines

Roads and their associated drainage systems alter water flows. These alterations can substantially increase erosion and decrease slope stability, especially if the roads are improperly located and designed. The result is usually an increase in stream sediments which can adversely impact riparian and aquatic habitats and the fish and wildlife that inhabit them. The following recommendations will help reduce road impacts on riparian and their associated aquatic habitats.

Recommendation. **Avoid constructing roads, utility lines, or conducting activities involving stream crossings within RHAs** - Where no viable alternative exists, road alignment should be perpendicular to streams to minimize riparian vegetation loss and habitat fragmentation (Oakley et al. 1985). Streams are preferably crossed by bridges instead of culverts. If culverts are used, they should be designed to convey a minimum 100-year peak flow event and ensure passage for both adult and juvenile fish per WDFW guidelines (WAC 220-110-070). These guidelines include a minimum culvert diameter of 46 cm (18 in). Culverts with deep road fill [>1.8 m (6 ft) above top of culvert inlet] should be avoided where streams are at risk of conveying debris flows to the crossing. Seek information and assistance from WDFW and DNR on culvert installation.

Rationale and Consequences. Roads in riparian areas, especially those running parallel to the stream course, remove valuable riparian habitat. Roads are a travel barrier for many species; hence, they can isolate riparian habitat from uplands. Vehicles disturb wildlife, and roads make riparian areas more accessible to people. Subjecting fish and wildlife to increased disturbance may cause sensitive species to leave an area or may reduce their productivity. Roads adjacent to riparian areas increase vehicle-related mortality of wildlife. Roads adjacent to streams can contribute excessive sedimentation to streams because of altered water flow, bare ground, and rapid water flow over impervious surfaces. All of these factors may result in a reduced ability of riparian and stream habitats to support diverse and abundant fish and wildlife populations.

When roads must enter riparian habitat, careful design and maintenance can reduce but not eliminate these impacts. Roads that cross streams perpendicularly and then exit the riparian area will minimize habitat fragmentation and loss. Adequately-sized culverts will prevent debris build-up and massive erosion when this debris dam breaks. It is unlikely that culverts large enough to pass debris will block fish migration.

<u>Recommendation</u>. **Improve road drainage network -** Improve the road drainage network throughout watersheds by removing unnecessary culverts, increasing the size of inadequate culverts, or replacing culverts with bridges.

Rationale and Consequences. Properly designed culverts can help control erosion, while poorly designed ones can exacerbate it. When culverts do not regularly pass debris, it accumulates and impedes water flow and fish passage. These debris dams are vulnerable to breaking during storm events, and then large quantities of water and debris stored behind the dam are sluiced downstream causing channel and bank erosion. While an individual event is not always undesirable and may resemble natural disturbances, the cumulative effect of many such occurrences can increase the frequency of sediment delivery and stream destabilization well beyond natural rates. Spawning and rearing habitat may then be damaged, stream turbidity may increase, and the frequent movement of woody debris may preclude the development of instream habitat features of importance to fish and wildlife. Road drainage improvements can reduce debris accumulations and reduce stream risks during storm and flooding events.

<u>Recommendation</u>. **Close unnecessary roads and retain roadless areas -** Close roads when not in use and deactivate unnecessary roads in unstable or erosive terrain. Deactivation should include restoration of natural drainage paths, removal of organic debris from fill, recovery of side-cast materials onto road surface, and revegetation. Fish and wildlife will best be served if areas that are currently roadless remain so; alternative means of resource removal should be explored (Reeves and Sedell 1992).

Rationale and Consequences. Limiting road densities and properly designing and maintaining roads will minimize the impacts to hydrology, wildlife, and habitat. By keeping presently roadless areas in a roadless condition, large areas of intact, undisturbed habitat used by species requiring large areas (e.g., lynx, bear, cougar, mountain caribou) can be sustained in Washington.

<u>Recommendation</u>. **Minimize road mileage across the landscape -** As a general guideline, road area should be limited to less than 3% of the watershed area (Cederholm and Reid 1987). On elk summer range, open-road densities should not be more than 1.5 mi/mi^2. On elk and Columbian black-tailed deer winter range, road densities should be less than 1 mi/mi^2. In mule deer and white-tailed deer winter range, road densities should be less than 0.5 mi/mi^2.

Rationale and Consequences. Significant effects of roads on fish and wildlife habitat can only be minimized, not eliminated, with careful road design and maintenance. Roads change basin hydrology through the replacement of largely pervious surfaces with impervious surfaces, alteration of water drainage patterns, and destabilization of some slopes. The effects of erosion and stream sedimentation can be minimized with proper location, design and maintenance of road systems. Limiting the extent of roads can further minimize negative impacts. In addition, roads provide human access to areas, thereby resulting in increased disturbance and potential poaching on fish and wildlife. Some species (e.g., elk) avoid roads and roadside areas, thereby reducing available habitat. Other species are negatively affected by roads because of increased stress during critical periods (e.g., wintering deer). Roads act as a barrier to the movement of some animals (e.g., small mammals, amphibians, black bear) because of their sensitivity to disturbed areas, limitations in mobility, or because of an increased susceptibility to predation, road kill, or poaching while crossing open roads.

Recommendation. **General road construction guidelines -**

- All new roads should be designed and constructed according to current best management standards; existing roads should be improved to meet these standards. Long-term commitment to road maintenance is essential. Specific information and assistance is available from WDFW and DNR.

- Care should be taken not to destabilize steep headwater slopes during roading activities to avoid sedimentation of salmonid spawning and rearing habitats (Cederholm 1994). This can be accomplished by building stable, well-maintained roads (Cederholm and Reid 1987).

- Road construction on slopes greater than 50% should be built to full-bench construction standards, and there should be a commitment to long-term maintenance.

- Use of full suspension yarding systems will minimize damage to riparian ecosystems, and at the same time significantly reduce road construction costs (Cederholm 1994).

Rationale and Consequences. The use of sensible techniques for road siting, construction, and maintenance can reduce problems associated with erosion and stream sedimentation. Properly locating roads by avoiding unstable slopes and riparian areas is of primary importance.

Recreational Use

Riparian areas are popular locations for outdoor recreation. Although not an entirely benign activity, recreational use of this sensitive and vulnerable ecosystem can be compatible with protection of fish and wildlife resources. Care must be taken, however, to design recreational facilities that have low impacts on riparian habitat. Responsibility is also placed on recreationalists to conduct themselves in a manner that is least disturbing to fish, wildlife, and their habitat. Providing educational materials to inform the public of this responsibility is encouraged.

The Washington Department of Fish and Wildlife recommends that new recreation facilities be placed outside RHAs. However, if this is not feasible, then the following guidelines should be adopted.

Recommendation. **Limit high-impact recreation facilities in Riparian Habitat Areas -** High-impact facilities are those that attract high densities of people or that involve buildings or vehicles (including recreational vehicles). Examples of high-impact facilities are: 1) camp and picnic grounds, 2) road access points, 3) boat ramps and marinas, and 4) motorized vehicle trails. It may be preferable to improve or expand existing facilities rather than build new ones. New facilities should be built outside recommended RHAs and be provided with developed access to streams. Access to stream banks should be localized by providing trails and features near the stream that discourage wandering along stream banks and through riparian habitat. Access locations should be hardened if necessary to protect stream banks. New recreational development in riparian areas where there are known regular occurrences of priority species such as spawning salmon, bald eagles, elk, moose, and grizzly bear should be avoided.

Rationale and Consequences. High-impact recreation facilities can cause severe soil compaction, alteration and loss of vegetation, erosion of stream banks, and disturbance to fish and wildlife. It is difficult to prevent this damage when the number of people is high and their use affects a sensitive area. If such facilities are developed within RHAs, local habitat conditions will likely degrade. This degradation may include the loss of ground and shrubby vegetation, loss of large woody debris and snags, decreased water quality, and destabilized stream banks. Sensitive fish and wildlife will likely be lost from the area or suffer declines in productivity.

Recommendation. **Carefully site new facilities -** New recreational facilities should be placed in locations that will have lesser impacts on riparian and stream habitat and sensitive fish and wildlife. For example, better locations may include the following:

- sites with stable soils and slopes;
- currently degraded or developed sites, such as agricultural or industrial lands;
- sites that have no known occurrences of priority species;
- lands which, if not used for recreation, would be vulnerable to intensive development.

Facilities should be located well away from streams and wetlands; preserve, where possible, the recommended RHA widths. Use well-designed and maintained trails and roads to access aquatic areas. Keep the number of trails and roads within the RHA to a minimum.

An evaluation process similar to that developed for ORV, hiking, and horse back-country recreation use (Sachet 1988) can be used to assist in locating suitable sites.

Rationale and Consequences. Carefully siting and designing new facilities can reduce or eliminate the impacts of erosion, disturbance to sensitive fish and wildlife, and alteration of natural riparian vegetation or important habitat features.

Recommendation. **Retain riparian habitat features at recreation sites -** To the greatest degree possible, retain native vegetation, downed logs, snags, rock outcroppings, and other natural features at all recreational sites. Prohibit fuel-wood gathering at campgrounds. Inform the public regarding the importance of snags and downed logs to fish and wildlife.

However, safety issues (especially involving snags) must be considered. Determine the safety hazard of each snag within recreation areas rather than implementing a broad scale removal of all snags. Pursue the topping of snags to a safe height rather than entire removal. Refer to U.S. For. Serv. et al. (1992) for assistance in determining the safety hazard of specific types of trees.

Rationale and Consequences. Snags and downed logs are important features that directly provide food and cover habitat for a group of specialized birds, mammals, and amphibians (Wash. Dept. Fish and Wildl. 1995). These features are also critical to a multitude of invertebrates and micro-organisms that assist in recycling the nutrients in wood needed to maintain healthy forest soils. Gathering of firewood at campgrounds will result in the removal of live vegetation, snags, and logs.

Recommendation. **Limit trails in riparian habitat** - Trails, especially those that impact soil stability and tend to cause significant erosion (e.g., trails for horses, ORVs, heavy use hiking), should not be located within recommended RHAs for most of their length. Instead, locate such trails well away from streams and wetlands, but provide occasional bends or perpendicular side trails for viewing or access to streams and wetlands (U.S. For. Serv. 1990). The number of stream crossings should be minimized. Stream crossings should be perpendicular to the stream and they should minimize actual contact with the stream (e.g., use long-span bridges). Crossings or stream contact points should be designed to minimize disturbance to stream banks, streambeds, and other sediment-producing situations (Sachet 1988).

