EXHIBIT F—ORDINANCE NO. 05-1077

ATTACHMENT 2. METRO'S TECHNICAL REPORT FOR FISH AND WILDLIFE HABITAT

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Attachment 2

Metro's Technical Report for Fish and Wildlife Habitat

April 2005

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INTRODUCTION

This chapter provides a summary of recent scientific literature and studies relevant to the protection of fish and wildlife habitat. The purpose of this technical report is to provide a sound scientific foundation for public policy related to the management of fish and wildlife habitat in the region.

Metro's Regional Urban Growth Goals and Objectives (RUGGOs; Metro 1995) state that the region should "Manage watersheds to protect and ensure to the maximum extent practicable the integrity of streams, wetlands and floodplains, and their multiple biological, physical, and social values," as well as that "A region-wide system of linked significant wildlife habitats should be developed. This system should be preserved, restored where appropriate, and managed to maintain the region's **biodiversity**." Based on the direction outlined in this policy, Metro is taking a watershed approach in the characterization of the best available science relating to fish and wildlife habitat.

A key goal of this technical report is to provide accessible information to help elected officials, planners, and the general public understand the needs of fish and wildlife, the effects of urbanization on these species, and the biological processes that support them. There are many ways to define "urban" (e.g., May et al. 1997a; Johnson and O'Neil 2001 [see Urban and Mixed Environs in upland habitat descriptions]; McIntyre et al. 2001), often described by the percent imperviousness or human population measures. However, researchers recognize that there is a gradient of urbanization and any classifications within this gradient are arbitrary. Thus for the purposes of this report we define urban as those areas with high human population density, a definition that includes areas that are generally known as "suburban." The technical report will also provide the basis for specific planning activities such as the *inventory* and assessment of watersheds and the riparian corridors and upland habitats that comprise them, identify environmental parameters for the *ESEE analysis*, and guide *program* development.

The main questions guiding this technical report include:
1) What are the key ecological attributes that characterize a healthy watershed?
2) What are the function and values of fish and wildlife habitat and how can they be retained?
3) What are the species of fish and wildlife that characterize the biodiversity of our region?
4) What are the impacts of urbanization on healthy watershed function and fish and wildlife habitat?
5) What is restoration and how is it best approached in an urban context?

The process we used to conduct the technical report is as follows:
- a literature search of major scientific journals and the internet, as well as consulting other literature reviews conducted within the Metro region and the Pacific Northwest,
- consultation with experts on specific issues such as species lists, habitat classification systems, and impacts of urbanization,
- review by Metro's Goal 5 Technical Advisory Committee, and
- peer review by outside entities

This technical report supports a holistic view of watershed function that emphasizes the interconnectedness of the system, including the relationship of riparian corridors with upland habitats and connectivity. This technical report is organized into the following main sections:

- **Watershed perspective**
- **Aquatic and riparian habitat**
- **Upland habitat**
- **Impacts of urbanization**
- **Restoration in an urban environment**

WATERSHED PERSPECTIVE

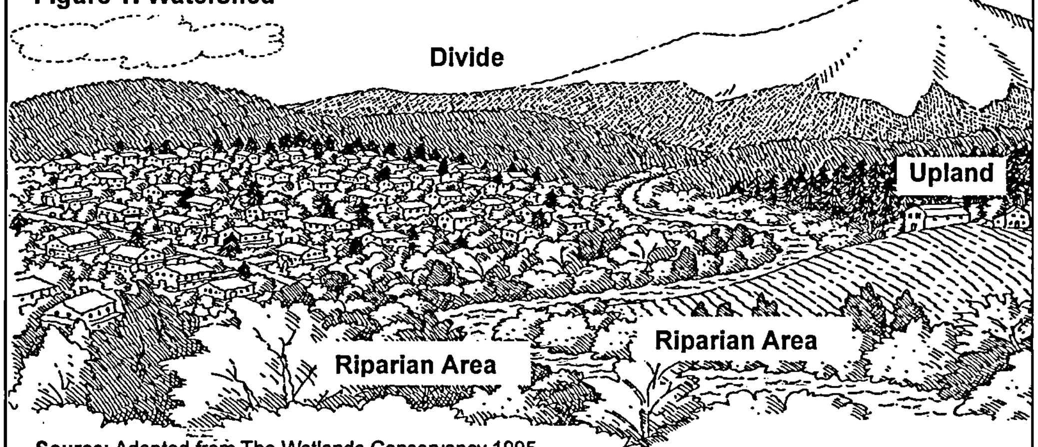
What is a watershed?

An aerial view of the Metro region reveals a network of rivers and streams draining from upland slopes to downstream river valleys. Every tributary, stream or river lies within its own watershed. A **watershed** (or drainage basin) is any area of land from which water, sediment, and organic and dissolved materials drain to a common point, such as a stream, river, pond, lake, or an ocean. According to the Pacific Rivers Council (1993):

> Watersheds are ecosystems composed of a mosaic of different land or terrestrial "patches" that are connected by (drained by) a network of streams. In turn, the flowing water environment is composed of a mosaic of habitats in which materials and energy are transferred and therefore connected through biologically diverse food webs.

Watersheds are hierarchical – small ones nest within larger ones. For example, when two small streams join, their combined drainage areas make up a larger watershed. Each mid-sized watershed contributes, in turn, to a larger watershed. Watersheds can be as large as all the land draining into the Columbia River or as small as 20 acres draining to a pond. Watersheds are separated by a ridge or mountain divide. In natural settings, patterns of drainage are determined by climate, tectonic movements, geomorphic processes and the nature and formation of the rock through which streams erode.

Figure 1: Watershed



Source: Adapted from The Wetlands Conservancy 1995

A common set of terms has been developed by the U.S. Geological Survey (USGS) to describe the hierarchical nature of watersheds, known as hydrologic unit cataloging (HUC). Beginning with the term "region," as the largest order of watershed, the terms "sub-region," "basin," "sub-basin," "watershed" and "sub-watershed" are used to described the relative sizes of drainages within geographic areas (Oregon Professional Network 1999). Under the HUC system, the Metro area is located in the Lower Columbia River and the Willamette River basins. The Tualatin and Clackamas rivers are examples of sub-basins in the region, and Johnson Creek is an example of a watershed. The HUC system is described in more detail in the inventory section.

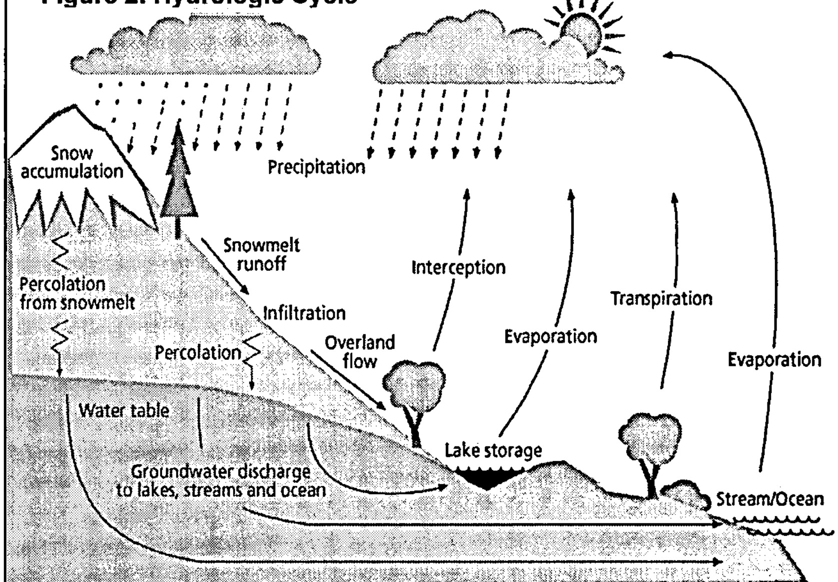
In this report, the term "watershed" is used in a broad sense, rather than describing a drainage areas of a particular size.

The major components of a watershed include the drainage network of tributaries, streams and rivers and their flow regimes, the associated **riparian vegetation, wetlands** and **floodplains** (the **riparian area), groundwater,** the **hyporheic zone** (the interface between groundwater and stream water), features within stream channels (e.g., bedrock, sediment, organic debris), and **upland** areas. The ecological health of a watershed depends on the health and connectivity between these components over space and time (Naiman et al. 1992). Connectivity refers to how tributaries are connected to larger rivers, how groundwater interacts with surface water, how water moves among streams, wetlands and floodplains, and how fish and wildlife move among watershed components.

Hydrologic cycle

Water is a crucial element that sustains life. It is the major vehicle through which **biotic** (living) and **abiotic** (non-living) materials are transferred from higher to lower land and eventually to the sea. Water moves through and across the landscape by means of surface and underground pathways or channels. Much of the water in channels moves downstream and joins to form larger stream or river systems. Hence, water is a key factor in the occurrence and distribution of organisms and the formation of **aquatic** and **terrestrial** habitat. Rivers and streams contain a small fraction of the world's fresh water, yet they perform a critical role in the continuous water cycle.

Figure 2: Hydrologic Cycle



Source: Adapted from Dunne and Leopold 1978

The **hydrologic cycle** (Figure 2) provides a useful framework for understanding the continuous cycling of water from the atmosphere to the earth and oceans and back again. The main processes of the hydrologic cycle involve **precipitation, evaporation** and **transpiration.** Precipitation, primarily in the form of rain and snow, transfers water from the atmosphere to the earth. A substantial portion of precipitation returns directly to the atmosphere through evaporation and transpiration. During rainstorms, vegetation and other natural (e.g., leaf litter, humus) and manmade surfaces (e.g., flat rooftops, parking lots) intercept and store a portion of rainwater. Some of this intercepted water evaporates during or immediately after the storm before infiltrating into the ground or being absorbed by plants. In addition, water evaporates from the streams, rivers and lakes, from the surface of the ground, and from moisture held in soil. Plants lose water to the atmosphere through a process called transpiration, during which an exchange of gases necessary for photosynthesis occurs. Transpired water originates from water that is taken in by the plant's roots (Montgomery 1986; Allan 1995; Federal Interagency Stream Restoration Working Group [FISRWG] 1998; Watershed Professional Network 1999). The loss of water due to the combined processes of evaporation and transpiration is referred to **evapotranspiration.**

Precipitation that reaches the ground takes several pathways to reach a stream channel or groundwater, and each affects the timing, quantity and quality of streamflow. The pathway followed is influenced by climate, vegetation, topography, geology, land use and soil characteristics (Allan 1995; Poff et al. 1997). Rainfall can be absorbed by soil up to a maximum rate, or **infiltration capacity**. Porous soils, such as coarse-textured sandy soils, usually have high infiltration capacity, whereas tightly packed, clayey soils have low infiltration capacity. When rainfall exceeds the infiltration capacity of the soil, **stormflow** (runoff) moves downslope as **overland flow**. Stormflow usually reaches the channel in a short time frame. Under normal conditions, relatively little runoff occurs in undisturbed regions that have porous soils and natural vegetative cover. In urban settings where paved and impermeable surfaces abound, substantial overland flow may occur (Allan 1995; FISRWG 1998).

Once water enters the soil it moves downward to the groundwater table where it is slowly discharged to the stream over a long period of time. The **baseflow** (or dry-weather flow) of a river is derived primarily from this groundwater. Shallow, **subsurface flow** occurs when there is a relatively impermeable layer underneath permeable topsoil. Water accumulates in this layer and moves downhill, reaching streams through their banks. This movement is faster than groundwater flow but slower than overland flow. **Saturated overland flow** occurs when the water table rises to the ground surface, usually during a large rainstorm, causing groundwater to break out of the saturated soil and to travel as overland flow (Allan 1995; Poff et al. 1997; FISRWG 1998; Watershed Professional Network 1999).

Billions of gallons of water move through the hydrologic cycle each year. Some of this water is temporarily diverted for human use or stored for extended periods of time (even tens of thousands of years), but it eventually makes its way back into the global water cycle. From the longer perspective of geological history, it is still viewed as moving continually through the hydrologic cycle (Montgomery 1986).

Stream corridor – a three-dimensional view

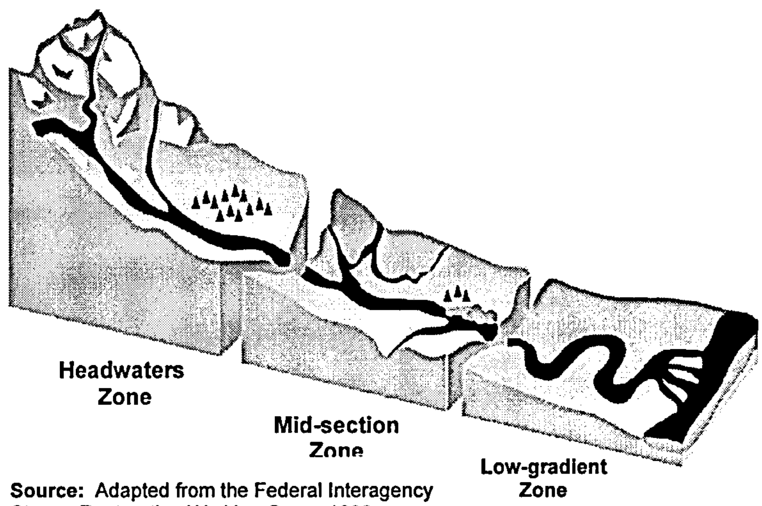
A stream corridor (or riparian corridor) includes the stream channel, the streamside (riparian) vegetation on both sides of the stream, associated wetlands, floodplains as well as other features (see ***Aquatic and Riparian Habitat*** section). Stream and river systems involve three-dimensional processes that connect the longitudinal (upstream-downstream), lateral (floodplains-upland) and vertical (hyporheic-stream channel) system components, all which vary both in space and through time (Naiman et al. 1992; Pacific Rivers Council 1993; Stanford and Ward 1993; FISRWG 1998).

Longitudinal (upstream-downstream)

Watersheds can be divided into three longitudinal zones that correspond to the structural progression that streams commonly exhibit as water flows from headwaters to the mouth (Figure 3). Changes occur in channel size and form; discharge (volume and velocity of water); sediment load, transport, and deposition; nutrients; habitats; and life forms as water flows and materials move downstream from the headwaters zone (FISRWG 1998; Mitchell 1999).

In this region, the **headwaters** zone is generally steeply sloped. Headwater streams carve deep, straight, V-shaped valleys and carry sediment and other materials downstream. The **mid-section** zone receives some of the sediment and other materials from upstream, but transfers much of it downstream. Slopes are typically gentler and the stream or river begins to meander. Narrow and discontinuous floodplains along the channel are temporary storage sites for sediments in long-term transport down the stream corridor. The **low-gradient zone** is where the greatest sediment deposition occurs. Sediments in this zone are smaller than in headwaters and mid-section zones and deposits are sorted by size. Slopes have worn down to low angles. Rivers meander in broad, flat valley floors, working and reworking the floodplain sediments in a dynamic balance of discharge and transport (FISRWG 1998; Mitchell 1999).

Figure 3: Longitudinal view (upstream-downstream)



Source: Adapted from the Federal Interagency Stream Restoration Working Group 1998

Longitudinal changes from the headwaters to the mouth of river ecosystems have been generalized in a conceptual model known as the **River Continuum Concept** (Vannote et al. 1980). Connections between the watershed, floodplain, and stream systems are identified by the model, as well as how biological communities develop and change from the headwaters to the mouth. A limitation to the River Continuum Concept is that it was developed on small streams (Junk et al. 1989).

Lateral (floodplains-upland)

Stream corridors usually exhibit three major components when viewed laterally (across the corridor): the stream channel, the floodplain and the transitional upland fringe (FISRWG 1998). The floodplain, which is an area on one or both sides of a stream channel that is periodically inundated by floodwaters, provides temporary storage for floodwaters and sediment produced by the watershed. Floodplains may be nonexistent or very narrow in steep headwater zones, yet quite expansive in low-gradient zones, where the floor of the stream valley is relatively flat. The transitional upland area serves as the edge or zone of change between the floodplain and the surrounding landscape, and is distinct from the surrounding uplands by its greater connection to the floodplain and stream (FISRWG 1998). Figure 4 in the *Aquatic and Riparian Habitat* section illustrates a cross-sectional view of a stream corridor (or riparian corridor). The transitional upland fringe corresponds to the "zone of influence" in Figure 4.

The **Flood-pulse Concept** describes the lateral interaction of streams with their floodplains. This concept is applicable primarily in unaltered large rivers systems with floodplains. It demonstrates how the predictable advance and retreat of floodwaters in the floodplain nourishes it with sediments, enhancing biological productivity and providing important habitat for insects, amphibians, reptiles and fish spawning (Junk et al. 1989; Bayley 1995; FISRWG 1998).