Rationale and Consequences. High-impact trails affect fish and wildlife habitat in a manner similar to roads. Their creation and continued use can change the flow of water, thereby destabilizing local areas and generating erosion and stream sedimentation. Trail soils are either compacted or constantly churned by the action of wheels, human feet, or pack animals. Because people are drawn to water, stream banks that are accessible with trails may become eroded through trampling and vegetation removal in areas of heavy use. Consequently, some degree of erosion and stream sedimentation can occur from altered drainage patterns and stream bank deformation. Furthermore, such trail use may disturb wildlife, causing either reduced productivity or abandonment of the area by sensitive wildlife. Perpendicular stream crossings will provide localized access for people to enjoy the water while retaining intact areas that are less disturbed than if trails run parallel to streams.

Recommendation. **Public education -** Educate the public on the sensitivity of riparian areas to damage and on their importance to fish and wildlife (Sachet 1988).

Rationale and Consequences. Much of the damage that occurs at recreation sites is from unintentional, unknowing actions. This damage may be reduced if people are made aware of specific habitat features of importance to fish and wildlife (e.g., downed logs, snags, herbaceous and woody vegetation).

Urban and Rural Lands

Although urban and rural areas have negatively affected riparian and aquatic habitat, a number of actions can improve the quality of fish and wildlife habitat in urban landscapes and improve the quality of life of people at the same time. The following recommendations should be implemented to the fullest extent possible in already urbanized and newly urbanizing areas.

Recommendation. **Near streams, choose land uses with minimal impacts -** If RHAs can't be adequately protected, emphasize activities and land uses that are compatible with or that minimize impacts on fish, wildlife, and water quality for 170 m (550 ft) on either side of the stream (Croonquist and Brooks 1993). These include (in decreasing order of desirability):

- non-use (additional buffer width);
- farm woodlots/non-farmed fields;
- fence rows, ditches, and unpaved roadsides with abundant shrubs, trees, or emergent wetland vegetation;
- low impact recreation (hiking trails, camp, and picnic sites);
- hay fields or other crops with infrequent tillage;
- corn and grain plantations;
- tree farming;
- moderately-grazed livestock pasture;
- urban parks;
- landscaping (preferably with abundant shrubbery, berries, and/or native vegetation).

Rationale. When current land uses preclude the full protection of recommended RHAs, impacts to stream and riparian areas can be minimized by choosing relatively low impact land uses adjacent to streams. The land uses listed above do provide some value to fish and wildlife and offer better protection to riparian and aquatic habitat than more intensive developments (e.g., parking lots, subdivisions, industrial complexes). Intensive land uses can have negative impacts on fish habitat downstream, perhaps even negating riparian protection efforts upstream. Selected land use activities can minimize significant negative effects and may help reduce losses of some fish and wildlife from urbanization.

Consequences. Reduced quality of fish habitat on the site and downstream, as well as reduced survival of wildlife in urban areas, will result from high-impact land uses adjacent to streams.

Recommendation. **Restore degraded riparian habitat -** Restore degraded riparian habitat wherever possible.

Rationale and Consequences. Most riparian habitat in urban and rural areas has been degraded to some extent. The restoration of degraded areas to achieve required habitat characteristics for fish and wildlife is needed to rebuild healthy fish and wildlife populations across the state. Restoration and future protection of riparian habitat should occur in urban and rural lands to match similar efforts occurring upstream in less developed areas of watersheds. Efforts to protect riparian habitat and restore stream habitat quality far upstream can be negatively offset by unhealthy conditions in downstream urban areas. Habitat quality throughout watersheds is particularly important to migrating fish.

Recommendation. **Limit impervious surfaces -** Land use planning should strive to limit the extent of impervious surface to less than 10% of an urban watershed.

Rationale and Consequences. Increasing impervious surfaces to more than 10% of an urban watershed will have corresponding effects on channel morphology, water quality, and fish and wildlife habitat functions regardless of the width of the riparian area.

Recommendation. **Control and purify stormwater run-off -** Examine and implement proven technology to control and purify stormwater run-off into aquatic areas. Such measures would include stormwater detention/retention systems, infiltration systems, and the treatment of stormwater.

Rationale. Special run-off control techniques are important in urban areas with a large proportion of impervious surface (>10%) to lessen or prevent impacts to riparian and aquatic systems from excessive peak flows and polluted water. Such impacts can be controlled, in part, by appropriately placed and designed stormwater control and treatment systems (Klein 1979, Booth and Jackson 1994).

Recommendation. **Adopt Stormwater Guidelines -** Adopt the guidelines in the Washington State Department of Ecology's (1992) Stormwater Manual to manage run-off into riparian areas. Because this manual only pertains to western Washington, adopt updates for eastern Washington when they become available (P. Powers, pers. comm.).

<u>Recommendation</u>. **Control pets -** Control disturbance and predation on wildlife by domestic pets by:

- keeping cats indoors and dogs in penned yards as much as possible;
- eliminating sources of food that attract and support stray cats and dogs (e.g., garbage or outdoor pet dishes);
- spaying or neutering all dogs and cats that are not specifically kept and controlled for breeding purposes;
- taking unwanted pets to a local animal welfare organization rather than releasing them in rural areas.

Rationale and Consequences. Uncontrolled domestic pets, especially cats, have the capacity to kill large numbers of native wildlife, particularly small mammals and birds. They also compete with native predators (especially raptors) for prey, disturb wildlife, and are known to transmit diseases to native wildlife. Dogs disturb wildlife and may prevent successful breeding or survival through critical periods such as severe winters. Because pets can be maintained at high densities by human care and feeding, their potential impact on native wildlife can be significant.

Restoration and Enhancement

Because an estimated 50-90% of streams in Washington are in a degraded condition, stream and habitat restoration is appropriate. First and most important is passive restoration, or the cessation of human activities that are causing degradation or preventing recovery (Kauffman et al. 1996). Given the ability of riparian ecosystems to naturally recover, often this is all that is needed to achieve successful restoration. Undertaking active restoration activities (e.g., instream structures, channel and streambank reconfiguration, and planting programs) without halting degrading land uses or allowing sufficient time for natural recovery to occur may exacerbate the degree of degradation and cause further difficulties in restoration (Kauffman et al. 1996). If passive restoration is unsuccessful or impractical, then more active approaches should be attempted.

The Washington Department of Fish and Wildlife strives for no net loss of fish and wildlife habitat (Policy-3000). When significant losses are unavoidable, WDFW strives to ensure that lost habitat is replaced by enhancing other habitat or by developing new habitat (Policy-3001). This philosophy also applies to riparian habitat. Because riparian habitat has been identified as a *priority habitat,* it should receive special consideration and additional replacement or restoration attention (Policy-3001).

The restoration of riparian habitat is not a quick-fix solution. If it is to be successful, careful planning, inventory, research, execution, maintenance, and long-term monitoring is essential. These efforts may span a number of years.

The Washington Department of Ecology (1993) explains that habitat restoration efforts are likely to be more successful than habitat creation efforts. Restoration success is dependent on understanding the complex and intricate interactions of natural systems and reinstating the physical and hydrologic features that support them. Because wetland creation or restoration cannot ever completely duplicate a natural system, protection of existing natural systems should be a priority (Kusler and Kentula 1989).

The National Research Council (1992) recommends preventing damage to riparian habitat and river systems by erosion control programs such as careful grazing management. They also suggest using "soft engineering" approaches, such as bio-engineering techniques, for bank stabilization and repair rather than "hard engineering" approaches such as dams, levees, channelization, and riprap wherever possible.

The EPA evaluated a number of restoration projects to determine successes and failures (Connin 1991). Among many determinants of success, the most important was adopting a watershed approach to restoration efforts. Projects that focused only on the immediate restoration site have not been successful without consideration of the entire watershed that affects stream flow, sedimentation, debris loading, and other factors.

The EPA also found that restoration projects have been successful at the following:

- increasing stream flow;
- increasing water depth;
- reducing instream sedimentation;
- reducing channel width;
- stabilizing stream banks;
- increasing animal and floral diversity;
- shifting from more xeric to mesic plant species;
- elevating water-table height;
- decreasing flooding frequency.

Although successes are documented, failures are too. Some common problems of failed restoration projects are exotic species invasion, destruction of restored vegetation by erosion, plant predation by livestock and wildlife, lack of vegetation regeneration, flooding, and failure to maintain water levels (Kusler and Kentula 1989). Revegetation without the creation of conditions that support riparian vegetation will only last the life span of the trees because plant regeneration, especially with trees, will not occur. If a riparian area has been damaged by a natural or human-related disturbance, the probability of continued disturbance must be considered. Any improvements resulting from rehabilitation projects can be negated by treating the symptom rather than the source of disturbance (Gregory and Ashkenas 1990).

Close work with fish and wildlife biologists is essential to successful restoration and enhancement efforts because stream and riparian habitat restoration is still experimental, varies greatly with specific conditions, and is not a "cookbook" effort. Restoration is not covered in any detail in this document because of its complexity; however, the following are general recommendations.

Recommendation. **Use state-of-the-art technology -** Because habitat restoration techniques are rapidly improving, utilize current techniques to restore degraded riparian areas and create habitat features important to fish and wildlife (e.g., snags and large organic debris).

Recommendation. **Consult the professionals -** Seek assistance from fish and wildlife biologists for all restoration and enhancement efforts. Assistance is available from the WDFW and the Natural Resources Conservation Service. Cost-share programs may also be available for riparian habitat restoration projects from the Natural Resources Conservation Service.

Recommendation. **Emulate natural conditions -** Emphasize revegetation with native plants and plant densities found in natural areas. Strive to restore biological diversity and a disturbance regime comparable to historic conditions.

Recommendation. **Use non-structural stream bank protection techniques -** Encourage the use of non-structural stream bank protection methods such as soil bio-engineering. Undisturbed riparian habitat areas and restriction of floodplain development are the most obvious solutions to eliminating the need for bank protection work. However, considerable development has already occurred in most floodplains. Use of non-structural techniques can provide property owners with needed protection and greatly reduce harmful impacts to the resource.

Recommendation. Use additional sources of information regarding riparian habitat restoration. Some suggestions include:

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APPENDICES

Appendix A. Common and scientific names of all plant and animal species listed in the text.