Vertical (hyporheic-stream channel)

An entire ecosystem, undiscovered until only a few decades ago, exists beneath and along the river. This is the hyporheic zone, or the zone of interchange between the stream and groundwater (see Figure 4 in the *Aquatic and Riparian Habitat* section). The hyporheic zone is most extensive in low-gradient streams, where wide riverbeds are underlain and surrounded by river rocks and gravel, allowing water to seep below the streambed and allowing exchange of water between the river and the sediment of the floodplain (Stanford and Ward 1993; Triska et al. 1993; Fernald et al. 2000).

Properties of both groundwater and channel water are blended in the hyporheic zone, significantly changing the water's chemical composition and stimulating biological activity (Stanford and Ward 1988; Naiman et al. 2000). The jumbled mix of stones and soil provide a wide range of microhabitats that vary in nutrient and oxygen content. A host of specialized insects and microorganisms take advantage of these living quarters, some never emerging to see the light of day. Important biological activities (such as **denitrification**, or the removal of excess nitrogen) take place in the hyporheic zone, mediated by these specialists. In addition, new evidence suggests that salmon in the Columbia River key in on hyporheic flow to select their spawning habitats because the flow replenishes oxygen, carries away waste, and moderates stream temperatures (Brinckman 2000). Thus, the hyporheic zone plays an important role in aquatic **food webs** by moderating nutrients, including providing insect food to instream wildlife.

Preserving the connection between the components of a stream or river system (i.e., upstream-downstream; floodplains-upland; hyporheic-stream channel) is vital to achieving or maintaining ecologically healthy watersheds (Naiman et al. 1992). The next section explores key attributes of healthy watersheds and the complex array of processes that occur within in them.

Physical, chemical, biological processes in healthy watersheds

The key processes contributing to watershed health are the delivery and routing of water, sediment and woody debris. The resulting stream characteristics are the best indicators of watershed vitality (Naiman et al. 1992). The health of a watershed and the characteristics of streams and rivers are influenced by the geology, topography, climate, natural disturbance regime, land use, soil and vegetation.

Some of the key attributes of watershed health in the Pacific Northwest include (Bisson et al. 1997; Naiman et al 1992; Poff et al. 1997; Hollenbach and Ory 1999):

- Uplands dominated by native forest cover
- Continuous stream corridors with healthy, fully functioning riparian zones
- Floodplains connected with river channels
- Unaltered hydrologic regimes
- Undisturbed hyporheic zones
- Natural input rates of sediment, organic matter, and nutrients that support healthy, productive and diverse fish and wildlife populations
- Lateral, longitudinal and vertical connections between system components
- Natural rates of landscape disturbances

This section provides an overview of the key physical, chemical, and biological processes occurring throughout watersheds that determine stream characteristics and, ultimately, the overall health of a watershed.

Note that a "healthy watershed" does not necessarily equate to pristine conditions. For example, urbanized areas are unlikely to return to pristine conditions within the time frames that matter to people because they are heavily modified and subject to continual human and natural disturbances. Realistically, there is a *gradient* of "healthy" conditions in which the range of possibilities are driven to a large degree by disturbance regime and the system's resiliency to those disturbances. Within this context some (perhaps as yet unknown) modified level of ecological function can be maintained or restored, even in urban areas. Stanford and Ward (1996) comment, "Although restoration to aboriginal state is not expected, nor necessarily desired, recovering some large portion of the lost capacity to sustain native biodiversity and bioproduction is possible by management for processes that maintain normative habitat conditions." Consideration of the key processes in a watershed – including disturbance regime – and the resiliency of the natural system involved can help guide watershed management (Resh et al. 1988; Petraitis et al. 1989).

Physical processes

Diverse stream and floodplain characteristics and plant communities are created by the interaction of the geology, hydrology, climate and **geomorphic** processes, and inputs of organic and inorganic material from hillsides and vegetation within a watershed (Gregory et al. 1991; Naiman et al. 1992; Spence et al. 1996; Rot et al. 2000). The following sections examine how hydrologic patterns influence streamflow, and how streamflow, the physical processes of erosion, sediment transfer, and deposition, and the input of organic and inorganic material form stream channels and create habitat.

Hydrologic pattern and streamflow

The hydrologic cycle, as described earlier, is the continuous cycling of water from the atmosphere to the earth and back again. Hydrologic pattern refers specifically to the type of precipitation, quantity of flow, seasonal water storage, and surface-subsurface water exchanges.

Local and regional streamflow reflects the variability of the hydrologic pattern (Naiman et al. 1992; Poff et al. 1997). Hydrologic connectivity is the water-mediated transfer of matter, energy, and/or organisms within or between elements of the hydrologic cycle; disruptions in hydrologic connectivity may have severe ecological consequences (Pringle 2001).

Precipitation (i.e., rain or snow) is the ultimate source of all streamflow. The intensity, timing and duration of a storm event influence, in part, how quickly water reaches the stream. The variability of climate and land use and their influence on vegetation, soil cover and condition also affect how quickly precipitation reaches streams. Poff et al. (1997) describe the importance of streamflow quantity and timing:

> Streamflow quantity and timing are critical components of water supply, water quality, and the ecological integrity of river systems (Poff and Ward 1989). Indeed streamflow, which is strongly correlated with many critical physiochemical characteristics of rivers, such as water temperature, channel geomorphology, and habitat diversity, can be considered a "master variable" that limits the distribution and abundance of riverine species.

Streamflow has two basic components: stormflow and baseflow (see *Hydrologic Cycle* section). Based on the timing and balance of stormflow and baseflow, three categories of streams are recognized: **perennial, intermittent** and **ephemeral** streams. Perennial streams flow year round, even during periods of no rainfall. Groundwater is a source of much of the water in the channel. Intermittent streams flow only during certain times of the year, but usually more than 30 days per year. Ephemeral streams flow only during or immediately after periods of rainfall, usually less than 30 days per year (FISRWG 1998).

The size and shape of a channel is determined by three variables: **discharge**, the volume of water moving down a channel per unit of time; **gradient**, the slope of the channel; and **sediment load,** the amount and size of sediment being transported. When one factor changes, the others adjust. Adjustment is reflected in seasonal changes in the slope of the water surface, the degree of **sinuosity** (curvature) of a stream, discharge, and sediment load (FISRWG 1998; Mitchell 2000).

A wide range of flow characteristics is key in the formation and maintenance of a variety of habitat features. The next section describes the geomorphic processes along a stream corridor that form drainage patterns, channels, floodplains, and other watershed and stream corridor features.

Physical habitat forming processes in stream channels

The primary geomorphic processes that operate throughout a watershed are **erosion, sediment** (soil particles) transport and sediment deposition (Naiman et al. 1993, FISRWG 1998). The hydrologic pattern within a watershed drives the geomorphic processes. The type of precipitation or disturbance, timing, frequency and magnitude of the event; runoff processes (surface and subsurface flow); gravity; wind; ice; chemical reactions; and vegetation influence the yield and rate of sediment delivery to streams. Stream channels are formed, sustained, and changed by the water, sediment and organic material they carry (Spence et al. 1991; Naiman et al. 1992; FISRWG 1998; Moses and Morris 2001).

Erosion and **sedimentation** occur naturally in a watershed and provide the sources and surfaces necessary for habitat formation for aquatic and terrestrial wildlife species (Naiman et al. 1992). A **disturbance**, be it natural or human-induced, is any significant change in the supply or routing of water, sediment, or woody debris that causes a measurable difference in channel structure and biological community. Natural disturbances such as floods, fire, landslides, plant diseases and insect outbreaks are an integral part of watershed dynamics. These events often result in significant structural changes to the stream channel and biological communities, both in the near term and over time. A natural disturbance, such as a landslide, may destroy aquatic and terrestrial organisms. However, such an event often revitalizes an area by depositing organic material, uncovering buried organic debris, and increasing sunlight by opening forest canopies. These areas often evolve into biologically productive sites over time (Gregory et al. 1991; Naiman et al. 1992).

Although some erosion occurs naturally, many urbanized watersheds experience a higher rate of soil erosion than that of undisturbed landscapes (Pacific Rivers Council 1996). Human disturbance, such as land-use practices associated with urbanization, agriculture, livestock grazing and timber harvest, contribute to this higher rate of soil erosion by altering the natural drainage basin. Many of these alterations have resulted in significant consequences such as landslides, flooding, channel erosion and destruction of aquatic habitat. For a full discussion of the impacts of urbanization, see the ***Aquatic and Riparian Habitat*** section.