Plants

Bearberry	*Arctostaphylos uva-ursi.*
Big leaf maple	*Acer macrophyllum*
Big sagebrush	*Artemisia tridentata*
Bitterbrush	*Purshia tridentata*
Bittercherry	*Prunus emarginata*
Black cottonwood	*Populus trichocarpa*
Black hawthorn	*Crataegus douglasii*
Bluegrass	*Poa* spp.
Bracken fern	*Pteridium aquilinum*
Bunchberry dogwood	*Cornus canadensis*
Cascara	*Rhamnus purshiana*
Coltsfoot	*Petasites* spp.
Common chokecherry	*Prunus virginiana*
Dandelion	*Taraxacum* spp.
Devil’s club	*Oplopanax horridum*
Douglas-fir	*Pseudotsuga menziesii*
Dwarf mistletoe	*Arceuthobium* spp.
Engelmann spruce	*Picea engelmannii*
Fescue	*Festuca* spp.
Giant horsetail	*Equisetum telmateia*
Hackberry	*Celtis* spp.
Hawthorne	*Crataegus* spp.
Ladyfern	*Athyrium filix-femina*
Mock orange	*Philadelphus lewisii*
Mountain alder (or thinleaf alder)	*Alnus incana*
Northern bedstraw	*Galium* spp.
Ocean spray	*Holodiscus discolor*
Oregon boxwood	*Pachistima myrsinites*
Oregon white oak	*Quercus garryana*
Pacific ninebark	*Physocarpus capitatus*
Paper birch	*Betula papyrifera*
Parsnip	*Heracleum* spp.
Pinegrass	*Calamagrostis rubescens*
Ponderosa pine	*Pinus ponderosa*
Prickly currant	*Ribes lacustre*
Quaking aspen	*Populus tremuloides*
Queencup beadlilly	*Clintonia uniflora*
Rabbitbrush	*Chrysothamnus nauseosus*
Red alder	*Alnus rubra*
Red elderberry	*Sambucus racemosa*
Red osier dogwood	*Cornus stolonifera*
Reed canarygrass	*Phalaris arundinacea*
Salmonberry	*Rubus spectabilis*
Sedges	*Carex* spp.
Sitka spruce	*Picea sitchensis*
Sitka alder	*Alnus sinuata*
Skunk-cabbage	*Lysichiton americanum*
Snowberry	*Symphoricarpos albus*
Spiny hopsage	*Spinacia oleracea*
Spirea	*Spiraea douglasii*
Sticky geranium	*Geranium* spp.
Subalpine fir	*Abies lasiocarpa*
Tall Oregon grape	*Berberis aquifolium*
Teasel	*Dipsacus* spp.
Thimbleberry	*Rubus parviflorus*
Thistle	*Cirsium* spp.
Trillium	*Trillium petiolatum*
Twinflower	*Linnaea borealis*
Vine maple	*Acer circinatum*
Water birch (or red birch)	*Betula occidentalis*
Waterleaf	*Hydrophyllum* spp.
Water parsley	*Oenanthe sarmentosa*
Western hemlock	*Tsuga heterophylla*
Western red cedar	*Thuja plicata*
Western serviceberry	*Amelanchier alnifolia*
Wild rose	*Rosa* spp.
Willow	*Salix* spp.

Fish

Bull trout	*Salvelinus confluentis*
Char	*Salvelinus* spp.
Chinook salmon	*Onchorynchus tshawytscha*
Coho salmon	*Onchorynchus kisutch*
Cutthroat trout	*Onchorynchus clarki*
Margined sculpin	*Cottus marginatus*
Minnows/shiners	Family *Cyprinidae*
Olympic mudminnow	*Novumbra hubbsi*
Pygmy whitefish	*Prosopium coulteri*
Sculpins	*Cottus* spp.
Smallmouth bass	*Micropterus dolomieui*
Sockeye salmon	*Onchorhynchus nerka*
Steelhead/rainbow trout	*Onchorhynchus mykiss*
Suckers	*Catostomus* spp.
Walleye	*Stizostedion vitreum*
Whitefish	Family *Coregonidae*

Amphibians

Bullfrog	*Rana catesbeiana*
Dunn’s salamander	*Plethodon dunni*
Olympic torrent salamander	*Rhyacotriton olympicus*
Pacific giant salamander	*Dicamptodon tenebrosus*
Pacific treefrog	*Pseudacris regilla*
Red-legged frog	*Rana aurora*
Rough-skinned newt	*Taricha granulosa*
Tailed frog	*Ascaphus truei*
Western red-backed salamander	*Plethodon vehiculum*

Reptiles

Common garter snake . . . . *Thamnophis sirtalis*
Painted turtle . . . . *Chrysemys picta*
Sharp-tailed snake . . . . *Contia tenuis*
Western terrestrial garter snake . . . . *Thamnophis elegans*
Western pond turtle . . . . *Clemmys marmorata*

Birds

American crow . . . . *Corvus brachyrhynchos*
American dipper . . . . *Cinclus mexicanus*
American kestrel . . . . *Falco sparverius*
American redstart . . . . *Setophaga ruticilla*
American robin . . . . *Turdus migratorius*
Bald eagle . . . . *Haliaeetus leucocephalus*
Belted kingfisher . . . . *Cerlye alcyon*
Brown creeper . . . . *Certhia americana*
Brown-headed cowbird . . . . *Molothrus ater*
Chipping sparrow . . . . *Spizella passerina*
Common loon . . . . *Gavia immer*
Dark-eyed junco . . . . *Junco hyemalis*
Downy woodpecker . . . . *Picoides pubescens*
Dusky flycatcher . . . . *Empidonax oberholseri*
European starling . . . . *Sturnus vulgaris*
Golden-crowned kinglet . . . . *Regulus satrapa*
Great blue heron . . . . *Ardea herodias*
Great horned owl . . . . *Bubo virginianus*
Harlequin duck . . . . *Histrionicus histrionicus*
House sparrow . . . . *Passer domesticus*
Lazuli bunting . . . . *Passerina amoena*
MacGillivray's warbler . . . . *Oporornis tolmiei*
Marbled murrelet . . . . *Brachyramphus marmoratus*
Mourning dove . . . . *Zenaida macroura*
Northern goshawk . . . . *Accipiter gentilis*
Northern harrier . . . . *Circus cyaneus*
Northern spotted owl . . . . *Strix occidentalis*
Osprey . . . . *Pandion haliaetus*
Pileated woodpecker . . . . *Dryocopus pileatus*
Red-breasted nuthatch . . . . *Sitta canadensis*
Red-tailed hawk . . . . *Buteo jamaicensis*
Red-winged blackbird . . . . *Agelaius phoeniceus*
Ruby-crowned kinglet . . . . *Regulus calendula*
Sandhill crane . . . . *Grus canadensis*
Song sparrow . . . . *Melospiza melodia*
Spotted towhee . . . . *Pipilo erythrophthalmus*
Spruce grouse . . . . *Falcipennis canadensis*
Swainson's thrush . . . . *Catharus ustulatus*
Tree swallow . . . . *Tachycineta bicolor*
Warbling vireo . . . . *Vireo gilvus*
White-crowned sparrow . . . . *Zonotrichia leucophrys*
Winter wren . . . . *Troglodytes troglodytes*
Wood duck . . . . *Aix sponsa*
Yellow-billed cuckoo . . . . *Coccyzus americanus*

Mammals

Beaver . . . . *Castor canadensis*
Black bear . . . . *Ursus americanus*
Black-tailed deer . . . . *Odocoileus hemionus*
Bobcat . . . . *Lynx rufus*
Columbian white-tailed deer . *Odocoileus virginianus leucurus*
Coyote . . . . *Canis latrans*
Deer mouse . . . . *Peromyscus maniculatus*
Douglas' squirrel . . . . *Tamiasciurus douglasii*
Elk . . . . *Cervus elaphus*
Ermine . . . . *Mustela erminea*
Fisher . . . . *Martes pennanti*
Gray wolf . . . . *Canis lupus*
Grizzly bear . . . . *Ursus arctos*
Long-tailed weasel . . . . *Mustela frenata*
Lynx . . . . *Lynx canadensis*
Marsh shrew . . . . *Sorex bendirii*
Marten . . . . *Martes americana*
Mink . . . . *Mustela vison*
Moose . . . . *Alces alces*
Mountain beaver . . . . *Aplodontia rufa*
Mountain lion . . . . *Felis concolor*
Mule deer . . . . *Odocoileus hemionus hemionus*
Muskrat . . . . *Ondatra zibethicus*
Nutria . . . . *Myocastor coypus*
Raccoon . . . . *Procyon lotor*
Red fox . . . . *Vulpes vulpes*
River otter . . . . *Lutra canadensis*
Rocky Mountain elk . . . . *Cervus elaphus nelsoni*
Southern red-backed vole . . . . *Clethrionomys gapperi*
Water shrew . . . . *Sorex palustris*
Water vole . . . . *Microtus richardsoni*
Wolverine . . . . *Gulo gulo*
Woodland caribou . . . . *Rangifer tarandus*

Appendix B. Riparian habitat functions or specific wildlife uses, organized by riparian habitat width (perpendicular distance from stream). Appendix C contains this information organized by riparian function.

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
4 (13)	Nutrient reduction	Doyle et al. 1977
6 (20)	Noise reduced by an equivalent of tripling of distance from noise to receiver	Johnson and Ryba 1992
10 (33)	Minimum needed for nutrient reduction	Petersen et al. 1992
11-31 (35-100)	Distance needed for shade retention, an important habitat component for Cascade torrent, Columbia torrent, Dunn’s, and Van Dyke’s salamanders	Brown and Krygier 1970, Brazier and Brown 1973, Steinblums et al. 1984
11-38 (35-125)	Buffer that provides 60-80% shade on stream surface; crucial to water temperature control	Brazier and Brown 1973, Steinblums et al. 1984, Johnson and Ryba 1992
12 (39)	Control of water temperature	Corbett and Lynch 1985
12-70 (39-230)	Riparian buffer capable of supporting small mammal communities comparable to undisturbed sites	Cross 1985
15 (50)	Minimum mean width supporting breeding populations of downy woodpeckers	Cross 1985
15 (50)	Minimum mean width supporting breeding populations of black-capped chickadees	Cross 1985
15 (50)	Sufficient width for mourning doves	Mudd 1975
15 (50)	80% of coarse woody debris input in a multiple canopy forest	Van Sickle and Gregory 1990
15-23 (50-75)	Some edge/mature forest adapted birds retained in clearcut landscape; neotropical migrant birds and pileated woodpeckers lost	Triquet et al. 1990
15 (50)	Median distance of coarse woody debris travel	Harmon et al. 1986
15 (50)	Minimum needed for nutrient reduction	Castelle et al. 1992
15-30 (50-98)	Control of water temperature	Hewlett and Fortson 1982
15-30 (50-98)	Provides minimal maintenance of most functions	Johnson and Ryba 1992
16 (52)	Nutrient reduction	Jacobs and Gilliam 1985
16-137 (52-137)	Edge effect on forest structure: the distance from an edge into a forest where its structure (e.g., stocking density, tree mortality) is affected by the adjacent open environment	Chen et al. 1992
17 (57)	Minimum mean width supporting a breeding population of white-breasted nuthatches	Stauffer and Best 1980