Erosion begins with the detachment of soil particles from upland areas, from the streambank, and from within the stream channel. Erosion produces sediment that moves in suspension from its site of origin by air, water, or gravity. Eroded particles, regardless of size, are subject to being transported and deposited downstream. Sediment particles can range in size from fine clay to boulders. Small particles are transported more easily and may be suspended in the water column (suspended or wash load) or in solution. Larger particles move downstream by saltation, or sliding, rolling or skipping along the streambed as bedload. Often only high flow events can move the largest particles downstream. Sediments drop out of water or stop moving when streamflow slows, losing power (i.e., slope and discharge) to move them (FISRWG 1998; Mitchell 1999).

As sediment, **large woody debris** (LWD) and other organic and inorganic materials are transported and deposited throughout a watershed, channel characteristics and aquatic and terrestrial habitats are formed. Large woody debris is important because it influences the routing and storage of water and sediments, as well as the development of channel bottom topography, including the formation and distribution of pools (Beschta 1979; Booth et al. 1997). Large woody debris is also an important source of aquatic cover and acts as a surface for biological activity by aquatic organisms (Gregory et al. 1991; Naiman et al. 1992). In addition, LWD helps dissipate energy generated from streamflow, slowing erosion and sediment transport rate and retaining organic debris, making it available to organisms living there (Naiman et al. 1992). Large woody debris is discussed in more detail in the ***Aquatic and Riparian Habitat*** section.

The structure and form of the channel changes as it moves from the headwaters to the mid-section and low-gradient zones as described below.

Habitat forming processes in headwater zones

In the Pacific Northwest, the majority of rivers draining into the Pacific Ocean originate in steep, mountainous terrain (Naiman et al. 1992). According to Wenger (1999), headwater streams make up the majority of stream miles in any watershed basin, and most streamflow originates from headwaters (Harr 1976). These streams are typically steep (eight degrees or more), flow in narrow bedrock channels with steep valley sides, and exhibit low to moderate sinuosity (Harr 1976; Naiman et al. 1992). They are naturally prone to catastrophic disturbances such as landslides and debris flows. These events can significantly alter the channel and destroy existing aquatic and terrestrial habitat and organisms. However, headwater streams and the surrounding landscape often are revitalized by these events and evolve into biologically productive areas (Naiman et al. 1992).

Headwater streams are vital to the hydrological, biological and geological processes within the watershed (Harr 1976; Pacific Rivers Council 1996; Meyer et al. 2001). For example, headwater streams typically:

- substantially increase water retention capacity in a watershed, resulting in downstream protection from flooding and channel damage
- retain sediments that would otherwise be deposited downstream
- contain substantial amounts of LWD that store sediments and provide habitat structure and sites for critical metabolic activity
- establish the basic chemical composition of unpolluted streams draining a landscape
- are the sites of most active uptake and retention of nutrients
- provide important thermal refuges for fish and other wildlife
- provide unique habitats for numerous species

Adapted from Meyer et al. 2001

Large woody debris delivered to headwater streams often becomes wedged in the narrow channel. Rapids and waterfalls are common within this zone. Accumulated wood and large boulders create obstructions that form a stair-stepped profile, effectively lowering overall gradient and dissipating energy. This results in less erosion to the streambed and banks, more sediment storage in the channel, and slower downstream movement of organic debris. Headwater streams are occasionally flushed of accumulated sediment and organic debris when natural disturbances such as debris flows occur (Swanson et al. 1982a,b; Gregory et al. 1991; Naiman et al. 1992).

Habitat forming processes in mid-section zones

Mid-section streams are typically larger than headwater streams. They are moderately steep (one to six degree slopes) in narrow valley floors. These streams receive some of the sediment, LWD and other organic material from the headwater zone, as well as from adjacent uplands, but tend to transport sediment rather than storing it for long periods (Naiman et al. 1992). Streambed materials range from gravel to boulders with large woody debris jams that create alternating **pools** and **riffles** (FISRWG 1998). Mid-section streams are usually narrow enough to accumulate large woody debris across the stream (Naiman et al. 1992). The valley within mid-section zones broadens, creating minor floodplains. Streams begin to bend, or **meander** and are typically a single channel, except where woody debris jams and other deposits create streamflow diversions. **Terraces, overflow channels** and **oxbow lakes** are limited because channels tend to contain flood flows. When flooding occurs, however, the duration is shorter than in low-gradient streams and rivers. Wetlands commonly form at the base of hillsides where runoff accumulates in saturated soils (Naiman et al. 1992).

Habitat forming processes in low-gradient zones

Increased sediment deposition and greater water volume occur in low-gradient zones (FISRWG 1998). Channels widen and become deeper. Complexity increases both in structure and in the plant communities that occupy the floodplain (Hughes 1997). The fine sediment particles stored in the floodplain in low-gradient zones easily erode, which favors the development of meandering floodplain channels and the creation of alternating pools and riffles, oxbows, sandbars, backwaters, undercut banks, braided channels, and floodplain pools. High water tables are also noted (Johnson and Ryba 1992; Naiman et al. 1992; Cohen 1997). Wetlands are often present along cutoff meanders and oxbow lakes. Large woody debris is scattered in large rivers but often accumulates at river bends or the upstream portion of islands and sandbars.

Flooding in these areas is not restricted to storm events. Lesser magnitude floods occur because of the dynamic accumulation of sediment, beaver dams and debris jams (Naiman et al. 1992). The floodplain provides temporary storage for floodwaters and sediment as well as some long-term storage of groundwater in deep sediments and wetlands. Floodplains expand and contract depending on the season, climate, precipitation, soil characteristics and local topography. Natural disturbances other than flooding may have limited influences on low-gradient streams because the floodplains are isolated from surrounding hillslopes (Naiman et al. 1992).

Episodic disturbances of the floodplain sediments by the meandering river create pockets of young, broadleafed and annual plants, which are nutrient rich and attractive to both wildlife and insects. The presence of large organic debris in floodplain channels affects local flow velocities, creating local zones of scour and deposition, varied channel topography and corresponding habitats (Mitchell, pers. comm. 2001).

Chemical and biological processes

The quantity, timing and variability of streamflow are important components of a healthy watershed, as described earlier. However, an appropriate flow regime does not guarantee a healthy ecosystem if the water quality is degraded. Sediment load (suspended sediment in water) temperature, and chemical composition of water play important roles in water quality and thus the characteristics of aquatic and terrestrial plant and animal communities. This section provides a brief overview of various chemical and biological components within a watershed, such as water quality, vegetation, carbon, nitrogen and phosphorus, aquatic insects and nutrient cycling.

Water quality

Water quality is a fundamental component of ecologically healthy watersheds. Water interacts with everything it touches. Flowing water carries a variety of materials, including:

- Suspended sediment
- Heat
- Dissolved gases (oxygen, carbon dioxide and nitrogen)
- Dissolved nutrients (various forms of nitrogen, phosphorus and carbon)

- Dissolved major ions and trace metals (e.g., calcium, silicate, sulfate, copper, zinc, lead, etc.)
- Suspended and dissolved organic matter (e.g. leaves, algae, LWD, etc.)
- Suspended inorganic matter (elements such as aluminum, iron, silicon, calcium, potassium, magnesium, sodium and phosphorus)
  (Naiman et al. 1992; FISRWG 1998)

Other important parameters relating to water quality include alkalinity, acidity and buffering capacity (buffering causes water to resist changes in pH), potential toxicants (wastes, insecticides, herbicides) and organic nutrients (forms of dissolved organic carbon) (Naiman et al. 1992). An overview is presented in this section of a few key elements of water quality: sediment, temperature and dissolved oxygen.

Sediment

As discussed in the previous section, the transport and deposition of sediment throughout a watershed are key channel and habitat forming processes. However, changes in sediment load and particle size can have negative impacts on water quality and aquatic habitat. Water quality is reduced when excessive amounts of fine sediment such as silt and clay particles enter the stream and become suspended in the water column, causing water to become cloudy, or turbid. In addition, some nutrients and toxic chemicals attach to soil particles on land and enter the water where the pollutants either settle with the sediment or become soluble in water (FISRWG 1998). See ***Aquatic and Riparian Habitat***, *Impacts of Urbanization* for detailed discussion.