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
18 (59)	Maintains stream temperature in a logged watershed (but does not fully mitigate changes in sediment, dissolved oxygen, or increased streamflow)	Moring 1975
18-38 (60-125)	Provides 50-100% shading	U.S. For. Serv. et al. 1993
20 (66)	10% mortality of instream mosquito larvae after application of permethrin	Payne et al. 1988
20 (66)	Nutrient removal using the multi-species riparian buffer strip system described by the authors	Schultz et al. 1995
23 (75)	Needed for maximum populations of pheasant, quail, and deer	Mudd 1975
20-50 (66-164)	Width of riparian vegetation	Strong and Bock 1990
25 (82)	Species sensitive to disturbance did not occur unless an undisturbed corridor this wide was present	Croonquist and Brooks 1993
25-50 (82-164)	Width of riparian vegetation	Medin and Clary 1991
30 (100)	Minimum width of riparian buffer to avoid affecting food supply of benthic invertebrates	Erman et al. 1977
30 (100)	Protects aquatic insect communities from sedimentation	Erman et al. 1977
30 (100)	Reduces fecal coliforms	Grismer 1981
30 (100)	Minimum width of riparian buffer that maintained invertebrate populations equal to those in control areas with no logging	Erman et al. 1977, Roby et al. 1977, Newbold et al. 1980
30+ (100+)	Large woody debris use by loafing harlequin ducks	Murphy and Koski 1989
$\geq$30 ($\geq$100)	Full complement of herpetofauna	Rudolph and Dickson 1990
30 (100)	Recommended buffer to control erosion of undercut banks for cutthroat, rainbow, and brown trout; and chinook salmon	Raleigh et al. 1986
30 (100)	Buffers incoming nutrient pollution when buffer contains trees (600 ft required when buffer is herbaceous or cropland)	Terrell and Perfetti 1989
30 (100)	80% of large woody debris input (coniferous riparian)	Van Sickle and Gregory 1990
30 (100)	Buffer provides same stream temperature as old growth	Beschta et al. 1987
30 (100)	90% sediment removal at 2% grade	Johnson and Ryba 1992

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
30 (100)	75-80% of suspended sediment removed from stormwater in logged areas; less effective where surface flows are channelized than where runoff is in sheets	Johnson and Ryba 1992
30 (100)	Removed nitrates, exceeding drinking water standards	Johnson and Ryba 1992
30 (100)	Stream temperatures maintained within 1° of baseline	Johnson and Ryba 1992
30-60 (100-200)	Belted kingfisher roosts	Prose 1985
30-95)100-312)	Amphibians and reptiles more numerous with buffer width in mature vegetation	Rudolph and Dickson 1990
30 (100)	Shannon index of macroinvertebrate diversity same as control with buffer of this size	Gregory et al. 1987
30-100 (100-328)	30m=90% foraging distance for beaver; 100m=maximum foraging distance (but 200m has been reported)	Allen 1983, Hall 1970
30 (100)	99% of large organic debris recruitment	Murphy and Koski 1989
30 (100)	Macroinvertebrate density begins to increase with buffer this size	Newbold et al. 1980
30 (100)	Nutrient reduction	Lynch et al. 1985
30-43 (100-141)	Nutrient reduction	Jones et al. 1988
30 (100)	Sediment removal	Erman et al. 1977, Moring 1982, Lynch et al. 1985
30 (100)	Water temperature control	Lynch et al. 1985
30-43 (100-141)	Water temperature control	Jones et al. 1988
30-38 (100-125)	75% of sediments removed	Karr and Schlosser 1977
30 (100)	Maintains fish habitat for cutthroat, brook and rainbow trout, and chinook salmon	Hickman and Raleigh 1982, Raleigh 1982, Raleigh et al. 1984, Raleigh et al. 1986
31-55 (100-180)	Distance needed for woody debris recruitment, an important habitat component for Cascade torrent, Columbia torrent, Dunn's, and Van Dyke's salamanders	Bottom et al. 1983, Harmon et al. 1986, Murphy and Koski 1989, McDade et al. 1990, Van Sickle and Gregory 1990
31-88 (100-289)	Distance needed for sediment control, important to maintaining habitat quality for Cascade torrent, Columbia torrent, Dunn's, and Van Dyke's salamanders	Erman et al. 1977, Lynch et al. 1985, Terrell and Perfetti 1989, Johnson and Ryba 1992
31 (102)	Contribution of woody debris to stream structure within this distance	Bottom et al. 1983
36 (118)	Nutrient reduction	Young et al. 1980

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
40 (133)	Minimum mean width supporting breeding populations of hairy woodpeckers	Stauffer and Best 1980
40 (133)	Minimum mean width supporting breeding populations of red-eyed vireos	Stauffer and Best 1980
45 (148)	Maximum distance of tree-fall (source of coarse woody debris)	Harmon et al. 1986
46 (151)	Maintains large woody debris	McDade et al. 1990, Robison and Beschta 1990
46 (151)	Provides travel corridors for marten when buffers are on both sides of streams in mature uncut basins	Freel 1991
46 (151)	Buffer width provides 80% shading of streams at minimum flow	Steinblums et al. 1984
50 (164)	Most bald eagles perch within this distance of water during daylight hours	Stalmaster 1980
50 (164)	Stream buffer needed to maintain harlequin nests	Cassirer and Groves 1990
50 (164)	Lesser scaup prefer nesting habitat within this distance in emergent vegetation	Allen 1986
50 (164)	Forest interior birds only occurred in corridors greater than 50m	Tassone 1981
50 (164)	100% of coarse woody debris input	Van Sickle and Gregory 1990
55 (180)	Maintains large woody debris	U.S. For. Serv. et al. 1993, Thomas et al. 1993
75-200 (246-656)	Recommended buffer for birds	Jones et al. 1988
75-100 (246-328)	Recommended leave strip for bald eagles along shoreline of major feeding areas	Stalmaster 1980
50-100 (164-328)	Riparian vegetation width in shrub-steppe	Medin and Clary 1991
60 (200)	Marten food/cover -- recommend no harvest	Spencer 1981
60 (200)	Adequate buffer to remove sediment as a result of logging -- buffer measured from edge of floodplain	Broderson 1973
60 (200)	Minimum riparian width needed to sustain forest-dwelling birds	Darveau et al. 1995
60-91 (200-300)	Effective buffer strip width to control non-channelized sediment flow	Belt et al. 1992
60-120 (200-399)	Microclimate edge effects into forest patches: light penetration, increased tree mortality, soil desiccation, temperature effects	Chen et al. 1990
61 (200)	Recommended no-cut zone around osprey nest	Zarn 1974, Westall 1986
61 (200)	Buffering distance for sediment from cropland, animal waste across ungrazed buffers, pesticides	Terrell and Perfetti 1989

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
61 (200)	Deer and elk -- distance hiding cover needed at 90% vegetative cover	Mudd 1975
63-88 (207-289)	Riparian width in Blue Mountains	Bull and Skovlin 1982
67 (220)	No small mammal species lost	Cross 1985
67-93 (220-305)	Recommended buffer for small mammals	Jones et al. 1988
75-100 (246-328)	Recommended leave strip along shorelines of major bald eagle feeding areas	Stalmaster 1980
80 (262)	Average distance of wood duck nests from water	Gilmer et al. 1978
90 (295)	Average distance of warbling vireo nests from water	Gilmer et al. 1978
91 (300)	Needed on each side of stream to provide a 600 ft travel corridor in mature uncut basins for fisher or a travel corridor between clearcuts for marten	Freel 1991
91 (300)	Recommended hiking trail buffer near osprey nests	Zarn 1994
91 (300)	Buffer required by yellow-billed cuckoo	Gaines and Laymon 1984
100 (328)	Recommended buffer for large mammals	Jones et al. 1988
100 (328)	Majority of beaver foraging	Allen 1983
100 (328)	Minimum distance needed to support area-sensitive neotropical migrants in forest/agricultural areas	Keller et al. 1993
100 (328)	Distance needed to maintain functional assemblages of common neotropical migratory birds	Hodges and Krementz 1996
100 (328)	Mink dens/cover/forage	Melquist et al. 1981, Allen 1986
100 (328)	Recommended disturbance free zone around great blue heron feeding areas	Short and Cooper 1985
100 (328)	Area of optimum mink cover and forage habitat	Allen 1986
100 (328)	Vegetation within this distance used by red fox and marten as travel corridors and habitat	Small 1982
100 (328)	Pileated woodpecker nests within this distance	Small 1982
100 (328)	Bald eagles nest within this distance	Small 1982
100 (328)	45% reduction in birds in agricultural areas if no fencerows within this distance of stream	Croonquist and Brooks 1993
100 (328)	Red fox and fisher use	Small 1982
100 (328)	Eagles nest within this distance of water	Small 1982
100 (328)	Buffer width that reduces nest predation	Temple 1986
100 (328)	Minimum buffer to provide adequate large woody debris in streams	K. Koski, pers. comm.

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
124 (407)	Northern flicker avoided isolated forest patches farther than this distance from water	Gutzwiler and Anderson 1987
100x300 (328x984)	Minimum riparian dimensions for yellow-billed cuckoo	Gaines 1974
119 (396)	Average distance of successful bald eagle nests from human disturbance	Grubb 1980
125 (410)	Size of naturally vegetated buffer needed to retain full complement of birds	Croonquist and Brooks 1993
127 (417)	Avian richness declines after this point in cottonwood floodplains	Sedgewick and Knopf 1986
133 (443)	Average distance from snowmobile traffic that elicited a locomotor avoidance response in mule deer	Freddy et al. 1986
150 (492)	Most pileated woodpeckers nest within this distance	Conner et al. 1975, Schroeder 1983
160 (525)	Distance microclimatic changes occur within a forest, due to disturbance created edges	Harris 1984, Franklin and Forman 1987
180 (590)	Slopes greater than 15% used as Rocky Mt. mule deer fawning habitat	Thomas et al. 1976
183 (600)	Distance needed on both sides of stream to provide travel corridor for fisher in clearcut landscapes	Freel 1991
183 (600)	Food and cover for dusky shrews	Clothier 1955
183 (600)	Wood duck nesting distance	Grice and Rogers 1965
183 (600)	Wood duck nesting where woody/herbaceous cover is between 50-75%	Sousa and Farmer 1983
183 (600)	Distance needed to filter confined animal waste	Terrell and Perfetti 1989
191 (636)	Average distance from foot traffic that elicited a locomotor avoidance response in mule deer	Freddy et al. 1986
200 (656)	Limit of mink use	Melquist et al. 1981
200 (656)	Minimum mean width to support breeding populations of American redstarts	Stauffer and Best 1980
200 (656)	Minimum mean width to support breeding populations of spotted towhees	Stauffer and Best 1980
200 (656)	Red-winged blackbird foraging distance from nests in wetlands	Short 1985
200 (656)	Distance from human activity at which feeding eagles are disturbed	Skagen 1980
200 (656)	Wood ducks nest within this distance	Lowney and Hill 1989
240 (787)	Distance brown-headed cowbirds penetrate from stream opening	Gates and Giffin 1991

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
250 (820)	Great blue herons nest within this distance; disturbance-free zone around nests is recommended	Short and Cooper 1985
250-300 (820-984)	Minimum buffer zone around peripheries of great blue heron colonies	Bowman and Siderius 1984, Kelsall 1989, Vos et al. 1985
250-300 (820-984)	Recommended buffer for eagle perch areas with little screening	Stalmaster 1987
305 (1,000)	Elk calving grounds are usually within this distance of water	Thomas 1979
350 (1,148)	Maximum distance from water where wood ducks will nest	Gilmer et al. 1978
400 (1,312)	Avoid road and foot travel within this distance of sandhill crane nests	Schlorff et al. 1983
800 (2,624)	During breeding season (March-August), avoid logging within this distance of sandhill crane nests	Schlorff et al. 1983

Appendix C. Riparian habitat buffer widths needed to retain various riparian habitat functions as reported in the literature, organized by riparian habitat function.

Riparian habitat function	Perpendicular distance from stream in meters (feet)	Source
WATER TEMPERATURE CONTROL		
60-80% shading	11-38 (35-125)	Brazier et al. 1973
	11-37 (35-120)	Johnson and Ryba 1992
	12 (39)	Corbett and Lynch 1985
	15-30 (49-100)	Hewlett and Fortson 1982
	18 (59)	Moring 1975
50-100% shading	18-38 (60-125)	U.S. Forest Service et al. 1993
	30 (100)	Lynch et al. 1985
	30 (100)	Beschta et al. 1987
	30 (100)	Johnson and Ryba 1992
	30-43 (100-141)	Jones et al. 1988
80% shading	46 (151)	Steinblums et al. 1984
LARGE WOODY DEBRIS		
	30 (100)	Murphy and Koski 1989
	31 (103)	Bottom et al. 1983
	45 (148)	Harmon et al. 1986
	46 (150)	McDade et al. 1990
	46 (150)	Robison and Beschta 1990
	50 (165)	Van Sickle and Gregory 1990
	55 (180)	Thomas et al. 1993
FILTER SEDIMENTS		
75% sediment removal	30-38 (100-125)	Karr and Schlosser 1977
90% of sediment removal at 2% grade	30 (100)	Johnson and Ryba 1992
Sediment removal	30 (100)	Erman et al. 1977, Moring et al 1982, Lynch et al 1985
	61 (200)	Terrell and Perfetti 1989
50% deposition	88 (289)	Gilliam and Skaggs 1988
Effective control of non-channelized sediment flow	60-91 (200-300)	Belt et al. 1992
FILTER POLLUTANTS		
Nutrient reduction	4 (13)	Doyle et al. 1977
Minimum	10 (33)	Petersen et al. 1992
	15 (49)	Castelle et al. 1992
	16 (52)	Jacobs and Gilliam 1985

Riparian habitat function	Perpendicular distance from stream in meters (feet)	Source
Nutrient removal using the multi-species riparian buffer strip system described by the authors	20 (66)	Schultz et al. 1995
Remove fecal coliforms	30-43 (100-141)	Jones et al. 1988
	30 (100)	Grismer 1981
	30 (100)	Lynch et al. 1985
Nitrates removed to meet drinking water standards	30 (100)	Johnson and Ryba 1992
Nutrient pollution in forested riparian areas	30 (100)	Terrell and Perfetti 1989
Nutrient removal	36 (118)	Young et al. 1980
Pesticides and animal waste	61 (200)	Terrell and Perfetti 1989
Nutrient pollution in herbaceous or cropland riparian areas	183 (600)	Terrell and Perfetti 1989
EROSION CONTROL		
Bank erosion control	30 (100)	Raleigh et al. 1986
High mass wasting area	38 (125)	Cederholm 1994
MICROCLIMATE INFLUENCE		
In forested ecosystem	61-122 (200-399)	Chen et al. 1990
	160 (525)	Harris 1984, Franklin and Forman 1987
WILDLIFE HABITAT		
General wildlife habitat	23 (75)	Mudd 1975
	9-201 (30-660)	Johnson and Ryba 1992
	61 (200)	Zeigler 1992
Species sensitive to disturbance	25 (82)	Croonquist and Brooks 1993
Aquatic insects	30 (100)	Erman et al. 1977
Benthic invertebrates - food supply	30 (100)	Erman et al. 1977
Macroinvertebrate density	30 (100)	Newbold et al. 1980
Macroinvertebrate diversity	30 (100)	Gregory et al. 1987
Riparian invertebrates	30 (100)	Erman et al. 1977, Roby et al. 1977, Newbold et al. 1980
Brook trout	30 (100)	Raleigh 1982
Chinook salmon	30 (100)	Raleigh et al. 1986
Cutthroat trout	30 (100)	Hickman and Raleigh 1982
Rainbow trout	30 (100)	Raleigh et al. 1984
Reptiles and amphibians	30-95 (100-312)	Rudolph and Dickson 1990

Riparian habitat function	Perpendicular distance from stream in meters (feet)	Source
Reptiles and amphibians	30 (100)	Rudolph and Dickson 1990
Birds	75-200 (246-656)	Jones et al. 1988
Full complement of birds	127 (417)	Sedgewick and Knopf 1986
	125 (410)	Croonquist and Brooks 1993
Nest predation reduced	100 (328)	Temple 1986
Forest interior birds only occur in corridors wider than 50 m	50 (164)	Tassone 1981
Minimum riparian width to sustain forest dwelling birds	60 (200)	Darveau et al. 1995
Minimum distance needed to support area-sensitive neotropical migrant birds	100 (328)	Keller et al. 1993
Distance needed to maintain functional assemblages of common neotropical migratory birds	100 (328)	Hodges and Krementz 1996
Great blue heron feeding	100 (328)	Short and Cooper 1985
Great blue heron nesting	250 (820)	Short and Cooper 1985
	250-300 (820-984)	Parker 1980, Short and Cooper 1985, Vos et al. 1985
Wood duck nesting	80 (262)	Gilmer et al. 1978
	183 (600)	Grice and Rogers 1965, Sousa and Farmer 1983
	200 (656)	Lowney and Hill 1989
Harlequin nesting	50 (164)	Cassirer and Groves 1990
Bald eagle buffer from human disturbance	121 (396)	Grubb 1980
Bald eagle disturbance during feeding	200 (656)	Skagen 1980
Bald eagle feeding areas	75-100 (246-328)	Stalmaster 1980
Bald eagle nesting	100 (328)	Small 1982
Bald eagle perching	50 (164)	Stalmaster 1980
Osprey nesting - no cut zone	61 (200)	Zarn 1974, Westall 1986
Pheasant and quail, eastern Washington	23 (75)	Mudd 1975
Mourning dove	15 (50)	Mudd 1975
Belted kingfisher roosts	30-61 (100-200)	Prose 1985
Downy woodpecker	15 (50)	Cross 1985
Hairy woodpecker	40 (133)	Stauffer and Best 1980
Pileated woodpecker and some neotropical migrants	15-23 (50-75)	Triquet et al. 1990
Pileated woodpecker nesting	150-183 (492-600)	Conner et al. 1975, Schroeder 1983

Riparian habitat function	Perpendicular distance from stream in meters (feet)	Source
Pileated woodpecker nesting	100 (328)	Small 1982
Black-capped chickadee	15 (50)	Cross 1985
White-breasted nuthatch	17 (57)	Stauffer and Best 1980
Red-eyed vireo	40 (133)	Stauffer and Best 1980
Warbling vireo nesting	90 (295)	Gilmer et al. 1978
Spotted towhee breeding populations	200 (656)	Stauffer and Best 1980
Brown-headed cowbird penetration from edge	240 (787)	Gates and Giffin 1991
Large mammals	100 (328)	Jones et al. 1988
Small mammals	67-93 (220-305)	Jones et al. 1988
	12-70 (39-230)	Cross 1985
	67 (220)	Cross 1985
Dusky shrew food and cover	183 (600)	Clothier 1955
Beaver	30-100 (100-328)	Allen 1983
Beaver foraging	100 (328)	Allen 1983
Fisher travel corridor	183 (600)	Freel 1991
Marten food and cover	61 (200)	Spencer 1981
Marten travel corridor	92 (300)	Freel 1991
Mink	100 (328)	Melquist et al. 1981, Allen 1986
	200 (656)	Melquist et al. 1981
Red fox, fisher, marten	100 (328)	Small 1982
Deer, Eastern Washington	23 (75)	Mudd 1975
Deer and elk cover	61 (200)	Mudd 1975
INSTREAM HABITAT		
Minimal maintenance of most functions	15-30 (50-100)	Johnson and Ryba 1992

Mean buffers:*

Temperature Control	27 m (90 ft)	Erosion Control	34 m (112 ft)
Large Woody Debris	45 m (147 ft)	Windthrow Protection	15 m (50 ft)
		Microclimate Influence	126 m (412 ft)
Filter Sediments	42 m (138 ft)	Wildlife Habitat	88 m (287 ft)
Filter Pollutants	24 m (78 ft)	Instream Habitat	15-30 m (50-100 ft)

* If a range of values was reported in the literature, the median of that range was used to calculate the means.

Appendix D. Riparian-related management recommendations for individual priority species, taken from Rodrick and Milner (1991), Larsen et al. (1995), and Larsen (1997). Refer to these publications for additional management recommendations outside the riparian zone.