Temperature

Water temperature is an important indicator of a watershed's vitality because of its controlling influence on the metabolism, development and activity of aquatic organisms (Naiman et al. 1992). Cold, well-oxygenated water is needed by many aquatic species. Shifting temperatures may have profound effects on aquatic species (e.g., salmon, trout, invertebrates) that can tolerate only a limited range of temperatures. Water temperature is influenced by many factors including groundwater and surface water flow, riparian vegetation (height and canopy density), incoming solar radiation, elevation, climate, stream size, water velocity and depth and **turbidity.**

Temperature changes as water flows downstream. Small streams in forested headwater zones typically have cooler water and stable temperatures because riparian canopy blocks incoming solar radiation. According to Naiman et al. (1992), these streams typically receive one to three percent of total available solar radiation. Mid-section zones typically receive 10 to 20 percent of total available solar radiation because of the gaps that appear in the riparian canopy. Daily temperatures fluctuate between 2-6° C; seasonal variation can be 5-20° C (Naiman et al. 1992). Low-gradient zones generally have wide gaps in riparian canopy but temperature fluctuation is not as great as mid-section streams. This is because larger rivers tend to be deeper and more turbid, restricting the amount of light penetrating through water (Naiman et al. 1992).

Dissolved Oxygen

Dissolved oxygen (DO) is a basic requirement for most aquatic species. Some species require high concentrations of DO (e.g., salmon and trout), while others can survive at lower levels (e.g., carp). Oxygen gas readily dissolves in water, which absorbs it directly from the atmosphere. In addition, aquatic plants release oxygen to the water as a byproduct of photosynthesis. Increased temperatures and **salinity** reduce the amount of oxygen the water can hold. Undisturbed streams generally contain an abundant supply of DO. Dissolved oxygen levels depend in part on the internal mixing and turbulence of water and instream characteristics such as waterfalls and rapids (FISRWG 1998).

Oxygen depletion occurs when oxygen-demanding waste (e.g., sewage, industrial waste, etc.) enters the stream. Oxygen-demanding waste loads are described by a parameter known as **biochemical oxygen demand** (BOD), a measure of the amount of oxygen required to break down organic matter. The more organic matter there is in a stream, the higher the BOD. Excessive aquatic plant growth, due to an overload of nutrients such as nitrates and phosphates, can also lead to oxygen depletion. This development is known as **eutrophication**. As plants die off and decompose, they become part of the organic matter load, increasing BOD (Montgomery 1986; FISRWG 1998).

Vegetation

Vegetation plays a critical role in healthy watersheds. Plant communities are dynamic. Soils, nutrients, and woody debris move from one area to another through precipitation and erosion, leaching, wind, natural and human disturbances, and a variety of other means. Eventually, gravity assists some of these materials down to the riparian zone.

Plant communities in riparian areas help determine what, how much, and when materials from upland areas enter the stream ecosystem. For example, a wide, mature riparian forest will capture many soils and sediments, nutrients, and woody debris, adding richness and complexity to soil and plant communities near the water and protecting water from excessive nutrient or soil inputs (Lowrance et al. 1986; Lowrance et al. 1988; Wenger 1999). A fine balance exists between having enough and having too much of these inputs to the stream. Riparian areas, and consequently the structure, functions and processes occurring within and around the stream, are fundamentally altered when significant upland and riparian vegetation is removed.

The River Continuum Concept generalizes the changes that occur in vegetation from the headwaters to the mouth (Vannote et al. 1980). In headwater streams, where forest canopy overhangs and shades the narrow channel, little sunlight is available to plants and algae within the stream, and most nutrients enter the stream from terrestrial sources. Such externally-derived nutrients are termed **allochthonous**, and consist primarily of large wood and leaf litter (Kauffman et al. 2001). Mid-section zone organisms rely more heavily on internally-derived nutrients (**autochthonous**), such as instream algae and plants (more sunlight is available) and fecal matter. However, small particles of pre-processed nutrients from upstream are also available; therefore, mid-reach streams tend to balance inputs from both external and internal sources. Low-gradient streams flow more slowly, receive abundant sunlight, and acquire nutrients from upstream sources, encouraging instream (autochthonous) plant production (Vannote et al. 1980; FISRWG 1998).

Carbon, nitrogen and phosphorus

Carbon, nitrogen and phosphorus are chemicals that play key roles in aquatic food webs (Meyer et al. 1988; Stanford and Ward 1993). Plants, like all life forms, need carbon because carbon forms the backbone of living molecules. Plants obtain and store carbon from carbon dioxide in the air. Animals obtain carbon from organic matter. Carbon becomes available to insects, fish and other wildlife as plants die, drop leaves, lose branches, or leach nutrients via water flow. Such nutrients are generally referred to as "organic matter" (Allan 1995). As the primary carbon source, riparian vegetation strongly influences carbon inputs to the stream.

When organic matter from the land enters water, it may be consumed or decomposed by insects and microorganisms, physically broken into smaller particles through abrasion, or leached and released into the water. These processes vary among vegetation types. For example, hardwood forests have a more seasonal component to nutrient inputs and leaves decompose relatively quickly, whereas coniferous inputs are more constant with relatively slow decomposition rates due to the waxy leaf surface (Gregory et al. 1991). Seasonal patterns of organic inputs help determine biological community composition.

Nitrogen and phosphorus are vital plant nutrients, although excessive inputs to the stream can lead to uncontrolled plant and algae growth (Allan 1995). Natural sources of nitrogen and phosphorus include plant decomposition and rock erosion. Nitrogen-fixing plants such as alder may also obtain atmospheric nitrogen (Pinay et al. 1993). Nitrogen is readily water soluble, while phosphorus is typically carried to the stream attached to soil particles. These differences in transport to the stream, combined with local geology (mineral leaching and erosion) and riparian vegetation, influence the amounts of nitrogen and phosphorus entering aquatic ecosystems.

Aquatic insects

Aquatic insects and microorganisms convert nutrients and organic matter into forms useable by other organisms. As described above, the importance of plants as instream nutrient sources changes between headwater, mid-section, and low-gradient zones. Aquatic insect communities are arranged accordingly, as theorized by the River Continuum Concept described earlier in this chapter (Vannote et al. 1980). For example, headwater insects specialize in breaking down coarse organic matter. In mid-section zones, most insects collect organic matter or graze on plants and **diatoms**. In low-gradient zones, coarse organic matter is relatively rare but fine organic matter is available from plants, decomposing insects, and sediments. Insects in these reaches tend to be collectors. In each zone, predatory insects comprise a relatively small, but important, component of aquatic insect communities. Throughout this downstream continuum, insects play an important role in converting and supplying nutrients to other instream organisms. Many fish species, including **salmonids**, rely on aquatic insects as their primary food resource (Spence et al. 1996).

Nutrient cycling

As discussed above, a variety of plant and animal materials serve as sources of carbon and nutrients within watersheds. Despite the fact that streamwater flows in one direction (downhill), carbon and nutrients are involved in a continuous cycle, known as **nutrient cycling:**

> ...Nutrient cycling describes the passage of an atom or element from a phase where it exists as dissolved available nutrient, through its incorporation into living tissue and passage through perhaps several links in the food chain, to its eventual release by excretion and decomposition and re-entry into the pool of dissolved available nutrients (Allan 1995).

Thus through a complex and variable set of processes relying on sunlight, land, water, plants and animals, essential nutrients are retained in aquatic ecosystems for use by other organisms. The presence, quantity and quality of riparian vegetation are vitally important to this dynamic web of life.

Summary

Many people think of rivers simply as water flowing through a channel. Streams and rivers are not stand-alone units. Every tributary, stream or river lies within its own watershed. A watershed (or drainage basin) is any area of land from which water, sediment, and organic and dissolved materials drain to a common point, such as a stream, river, pond, lake, or an ocean. Watersheds are complex ecosystems that are comprised of a drainage network of tributaries, streams and rivers, floodplains, upland and riparian vegetation, groundwater, the hyporheic zone, and features within stream channels. The ecological health of a watershed and its value for fish and wildlife depends on preserving the connectivity between these components over space and time (Naiman et al. 1992). This highlights why scientists recommend investigating, managing and restoring aquatic and terrestrial systems using a watershed perspective (Forman and Godron 1986; Karr 1991; Pacific Rivers Council 1993; Federal Ecosystem Management Assessment Team [FEMAT] 1993; Karr and Chu 1999; Watershed Professional Network 1999; Naiman et al. 2000).