Species	Recommendations
INVERTEBRATES	
Silver-bordered bog fritillary (*Boloria selene atrocostalis*)	• Avoid activities that result in wetland drainage or water table alteration. • Carefully monitor insecticide and herbicide applications near occupied habitat, and use alternative treatments whenever possible. Specific buffer distances and treatment options need to be determined on a site-by-site basis.
AMPHIBIANS AND REPTILES	
Dunn's salamander (*Plethodon dunni*) Van Dyke's salamander (*Plethodon vandykei*)	• Maintain riparian habitat along all streams where the salamanders are present. • Maintain 60-80% shade along stream banks and wet talus seepage areas. • Leave understory plants and noncommercial trees in seepage areas during logging operations. • Retain woody debris of all size and decay classes. • Avoid land use practices that contribute to stream sedimentation. • Avoid logging within 30 m (100 ft) of Type 4 and Type 5 waters. • Protect an additional 38 m (125 ft) in unstable portions of riparian areas to avoid mass wasting.
Oregon spotted frog (*Rana pretiosa*) Columbia spotted frog (*Rana luteiventris*)	• Avoid the removal of riparian vegetation in areas inhabited by spotted frogs. • Activities that alter riparian areas and wetlands, such as intentional flooding, dredging, draining, or filling, should be avoided where spotted frogs occur. • Avoid activities that could cause water temperature to fall below 7 C (45°F) or rise above 28 C (82°F) during the breeding season. • Avoid diverting stormwater runoff from urban developments into spotted frog habitat. • Avoid applying pesticides or herbicides in or adjacent to wetlands used by spotted frogs.
Western pond turtle (*Clemmys marmorata*)	• Avoid disturbance within 400-500 m (1,300-1,600 ft) around all bodies of water inhabited by western pond turtles. • Avoid constructing barriers such as roads, ditches, and chain-link fences in or around wetlands occupied by western pond turtles. • Avoid draining, dredging, or filling wetlands. • Avoid changes that might cause vegetation in and around occupied wetlands to become too dense for turtles to negotiate. • Emergent logs and stumps should not be removed from waters where western pond turtles occur.
BIRDS	
Common loon (*Gavia immer*)	• Erect no structures within 150 m (492 ft) of nest sites.

Great blue heron (*Ardea herodias*)	• Establishment of buffer distances will be influenced by factors pertaining to a specific heron colony. Whenever possible, a minimum habitat protection buffer of 250 to 300 m (820 - 980 ft) from the peripheries of a colony should be established. • Stands of large trees at least 17 m (50 ft) high and at least 4 ha (10 ac) in extent should be left in the vicinity of heron breeding colonies and feeding areas as alternative habitat. • Feeding areas, especially wetlands, should be protected within a minimum radius of 4 km (2.5 mi) of existing colonies. Each potential foraging area should have a surrounding disturbance free zone of at least 100 m (328 ft).
Sandhill crane (*Grus canadensis*)	• Avoid vehicle and foot traffic within 400 m (0.25 mi) of nesting areas during the breeding period (March -August). • Avoid logging within 800 m (0.5 mi) of nests during the breeding period. • Do not alter water levels in wetlands used by cranes. • Exclude cattle from crane breeding sites.
Harlequin duck (*Histrionicus histrionicus*)	• Maintain woody debris and riparian vegetation in and adjacent to streams. A 30 m (100 ft) buffer along nesting streams is necessary to recruit suitable large woody debris for loafing, and a larger buffer may be necessary on second growth stands. • Trails or roads should be farther than 50 m (165 ft) and not visible from the stream, and fishing activity should be limited on streams used by nesting harlequins. • Avoid logging in the riparian corridor.
Cavity-nesting ducks (A*ix sponsa, Bucephala albeola, Bucephala clangula Bucephala islandica, Lophodytes cucullatus*)	• Maintain or create snags near suitable nesting habitat (e.g., low gradient rivers and sloughs). • Avoid logging flooded timber, and leave woody vegetation along shores of nesting and brood-rearing areas.
Bald eagle (*Haliaeetus leucocephalus*)	• Maintain appropriate disturbance-free buffers around nests, perches, roosts, and foraging areas [approximately 120-800 m, (400-2600 ft), depending on site-specific factors]. • Consult WDFW to develop a Bald Eagle Site Management Plan.
Osprey (*Pandion haliaetus*)	• Minimize human activities within 201 m (660 ft) of active nests. • Retain all trees within a 61 m (200 ft) radius of a nest or within 61 m (200 ft) of a shoreline where a nest is located. • Between 61 m (200 ft) and 335 m (1,100 ft) of a shoreline where nesting occurs, maintain a “restricted cutting zone” in which at least two dominant live trees and two suitable snags per acre are retained. • Roads should be closed during breeding season if they are located near a pair that is sensitive to disturbance. In remote areas, campsites and hiking trails should not be located within 1 km (0.7 mi) and 91 m (300 ft) of occupied nests, respectively.
Blue grouse (*Dendragapus obscurus*)	• Protect streams, springs, and meadows from livestock grazing and logging operations in order to provide brooding and feeding areas.
Band-tailed pigeon (*Columba fasciata*)	• Protect mineral springs and surrounding trees and shrubs.

Yellow-billed cuckoo (*Coccyzus americanus*)	• Do not remove riparian vegetation, avoid bank stabilization and channelization projects, and exclude livestock from areas used by the yellow-billed cuckoo. • Do not use insecticides near riparian areas occupied by the yellow-billed cuckoo.
MAMMALS	
Marten (*Martes americana*)	• Leave forested buffer strips at least 100 m (330 ft) wide along waterways, including headwater streams. • Avoid road building, skidding, and other logging activities within 60 m (200 ft) of riparian areas. • Livestock should not be allowed to denude stream banks and should be excluded from riparian areas where marten occur.
Columbian white-tailed deer (*Odocoileus virginianus leucurus*)	• Maintain tidal spruce forests and protect riparian areas.
Rocky Mountain mule deer (*Odocoileus hemionus hemionus)*	• Maintain quality, disturbance-free fawning areas near water.
Elk (*Cervus elaphus*)	• Protect calving habitat from disturbance between May 1 and June 30. Habitat should be provided within 300 m (1,000 ft) of water on gentle slopes that contain at least 40 percent of the area in cover. • Optimal vegetative buffer from disturbance in a westside forested area is 66 m (200 ft) with canopy closure greater than 70% and trees over 12 m (40 ft) in height. • In eastern Washington, water sources for elk should be protected from grazing.
Moose (*Alces alces*)	• Provide buffers wide enough to conceal an adult moose around one-half or more of the perimeter of aquatic feeding sites.

GOVERNMENT ORGANIZATIONS

United States Environmental Protection Agency

Region 10 Public Affairs Office, Seattle 1-800-424-4372
Provides information, brochures, and technical help on pesticide application.

Washington State Department of Agriculture

Pesticide Management
General Information . . . . . (360) 902-2010
Assistant Director . . . . . (360) 902-2011

Compliance
Enforces state and federal pesticide laws; investigates complaints of pesticide misuse.
Manager . . . . . (360) 902-2036
Olympia Compliance . . . . . (360) 902-2040
Mount Vernon Compliance . . . . . (360) 428-1091
Spokane Compliance . . . . . (509) 625-5229
Wenatchee Compliance . . . . . (509) 664-3171
Yakima Compliance . . . . . (509) 575-2746

Registration
Registers pesticides sold and used in Washington.
Manager . . . . . (360) 902-2026
Pesticide Registration - Olympia . . . . . (360) 902-2030
Pesticide Registration - Yakima . . . . . (509) 575-2595

Program Development and licensing
Licenses pesticide application equipment and pesticide dealers; commercial, public, and private pesticide applications; and operators and consultants. Conducts waste pesticide disposal program; responsible for public outreach and education.
Manager . . . . . (360) 902-2051
Pesticide Licensing and Recertification . . . . . (360) 902-2020
Waste Pesticide Collection . . . . . (360) 902-2050
Farmworker Ed. and Pest. Licensing - Yakima . . . . . (509) 575-2746

Washington Department of Ecology

Regional Contacts
Provides information and permits on applying pesticides directly or indirectly to open bodies of water.
Eastern Region, Spokane . . . . . (509) 456-2873
Central Region, Yakima . . . . . (509) 457-7207
Northwest Region, Bellevue . . . . . (425) 649-7070
Southwest Region, Olympia . . . . . (360) 407-6292

Washington Department of Fish and Wildlife

Regional Contacts

A regional program manager will direct your questions to a biologist. The department can provide information on what priority habitats and species are known to be in your area and on the life requisites of priority species.

Region 1, Spokane . . . . (509) 456-4082
Region 2, Ephrata . . . . (509) 754-4624
Region 3, Yakima . . . . (509) 575-2740
Region 4, Mill Creek . . . . (425) 775-1311
Region 5, Vancouver . . . . (360) 696-6211
Region 6, Montesano . . . . (360) 249-4628

PHS Data Request Line . . . . (360) 902-2543

Mapped information and management recommendations for Washington's priority habitats and species can be obtained by calling this PHS Data Request number.

Washington Poison Control Center . . . . (800) 732-6985

Provides information on who to contact in case of exposure to, or spill of pesticides and other toxic substances

WASHINGTON STATE UNIVERSITY COOPERATIVE EXTENSION SERVICE COUNTY AGENTS

County	Address	City	Phone #	County	Address	City	Phone #
Adams	210 W. Broadway	Ritzville 99169	(509) 659-0090 Ext. 214	Lewis	360 NW North St.	Chehalis 98532	(360) 740-1212
Asotin	125 Second St.	Asotin 99402-0009	(509) 243-2018	Lincoln	P.O. Box 399	Davenport 99122	(509) 725-4171
Benton	1121 Dudly Ave.	Prosser 99350	(509) 786-5609	Mason	11840 Hwy 101 N	Shelton 98584	(360) 427-9670 Ext. 395
Benton	5600-E W Canal Pl.	Kennewick 99336	(509) 735-3551	Okanogan	P.O. Box 391	Okanogan 98840	(509) 422-7245
Chelan	400 Washington St.	Wenatchee 98801	(509) 664-5540	Okanogan	Lake Roosevelt, 708 Crest Drive	Coulee Dam 99116	(509) 633-9196
Clallam	223 East 4th St.	Port Angeles 98362	(360) 417-2279	Pacific	P.O. Box 88	South Bend 98586	(360) 875-9331
Clark	11104 NE 149th St.	Bush Prairie 98606	(360) 254-8436	Pend Oreille	418 South Scott	Newport 99156	(509) 447-2401
Columbia	202 S. 2nd St.	Dayton 99328	(509) 382-4741	Pierce	3049 S 36th,Ste. 300	Tacoma 98409	(253) 591-7180
Cowlitz	207 4th Ave N	Kelso 98626	(360) 577-3014	San Juan	315 Court St.	Friday Harbor 98250	(360) 378-4414
Douglas	PO Box 550	Waterville 98858	(509) 745-8531	Skagit	220 E College Way, Suite 180	Mount Vernon 98273	(360) 428-4270
Ferry	350 E. Delaware	Republic 99166	(509) 775-5235	Skamania	P.O. Box 790	Stevenson 98628	(509) 427-9427
Franklin	Courthouse	Pasco 99301	(509) 545-3511	Snohomish	600 128th St. NE	Everett 98208	(425) 338-2400
Garfield	PO Box 190	Pomeroy 99347	(509) 843-3701	Spokane	222 N Havana	Spokane 99202	(509) 533-2048
Grant	1st and C St.	Ephrata 98823	(509) 754-2011 Ext. 412	Stevens	230 Williams Lake Rd	Colville 99114	(509) 684-2588
Grays Harbor	100 Broadway W.	Montesano 98563	(360) 249-4332	Thurston	921 Lake Ridge Dr. SW, Rm. 216	Olympia 98501	(360) 786-5445
Island	501 N Center	Coupeville 98239	(360) 679-7327	Wahkiakum	68 Main St.	Cathlamet 98612	(360) 795-3278
Jefferson	201 W. Patison	Port Hadlock 98339	(360) 379-5610	Walla Walla	317 W. Rose St.	Walla Walla 99362	(509) 527-3260
King	612 Smith Tower	Seattle 98104	(206) 296-3900	Whatcom	11 N Forest St., Suite 201	Bellingham 98225	(360) 676-6736
Kitsap	614 Division	Port Orchard 98366	(360) 876-7157	Whitman	310 N Main, Rm. 209	Colfax 99111	(509)397-6290
Kittitas	Courthouse - Rm 217	Ellensburg 98926	(509) 962-7507	Yakima	128 N 2nd St., Rm. 233	Yakima 98901	(509) 575-4218
Klickitat	228 W Main, Rm 210	Goldendale 98620	(509) 773-5817				