AQUATIC AND RIPARIAN HABITAT

Introduction

Natural riparian corridors provide valuable habitat for fish and wildlife. For example, in the Metro region, 93 percent of all (non-fish) wildlife species regularly use water-associated habitats, and 45 percent are closely associated with these habitats (Metro's Species List). Riparian corridors are exceptionally productive ecosystems. The interaction between rivers and streams and their adjacent riparian and upland areas provides for a unique and diverse ecological system consisting of:

> ...nonliving parts such as groundwater, rocks, and soil; ground cover, understory, and canopy plants; and animals such as insects, reptiles, birds, and mammals. Organisms and nutrients are moving back and forth between aquatic and upland areas, water levels are fluctuating, the channel is shifting laterally, and the riparian vegetation is many-layered. This complex, dynamic environment sustains a large variety of species, life history patterns, and nutrient cycles (Constantz 1998).

This chapter examines the unique characteristics present in riparian corridors that account for the diversity of plant and animal species found there and covers the following topics:

- Definition of a riparian corridor
- Ecological functions of riparian corridors
- Riparian habitat types and species associations
- Impacts of urbanization
- Wildlife use of urban riparian corridors
- Riparian area width

Riparian corridors

The term "riparian" is derived from the Latin word "riparius" meaning "of or belonging to the bank of a river" (Naiman and Decamps 1997). Riparian area refers to the land and vegetation adjacent to waterbodies such as streams, rivers, wetlands and lakes that are influenced by perennial or intermittent water. Riparian areas are dynamic biological and physical systems that act as the interface between terrestrial (land) and aquatic (water) ecosystems (Gregory et al. 1991; Naiman and Decamps 1997). The term **riparian corridor**, as used in this report, includes the stream or river; the riparian vegetation; off-channel habitat such as wetlands, side channels, and the floodplain; the hyporheic zone; and the **zone of influence**, as shown in Figure 4 on the following page.

The spatial extent or width of the riparian area is difficult to delineate. Naiman and Decamps (1997) describe the riparian area as encompassing "the stream channel between the low and high water marks and that portion of the terrestrial landscape from the high water mark toward the upland where vegetation may be influenced by elevated water tables or flooding and the ability of the soils to hold water." Gregory et al. (1991) further describes riparian areas as "three-dimensional zones of direct interaction between terrestrial and aquatic ecosystems," the boundaries of which "extend outward to the limits of flooding and upward into the canopy of streamside vegetation."

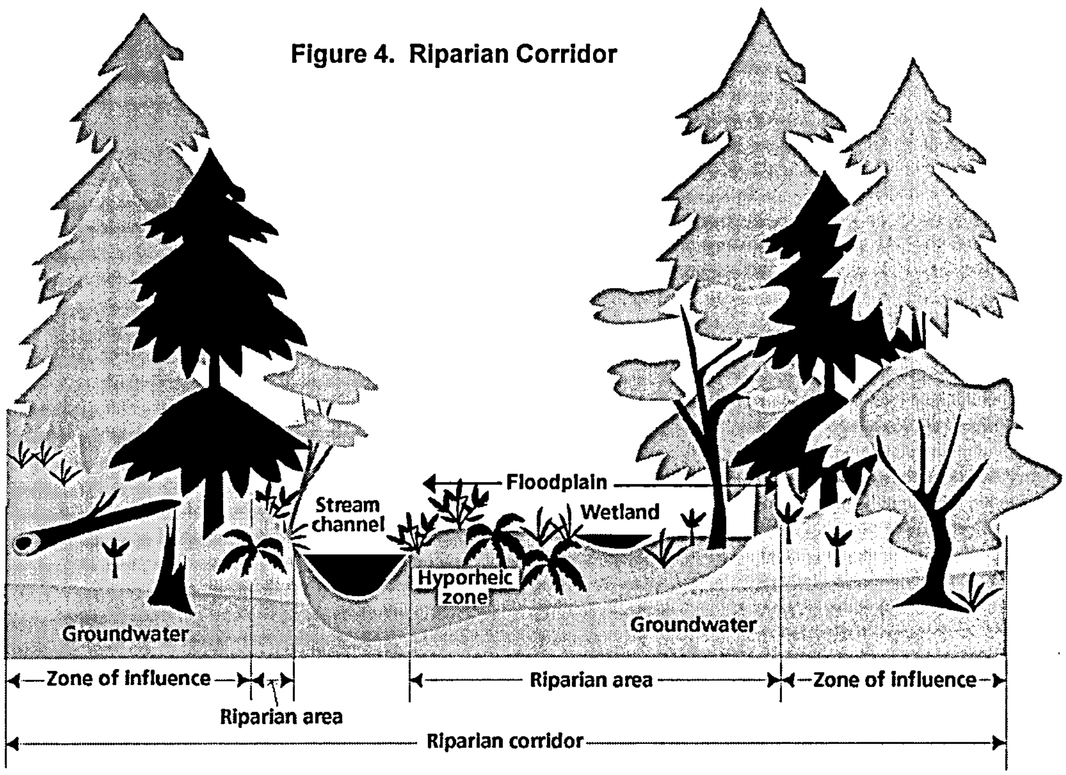


Figure 4. Riparian Corridor

The riparian area may contain stream-associated wetlands. Wetlands may occur adjacent to stream channels and within the floodplain of the riparian corridor. They are defined by hydrology, **hydric soils**, and vegetation that depend on frequent and recurrent shallow inundation or saturation at, or near, the soil surface. Swamps, marshes, bogs and similar areas are generally considered wetlands (FEMAT 1993; FISRWG 1998; Kauffman et al. 2001). Plant communities of wetland habitats are dominated by species adapted to survive and grow under periods of anaerobic (absence of oxygen) soil conditions (FEMAT 1993).

Because wetlands may occur within riparian areas, the scientific literature often treats wetlands and riparian areas as synonymous to simplify discussion (FEMAT 1993). This report uses that same approach in its discussion of the ecological functions of riparian corridors for fish and wildlife habitat. However, wetlands are recognized for their highly valuable and productive habitats in *Riparian Habitat Types and Species Associations*, below. Other important wetland and riparian functions such as water storage, sediment trapping, flood damage reduction, water quality improvement/pollution control and groundwater recharge are examined in Metro's (1997b) Policy Analysis and Scientific Literature Review for Title 3.

The riparian area includes the entire extent of the floodplain, an integral part of the riparian corridor in low-gradient streams and rivers. A floodplain is defined as the area adjacent to the stream or river channel that becomes inundated with overbank flows during storm events. According to Bayley (1995), the floodplain is "that part of the river-floodplain ecosystem that is regularly flooded and dried, and it represents a type of wetland." Well-developed, complex floodplains are characteristic in large river systems where there are long periods of seasonal flooding, oxbow lakes, wetlands, a diverse forest community and moist soils (Gregory et al. 1991; Naiman et al. 1992; Spence et al. 1996; Poff et al. 1997).

Flood events of different size and frequency play a vital role in maintaining a **diversity** of riparian plant species and aquatic habitat (Junk et al. 1989; Swanson et al. 1998). Biological productivity is enhanced in floodplains because sediment and nutrients are deposited during the advance and retreat of floodwaters (Bayley 1995). Small floods transport fine sediments downstream and laterally, and help create spawning habitat for fish. Intermediate and large floods create opportunities for organic material input, including LWD, and allow for the nourishment and establishment of plant species (Poff et al. 1997).

Most streams have a channel migration zone (CMZ) in reaches where the channel is not constrained by narrow valleys or ravines (e.g., steep headwater channels) (May 2000). Over time, streams move back and forth across the valley floor in a process called lateral migration (FISRWG 1998). The CMZ is the lateral extent of likely channel movement over the past 100-year period (May 2000), or where aquatic or wetland habitat could possibly exist at some time in the future (Pollock and Kennard 1998). The 100-year flood is often used for purposes of delineating the extent of the floodplain (May 2000), although the CMZ includes lower terraces and hillslopes adjacent to the floodplain where the stream is likely to meander (Pollock and Kennard 1998).

The hyporheic zone is another critical component of the riparian corridor. It is the saturated sediment underneath a stream or river channel and below the riparian area where groundwater and channel water mix. Properties of both groundwater and channel water are blended in the hyporheic zone, significantly changing the chemical composition and stimulating biological activity (Stanford and Ward 1988; Naiman et al. 2000).