NON-GOVERNMENT ORGANIZATIONS

Agricultural Support Groups

Tilth Producers . . . . (800) 731-1143
Chapter of Washington Tilth
P.O. Box 85056
Seattle, WA 98145-1056
Provides a directory of organic growers, food and farm suppliers, and resources, called the Washington Tilth Directory. Can help place farmers wishing to reduce pesticide use in touch with those who have already done so.

Northwest Coalition for Alternatives to Pesticides . . . . (541) 344-5044
P.O. Box 1393
Eugene, OR 97440
Provides information on a network of farmers practicing sustainable agriculture.

Palouse-Clearwater Environmental Institute . . . . (208) 882-1444
P.O. Box 8596
4th, Suite 1
Moscow, ID 83843
Coordinates farm/consumer improvement clubs in eastern Washington and is the western coordinator of the Campaign for Sustainable Agriculture.

Alternative Energy Resources Organization . . . . (406) 443-7272
25 S. Ewing Suite 214
Helena, MT 59601
Coordinates a network of farm improvement clubs and produces a list of organic growers in Montana. Has information on growing grains in the Palouse region.

Financial Support for Farmers Shifting to Sustainable Agriculture

Cascadia Revolving Loan Fund . . . . (206) 447-9226
157 Yesler Way, Suite 414
Seattle, WA 98104
A non-profit organization that lends money to small businesses.

Sustainable Agriculture Research and Education
Western Region SARE/ACE Program
ASTE Bldg. UMC 2310, Utah State University,
Logan, UT 84322-2310
A federal grant program for farmer-directed, on-farm research. The grants are called Farmer/Rancher Research Grants.

The Organic Farming Research Foundation . . . . (408) 426-6606
P.O. Box 440
Santa Cruz, CA 98061
Provides funding for organic farming methodology research.

Insectaries

Northwest Biocontrol Insectary/Quarantine Insectary . . . . (509) 335-5815
Terry Miller
Can provide limited technical advice on using beneficial insects as biological control agents.

Integrated Pest Management and Non-Chemical Alternatives

Bio-Integral Resource Center . . . . (510) 524-2567
P.O. Box 7414
Berkeley, CA 94707
Publishes "Common Sense Pest Control Quarterly", and "The IPM Practitioner Monitoring the Field of Pest Management."

Integrated Fertility Management . . . . (800) 332-3179
333 Ohme Gardens Rd.
Wenatchee, WA 98801
Provides information on organic farming, biological pest control, and soil amendments. Also provides a network with which growers can contact each other.

Northwest Coalition for Alternatives to Pesticides . . . . (541) 344-5044
Provides information regarding integrated pest management, a list of private consultants, as well as other sources and contacts.

Washington Toxics Coalition . . . . (206) 632-1545
Has an information file on many topics involving chemical pesticides, including effects on the environment and on human health, as well as alternatives to household and garden chemicals.

National Organizations

Appropriate Technology Transfer for Rural Areas . . . . (800) 346-9140
P.O. Box 3657
Fayetteville, AK 72702
Information service on sustainable agriculture and crop production.

Chemical Referral Center (Non-emergency phone number) . . . . (800) 262-8200
Sponsored by the Chemical Manufacturers Association. Will refer callers to the manufacturers of chemicals and provide telephone numbers of other hotlines.

National Agricultural Library . . . . (301) 504-6559
Alternative Farming Systems Information Center
10301 Baltimore Blvd.
Beltsville, MD 20705-2351
Provides bibliographies on agricultural topics; will do individual searches on national agricultural databases for free. Provides specific, technical information.

National Pesticide Telecommunication Network . . . . (800) 858-PEST (7378)
Provides 24-hour information on pesticide products, poisoning, cleanup and disposal, enforcement contacts, certification and training programs, and pesticide laws.

Safety, Storage, Handling, and Disposal

Washington Toxics Coalition . . . . (206) 632-1545
Has an information file on many topics involving chemical pesticides, including effects on the environment and on human health.

Local Solid Waste/Recycling Centers
Your county or municipal solid waste center may be of assistance when disposing of pesticides and herbicides.

GLOSSARY

Aggradation: The geologic process of filling and raising the level of the streambed or floodplain by deposition of material eroded and transported from other areas (Gregory and Ashkenas 1990).

Anadromous fish: Fish that are hatched and reared in freshwater, move to the ocean to grow and mature, and return to freshwater to reproduce. Salmon, steelhead, and shad are examples (U.S. For. Serv. et al. 1993).

Anchor ice: Ice formed below the surface of a stream or open body of water, on the streambed or on a submerged body or structure (Helm 1985, U.S. For. Serv. 1992).

Aquatic ecosystem: Any body of water, such as a stream, lake or estuary, and all organisms and non-living components within it, functioning as a natural system (U.S. For. Serv. et al. 1993).

Aquatic habitat: Habitat for fish and other aquatic organisms within bodies of water, particularly streams or rivers.

Aquifer: Water-bearing rock or rock formations that are underground.

Backwater: An off-channel pool or eddy at lateral margins of the channel that is protected from high velocity flows, usually by abundant woody debris or boulders. The opening to the main channel is less than the long axis of the backwater itself (Gregory and Ashkenas 1990).

Bank stability: The ability of stream banks to withstand the erosive forces of water. Bank stability increases in the presence of deeply rooted plants (Gregory and Ashkenas 1990).

Basin: The area of land that drains water, sediment, and dissolved materials to a common point along a stream channel (Gregory and Ashkenas 1990).

Biodegrade: To decompose by natural processes.

Bio-engineering: The use of vegetation, living organisms, and natural features of the environment to alter or repair an area.

Biomass: The total weight of living matter of a given type in a given area. Species biomass is the total weight of all living organisms per unit of space. Community biomass is the total weight of all the species, plant and animal, in a given unit of space.

Buffer: An area of intact vegetation maintained between human activities and a particular natural feature, such as a stream or a bird's nest. The buffer reduces potential negative impacts by providing an area around the feature that is unaffected by the activity.

Candidate species: Fish and wildlife species that will be reviewed by the Washington Department of Fish and Wildlife for possible listing as endangered, threatened, or sensitive. A species will be considered for candidate listing if evidence suggests its status meets the criteria for endangered, threatened or sensitive listings. Species currently listed as threatened or sensitive may also be designated a candidate species if their status is in question. Candidate species will be managed by the Department, as needed, to ensure the long-term survival of populations in Washington.

Canopy layers: The vertical layers or stories of vegetation within a forest that extend from the ground to the top of the tallest tree. Canopy layers are formed by a combination of trees, shrubs, herbaceous plants, mosses, fungi, humus, and various age classes of these plants. Species from different layers often have different light and moisture requirements.

Carrying capacity: The number of individuals of a particular species that the resources of a given habitat or area can support (Gregory and Ashkenas 1990).

Channel sinuosity: A characteristic shape of many stream or river channels that winds with many curves or bends.

Channelized stream: A stream that has been straightened, runs through pipes or revetments, or is otherwise artificially altered from its natural, meandering course.

Conifer: A cone-bearing tree, such as a hemlock, spruce, fir, or pine tree. Coniferous trees are predominantly evergreen.

Connectivity: Unbroken linkages in a landscape, typified by streams and riparian areas (Gregory and Ashkenas 1990).

Cover: Any feature that provides protective concealment for fish and wildlife. Cover may consist of live or dead vegetation or geomorphic features such as boulders and undercut banks. Cover may be used to escape from predators or weather, or for feeding or resting (Gregory and Ashkenas 1990).

Cumulative effects: "Diverse phenomena resulting from the collective impacts of management activities. These are negative or undesirable consequences that can involve the additive effects of a repeated single activity, such as forest harvest, or the synergistic or additive effects of two or more activities. Cumulative effects may show threshold behavior: the cumulative impacts are minimal up to some critical point, after which major changes occur -- through time at a particular site or through time and across space" (Franklin 1992:37-38).

Debris torrent/flow: Rapid movements of material, including sediment and woody debris, within a stream channel. Debris torrents frequently begin as debris slides on adjacent hillslopes.

Deciduous: A plant that sheds or looses its foliage at the end of a growing season.

Degradation: Lowering of the streambed or widening of the stream channel by erosion. The breakdown and removal of soil, rock, and organic debris (Gregory and Ashkenas 1990).

Deposition: The settlement of material out of the water column and onto the streambed.

Depositional soils: Soils derived from deposited sediments.

Diversity: The variety, distribution, and abundance of different plant and animal communities and species within an area (U.S. For. Serv. et al. 1993).

Downed log: All or a portion of a tree that has fallen or been cut and left on the forest floor, in a stream, or partially suspended against another tree or structure.

Drainage system: All of the elements of the landscape through or over which water travels. These elements include the soil and vegetation that grows on it, the geologic materials underlying that soil, the stream channels that carry water on the surface, and the zones where water is held in the soil and moves beneath the surface. Also included are any constructed elements, including pipes and culverts, cleared and compacted land surfaces, and pavement and other impervious surfaces that are not able to absorb water at all (Booth 1991).

Ecological function: A particular role or process that a feature or combination of features serve within a ecosystem (e.g., riparian habitat contributes organic debris to the stream system). When an area is referred to as a fully functional ecosystem it contains all the elements (features) and functions of a natural system.

Ecosystem: A complete interacting system of organisms considered together in their environment. A biotic community and its abiotic environment (Gregory and Ashkenas 1990).