Beyond the riparian area is the "zone of influence" – the transition area between the riparian area and the upland forest where vegetation is not directly influenced by hydrologic conditions (Naiman et al. 1992; Gregory et al. 1991). Vegetation in this zone still influences the stream by providing shade, microclimate, fine or large woody materials, nutrients, organic and inorganic debris, terrestrial insects, and habitat for riparian-associated wildlife. The extent of the zone of influence depends on stream size and geomorphology. For example, a small headwater stream in a steeply sloped area is influenced by upland vegetation beyond the riparian area that contributes organic material through overland flow and direct leaf-fall. Large streams, on the other hand, are more influenced by the riparian vegetation in the immediate riparian area and inputs from upstream than by upland vegetation (Naiman et al. 1992). The zone of influence may be considered part of the riparian area (Gregory et al. 1991; Naiman et al. 1992; Naiman and Decamps 1997; Knutson and Naef 1997).

Riparian vegetation refers specifically to plant communities occurring within the riparian area that are adapted to wet conditions and are distinct from upland communities (Knutson and Naef 1997). Riparian areas are composed of a mixture of herbs and grasses, shrubs, deciduous trees, and coniferous stands of various ages. Younger vegetation occurs immediately adjacent to the stream channel and commonly consists of deciduous shrubs and trees. Generally, older plant communities such as alder, cottonwood and willow are found in floodplains farther from the channel (Gregory et al. 1991). The distribution, structure and composition of riparian plant communities are largely determined by (derived from: Thomas et al. 1979; Swanson et al. 1982b; Gregory et al. 1991; Naiman and Decamps 1997; FISRWG 1998; Naiman et al. 2000):

- climate
- light and water availability
- topographic features
- chemical and physical properties of the soil, including moisture and nutrient content
- the existence of tributary and groundwater flows
- natural disturbance regimes (e.g., floods, wind, fire, insect outbreaks, plant diseases, etc.)

The integrity of the aquatic and terrestrial ecosystems is greatly influenced by the quantity, composition, and structure of riparian plant communities. Plant communities that cover large areas and that have an array of vertical (e.g., trees vs. shrubs) and horizontal (e.g., young stands vs. old growth) structural characteristics can support numerous animal species (O'Neil et al. 2001). In addition, riparian vegetation, through its root system and input of woody debris, influences stream channel characteristics. Riparian vegetation also directly affects aquatic organisms by providing organic materials to the aquatic food web (Gregory et al. 1991).

Riparian plant communities typically change from the headwaters to the mouth because of differences in gradient, hydrology, geomorphology and disturbance regimes (Harr 1976; Kauffman et al. 2001). For example, steep slopes in headwater zones often restrict the extent of the riparian vegetation, which may closely resemble that of upland areas (McGarigal and McComb 1995). Mid-section zones tend to have a band of riparian vegetation that is influenced by channel dynamics (e.g., meandering, flooding). Riparian vegetation in large, low-gradient rivers is generally composed of specialized and disturbance-adapted species that flourish in floodplains where periodic inundation occurs (Naiman et al. 1992). For example, common riparian plant species such as willows and cottonwoods depend on flooding for regeneration.

Ecological functions of riparian corridors for fish and wildlife habitat

The ability of the riparian corridor to attract and support fish and wildlife is dependent on the structural and functional integrity of the aquatic, riparian and upland ecosystems (Knutson and Naef 1997; May et al. 1997b). Metro's Title 3 *Policy Analysis and Scientific Literature Review* (Metro 1997b) and this section examine the many functions that riparian corridors provide for fish and wildlife habitat.

Riparian contributions to aquatic habitat

Aquatic insects, amphibians, and fish are strongly influenced by the composition and structure of riparian areas and the contribution of riparian areas to instream habitat (e.g., large and small woody debris) and organic inputs (e.g., leaves, needles, insects). Salmonids are a general indicator of watershed health or degradation. Their survival depends on a high-quality, stable environment from tributary streams through major rivers to the ocean. They require cool, clean flowing water with a high level of dissolved oxygen; clean gravel in the streambed for reproduction, a variety of in-stream cover, sufficient food sources, and unimpeded access from spawning and rearing areas to the ocean. Four important factors influence streams as habitat for salmon: water quality, streamflow, physical structure of the stream corridor, and food supply. Riparian areas provide many functions that are vital for healthy aquatic habitat, including:

- Microclimate and shade
- Bank stabilization and sediment control
- Pollution control
- Streamflow moderation
- Organic matter input
- Large woody debris

The influence riparian areas exert on a stream is related to the size of the stream, its location in the watershed, the hydrologic pattern and local landforms (Naiman et al. 1992; Naiman et al. 1993). Retention of a natural riparian buffer has been shown to partially ameliorate the adverse effects of urbanization on aquatic wildlife (Horner et al. 2001; see also *Impacts of Urbanization* section).

Microclimate and shade

Riparian vegetation exerts strong control on the stream microclimate by protecting it against climatic changes caused by land use activities outside the riparian corridor (Naiman et al. 1992; Pollock and Kennard 1998; Kauffman et al. 2001). The **microclimate** of riparian corridors is uniquely different from upland areas because of its proximity to water, which influences soil moisture, temperature, and relative humidity (Thomas et al. 1979; Swanson et al 1982b; Naiman et al. 1992; Pollock and Kennard 1998; Kauffman et al. 2001). Variations in microclimate directly influence ecological patterns and processes (Chen et al. 1999).

The position of riparian areas along streams ensures adequate soil moisture available to riparian-associated plants throughout most of the year. For example, in Oregon headwater streams Olson et al. (2000) found cooler temperatures and increased relative humidity near the stream compared to upslope. Because of these factors, riparian vegetation is buffered from the stress of evapotranspiration during the summer (Swanson et al. 1982b; Naiman et al. 2000). During winter months, riparian areas can be warmer than upland areas because they are not exposed to the winds more common in higher elevations (Swanson et al. 1982b). According to Swanson et al. (1982b), the riparian zone is "one of the best suited portions of the watershed for seasonally prolonged metabolic activity." Microclimate also influences water quality by helping regulate water temperature (Pollock and Kennard 1998).

Shade is another important function of riparian vegetation that influences water temperature. Water temperature is one of the most crucial environmental factors influencing salmon and other aquatic species. Most salmon have evolved to take advantage of temperature regimes in their home streams (Pauley et al. 1989). In general, salmon require cold water ranging in temperatures between 4° C and 17° C (39° F and 63° F) for spawning, incubation and rearing (Beauchamp et al. 1983; Pauley et al. 1986; Pauley et al. 1988; Pauley et al. 1989). Essentially all biological processes in salmon's life cycle are affected by water temperature including the timing of spawning, incubation and emergence from gravel, appetite, metabolic rate, development and growth rate, susceptibility to disease and parasites, timing of **smoltification** and ocean migration (Naiman et al. 1992; Spence et al. 1996).

Daily and seasonal water temperature are influenced by elevation, shade, streamflow, stream velocity, surface area, depth, undercut embankments, organic debris and the inflow of surface water and groundwater (Budd et al. 1987). Riparian vegetation moderates the amount of light reaching the stream channel by blocking or filtering solar radiation. The resulting shade helps to maintain cooler water temperature. The effectiveness of riparian vegetation in producing shade depends on the composition, height, and density of riparian vegetation, and the width of the stream channel and its orientation relative to solar angle (Gregory et al. 1991; Naiman et al. 1992; FEMAT 1993; Spence et al. 1996; Palone and Todd 1997; Kauffman et al. 2001). Riparian vegetation is less effective in providing shade and moderating stream temperature as streams increase in size. It has the greatest impact on headwater streams where it helps maintain temperature of surface water as well as shallow groundwater that feeds the stream. Although shading on larger rivers may have little or no influence on water temperature, overhanging riparian vegetation along the banks creates cooler microhabitat for fish and aquatic organisms (Palone and Todd 1997).

Bank stabilization and sediment control

Riparian vegetation provides bank stabilization and sediment control. Sediment delivered to streams and rivers originates from streambank erosion, from within the channel, from upland land use activities, and from natural disturbances (e.g., debris flows). Sediment occurs naturally in any stream, but changes in the **total sediment load** and particle size that exceed natural rates can have negative impacts on fish and other aquatic habitat (Beauchamp et al. 1983) (see *Impacts of Urbanization*).