Ecotone: A transition or junction zone between two or more naturally-occurring diverse communities (Gregory and Ashkenas 1990).

Endangered species: Wildlife species native to Washington that are seriously threatened with extinction throughout all or a significant part of their ranges within the state.

Evapotranspiration: Loss of water from the soil due to the combination of evaporation and the transpiration of plants growing on the soil.

Eutrophication: A process that involves excessive plant and animal growth in water bodies as a result of high amounts of mineral and organic nutrients and low amounts of dissolved oxygen.

Extirpation: The elimination of a species from a particular local area (U.S. For. Serv. et al. 1993).

Flood: An abrupt increase in water discharge. Frequently, flows that exceed the bank capacity of a given stream (Gregory and Ashkenas 1990).

Floodplain: Relatively flat surfaces adjacent to active river or stream channels, formed by deposition of sediment during major flood events. Some floodplains are inundated only during extremely large, infrequent floods, while others are flooded commonly. Floodplain boundaries are defined by the break in slope between the hillsides and the relatively flat floor of the river valley (Gregory and Ashkenas 1990).

Forb: An herbaceous, fleshy-leafed plant other than grass.

Fry: Recently hatched fish, up to one year of age.

Geomorphology: The geological study of land form evolution and configuration.

Guild: A group of species in a community that exploit the same set of resources in a similar manner, but are not necessarily closely related taxonomically (Ehrlich et al. 1988). For example, the group of birds that forage for insects on the ground would be considered in a guild.

Hard engineering: The use of permanent, unnatural structures such as dams, levees and riprap, and activities such as periodic dredging, to fight problems such as flooding and erosion. Often these techniques completely change the natural structure of an area, and require periodic maintenance.

Herb layer: A layer of vegetation that consists of herbaceous plants (non-woody, non-grass). The herb layer is generally closest to the ground. Examples of herbs include twin flower and wild ginger.

Humus: Decayed or decaying plant material usually present on the top of inorganic soil.

Leachates: Suspended or dissolved material that is extracted from soil or decomposing material and carried along with the water as it percolates through a medium.

Litter: Dead plant material, commonly leaves, needles, twigs, etc. (Gregory and Ashkenas 1990).

LWD: “Large woody debris” Large woody material that has fallen to the ground or into a stream. An important part of the structural diversity of streams, LWD is also referred to as “coarse woody debris” (CWD). Either term usually refers to pieces at least 51 cm (20 in) in diameter (U.S. For. Serv. et al. 1993).

Mass failure: Movement of aggregates of soil, rock and vegetation down slope in response to gravity (Gregory and Ashkenas 1990).

Mesic: Pertaining to moisture or moist conditions.

Microclimate: Localized climate conditions. The climatic conditions within a well defined, small or local habitat or habitat feature (e.g., the climatic conditions within a snag, the climatic conditions under the shrub layer of a forest).

Multi-layered canopy: Vegetation with two or more distinct layers in the canopy (a layer of foliage, e.g., tall shrubs). Also referred to as multi-storied.

Native plants or animals: Plants or animals that naturally occur in a given area.

Niche: A species' structural and functional role in an ecosystem (e.g., the niche of a woodpecker is a bole foraging insectivore that nests in cavities).

Nodes: Areas wider than the buffer to which they are attached, and occur at frequent, irregular intervals along the buffer. Nodes insure that the buffer includes mature or otherwise significant vegetation associated with the specific occurrence of a wildlife species.

Obligates: Species that depend on a particular habitat type or a specific element in a habitat type to meet one or more of their life requisites.

Off-channel habitat: Streamside channels, sloughs and seasonal wetlands within a riparian area but off the main channel that provide important habitat for fish and amphibians, especially as overwintering habitat for juvenile fish.

Oxbow: A U-shaped bend in a river. Often this bend becomes an area of slow flowing water, like a pond connected to the main channel, or is cut off from the main channel when water re-routes.

Peak flow: The highest discharges attained during a particular flood event for a given stream (Gregory and Ashkenas 1990).

Priority habitat: A habitat type with unique or significant value to many vertebrate and invertebrate species. A priority habitat contains one or more of the following attributes:

- comparatively high fish and wildlife density;
- high fish and wildlife species diversity;
- important fish and wildlife breeding habitat;
- important fish and wildlife seasonal ranges;
- important fish and wildlife movement corridors;
- limited availability;
- high vulnerability to habitat alteration;
- unique or dependant species.

Priority species: Fish and wildlife species requiring protective measures for their perpetuation due to their population status, their sensitivity to habitat alteration and/or their recreational, commercial, or tribal importance.

Rain-on-snow-events: The rapid melting of snow as a result of rainfall. The combined effect of rainfall and snow melt can cause high overland and stream flows resulting in severe hillslope and channel erosion (Harr 1986).

Rearing habitat: Areas required for successful survival to adulthood by young animals. For trout, rearing areas may be the edges of streams, whereas for elk, it may be thickets in riparian areas (Gregory and Ashkenas 1990).

Recovery: Return of an ecosystem to a defined condition after a disturbance (Gregory and Ashkenas 1990).

Rehabilitation: The process of restoring a site to a former state or desired condition (Gregory and Ashkenas 1990).

Resident fish: Fish species that complete their entire life cycle in freshwater.

Riparian habitat: The area adjacent to flowing water that contains elements of both aquatic and terrestrial ecosystems which mutually influence each other. This habitat includes the area with riparian vegetation and the riparian "area of influence," and is delineated by function rather than form.

Riparian Habitat Area (RHA): A standardized management area on either side of a stream that is designed to include the full range of riparian habitat functions.

Riparian Management Zone (RMZ): A specified area alongside Type 1,2 and 3 Waters where specific measures are taken to protect water quality and fish and wildlife habitat (WAC 222-16-020).

Riparian vegetation: Vegetation that requires the continuous presence of water, or conditions that are more moist than normally found in the area.

Riparian zone: The area directly adjacent to flowing water that is characterized by moist soils and plants that require moist conditions.

Rivulets: A small brook or stream.

Rotation period (rotation interval): The planned number of years between the regeneration of a timber stand and its harvest at a specified stage.

Sediment: Material carried in suspension by water, which will eventually settle to the bottom (Gregory and Ashkenas 1990).

Sedimentation: The process of sediment being carried and deposited in water.

Sensitive species: Fish and wildlife species native to Washington that are vulnerable or declining, and are likely to become endangered or threatened in a significant portion of their ranges within the state, without cooperative management or the removal of threats.

Shorelines of the State: All of Washington's saltwater areas, and freshwater systems (both lotic and lentic) of a certain size. Included are associated wetlands and the lands underlying them. Freshwater qualifications are as follows: lakes with a surface acreage of one thousand acres or more, measured at the ordinary high water mark; rivers west of the Cascade crest downstream of a point where the mean annual flow is measured at one thousand cubic feet per second or more; rivers east of the Cascade crest downstream of a point where the annual flow is measured at two hundred cubic feet per second or more, or those portions of rivers east of the Cascade crest, downstream from the first three hundred square miles of drainage area, whichever is longer (Shoreline Management Act, RCW 90.58.030).

Side channel: A portion of the active channel that does not carry the bulk of the stream flow. Side channels may carry water only during winter flows, but are still considered part of the total active channel (Gregory and Ashkenas 1990).

Slope stability: The degree to which a slope resists the downward pull of gravity. The more resistant the slope, the more stable it is (Gregory and Ashkenas 1990).

Snags: Standing dead or partially-dead trees that show signs of decay. Snags suitable for wildlife use, particularly nesting or denning, are at least 25 cm (10 in) in diameter at breast height (dbh) and at least 2 m tall (6.5 ft) (Neitro et al. 1985).

Snow interception: The capture and holding of snow by a layer of vegetation, usually the upper canopy layer.

Soft engineering: Engineering techniques that use natural processes and materials to alter or restore an area. Soft engineering alters the environment as little as possible, and avoids the long-term need for human intervention.

Spawning gravel: Sorted, clean gravel patches of a size appropriate for the needs of resident or anadromous fish (Gregory and Ashkenas 1990).

Stream bank: The part of a stream channel, when seen in cross-section, that restricts sideways water movement at normal flows. It represents a distinct break in slope from the streambed (Gregory and Ashkenas 1990).

Stream types:

- **Type 1:** All waters within their ordinary high-water mark as inventoried in "Shorelines of the State."
- **Type 2:** All waters not classed as Type 1, with 20 feet or more between each bank's ordinary high water mark. Type 2 waters have high use and are important from a water quality standpoint for domestic water supplies, public recreation, or fish and wildlife uses.
- **Type 3:** Waters that have 5 or more feet between each bank's ordinary high water mark, and which have a moderate to slight use and are moderately important from a water quality standpoint for domestic use, public recreation, and fish and wildlife habitat.
- **Type 4:** Waters that have 2 or more feet between each bank's ordinary high water mark. Their significance lies in their influence on the water quality of larger water types downstream. Type 4 streams may be perennial or intermittent.
- **Type 5:** All other waters, in natural water courses, including streams with or without a well-defined channel, areas of perennial or intermittent seepage, and natural sinks. Drainage ways having a short period of spring runoff are also considered to be Type 5 (Washington Forest Practices Board 1992).

Structure: The configuration of elements, parts, or constituents of a habitat, plant, or animal community (Gregory and Ashkenas 1990).

Substrate: The material forming the underlying layer of streams. Substrates may be bedrock, gravel, boulders, sand, clay, etc. (Gregory and Ashkenas 1990).

Succession: The progressive development of vegetation from bare ground towards its highest ecological expression, the climax community; the natural replacement of one plant community by another.

Terrestrial wildlife species: Wild animals that live primarily on land.

Threatened species: Fish and wildlife species native to Washington that are likely to become endangered within the foreseeable future throughout significant portions of their ranges within the state, without cooperative management or the removal of threats.

Transpiration: The loss of water vapor through the leaf and stem surfaces of plants.

Travel corridor: A route followed by animals along a belt or band of suitable cover or habitat.

Turbidity: The relative clarity of the water, which may be affected by suspended material.

Ubiquitous: Widely or commonly occurring, or occurring everywhere.

Understory: The assortment of trees, shrubs, and herbs growing under the canopy formed by taller trees. In range management, it is herbaceous and shrub vegetation under a brushwood or tree canopy.

Upland: The portion of the landscape above the valley floor.

Watershed: Land area from which water drains toward a common watercourse in a natural basin. Organic matter, dissolved nutrients, and sediments also move toward the same watercourse within a watershed. A watershed is dimension less and depends on the area needed in the analysis. It could be a mainstem stream and all its tributaries or a headwater stream and its drainage area.

Xeric: Pertaining to dry conditions.