Stable streambanks provide resistance to erosion. The root network of riparian vegetation increases resistance to erosion by anchoring soil and stabilizing the bank. Woody riparian species such as willow, alder and dogwood have a dense root network that is effective in protecting streambanks (Bureau of Land Management 1999). During periods of high water flow, streambanks are especially vulnerable to the erosive forces of water. The physical structure provided by riparian vegetation slows water, mechanically filters and stores fine silt and sediment, and holds materials in place (Swanson et al. 1982a; Gregory et al. 1991; Knutson and Naef 1997; Naiman and Decamps 1997). This process may also facilitate bank building as sediment is deposited on the streambank and floodplain, allowing the channel to narrow and deepen (Spence et al. 1996). Vegetative material also enters the system during high flows, contributing to the complexity of aquatic habitat.

Streams of all sizes benefit from the regulating influence that riparian vegetation has on the amount of sediment entering aquatic habitats. Riparian vegetation is especially important in headwater zones where many natural disturbances occur and where the cumulative effect of uninhibited sediment entry from many small streams can significantly impact larger downstream reaches (Knutson and Naef 1997). Unconstrained floodplains are important as sites for sediment retention (Kauffman et al. 2001).

Pollution control

Riparian vegetation can be effective in trapping excess nutrients, such as nitrogen and phosphorus found in fertilizers, and pollutants such as insecticides, herbicides and industrial chemicals carried in surface water runoff (see *Impacts of Urbanization*). Riparian vegetation functions as a nutrient filter by retaining sediment from overland flow (Spence et al. 1996; Knutson and Naef 1997; Naiman and Decamps 1997; Kauffman et al. 2001). Pollutants can be found in either the dissolved and particulate forms, although the particulate form is more common. The removal of fine sediment and organic matter also often removes a large percentage of pollutants (May 2000).

Riparian vegetation also takes up nutrients for plant growth from stream-adjacent soil solution and from stream water itself, as in the case of hydrophytic roots (adapted to grow in water). Plants store nutrients in the form of woody (long-term) and non-woody (short-term) plant material. Nutrients are released from dead organic matter by leaching and decomposition. Nutrient uptake also occurs during decomposition (Swanson et al. 1982a).

Microbial processes occurring in riparian areas may also reduce excess nutrients. These processes include immobilization of nutrients, denitrification of nitrate and degradation of organic pollutants (Palone and Todd 1997). Microorganisms take up or "immobilize" nutrients just as plants do, and these nutrients are re-released following the death and decomposition of microbial cells and are stored in soil organic matter. Denitrification is the process where anaerobic microoganisms (organisms that can live in the absence of oxygen) convert nitrate to nitrogen gas. Denitrification is a key nitrate removal mechanism in riparian areas (Naiman et al. 1992; Palone and Todd 1997). Degradation of organic pollutants occurs as microorganisms consume organic compounds as food sources (Palone and Todd 1997).

Streamflow moderation

Streamflow variability (i.e., volume and velocity) influences the structure and dynamics of stream ecosystems and creates a variety of habitats (e.g., deep pools, riffles, etc.) for salmonids and other aquatic organisms. Streamflow is the collection of direct precipitation and water that has moved over and through the landscape into the channel. As described in the ***Watershed Perspective*** section, the pathway water follows to reach the channel (i.e., surface water runoff vs. subsurface flow) affects the timing, quantity and quality of streamflow. In urbanized landscapes where surface water runoff, rather than infiltration, is the dominant pathway, increased peak storm flows and decreased summer flows to streams occur, both of which significantly degrade salmon habitat (Booth 1991; Schueler 1994; Booth and Jackson 1997; Morgan and Burton 1998; Karr et al. 2000; Booth et al. 2001). In addition, increases in the volume and velocity of surface water runoff often leads to increased frequency and magnitude of flooding (see *Impacts of Urbanization*).

Riparian and upland vegetation helps moderate streamflow by intercepting, absorbing and storing rainfall (Knutson and Naef 1997; Palone and Todd 1997). Streamflow can be affected by the abundance and distribution of riparian vegetation, which creates roughness that helps slow water movement to the stream. The roots of riparian plants increase soil porosity and promote water infiltration (Swanson et al.1982b; FISRWG 1998). Riparian-associated wetlands help moderate streamflow by reducing flood flows and the velocity of floodwaters. Wetlands are also important storage areas for flow, particularly during dry seasons, when they become a source of water to the stream (FEMAT 1993).

Healthy soils directly contribute to healthier water resources by storing water and nutrients, regulating the flow of water, and immobilizing and degrading pollutants (FISRWG 1998; Marx et al. 1999; Moses and Morris 2001). Soil is made up many components including inorganic mineral particles of various sizes (clay, silt and sand), organic matter in various stages of decomposition, and many species of living organisms. Healthy soils are vital in the establishment and nourishment of plants and provide habitat for millions of organisms. Areas with natural vegetation cover and leaf litter provide organic matter to the soil and usually have high infiltration rates (FISRWG 1998; Marx et al. 1999). Water that is stored in soil is slowly discharged to the stream through subsurface flow.

Soil quality is typically degraded along urban stream corridors where development activities often include removal of natural riparian vegetation, compaction of soil, and placement of fill (Marx et al. 1999; Moses and Morris 2001). Soil compaction reduces water infiltration and contributes to water runoff.

Organic matter input

Forest ecosystems adjacent to stream corridors provide over 99 percent of the energy and carbon sources in aquatic food webs (Budd et al. 1987). Riparian plant communities determine the quantity, quality, and timing of nutritional resources delivered to the stream channel (Swanson et al. 1982a; Gregory et al. 1991; Naiman and Decamps 1997). Leaves, fruit, cones, insects and other organic matter fall directly into the stream channel from the riparian area, or move by wind, erosion or as dissolved materials in subsurface water flowing from the hyporheic zone (Gregory et al. 1991; Naiman et al. 1992). Insects are an essential food source in the early stages in the salmon's life cycle (Cederholm et al. 2000). Fallen insects from riparian vegetation can make up 40 to 50 percent of the diet of trout and juvenile salmon during the summer months (Johnson and Ryba 1992).

Over 80 percent of the plant material input from deciduous riparian forests are leaves that are delivered to the stream over a six to eight week period during autumn. Cones and wood make up 40-50 percent of the material delivered from coniferous riparian forests (Naiman et al. 1992). Leaves from deciduous trees are high in nutrients and break down for processing in four to six months, whereas conifer needles may persist in streams for one to two years. Shrub and herb-dominated riparian communities also provide significant input to many streams (Gregory et al. 1991). These externally-derived materials are processed by detritivorous (shredders) insects that break down wood fragments, needles, leaves and other debris into smaller pieces.

The importance of salmon

In addition to organic material derived from adjacent riparian vegetation and from within the stream, many aquatic and terrestrial species rely on salmon eggs, fry, live adults and carcasses as a food source. Salmon were historically in many of the region's streams, and they still use certain streams as well as the mainstem Willamette River through downtown Portland. Salmon are a key link in biodiversity and productivity of Pacific Northwest streams, and forge a strong connection between aquatic and terrestrial ecosystems through nutrient cycling, as the following example illustrates (Cederholm et al. 2000; Cederholm et al. 2001).

Freshwater macroinvertebrates gain energy and mass by consuming algae, detritus, and bacteria. Every species of salmon fry rely on these spineless creatures (both aquatic and terrestrial) for food (Meehan 1996). The complexity of instream habitat and riparian vegetation increase the number and type of insects available to the tiny fish. The fish grow and some head out towards the Pacific Ocean, where they gather similar nutrients from the saltwater which will be carried back inland. Others are consumed by animals living in water and on land, cycling back into the nutrient pool.

The adult salmon, now ready to spawn, head back to their natal inland stream, where they lay millions of eggs. Many of the eggs are eaten by macroinvertebrates and other fish. A few make it to hatching, where they too are at risk of being eaten. Meanwhile, multitudes of adult fish have completed their life cycle and die in the stream, where they add nutrients that stimulate production of plants, algae and bacteria; are consumed by instream organisms, including salmon; or are consumed by seasonal congregations of wildlife such as Bald Eagles, river otter, gulls, merganser and black bear. A gull eats a salmon carcass, flies upslope and is taken by a Peregrine Falcon. The bear, having gorged on dead and live spawning salmon, moves upslope to eat huckleberries, where its excrement deposits salmon-based nutrients. Invertebrates opportunistically feed on all of these salmon products and disperse throughout the landscape. Animals are fed, soils are built, and plant communities grow.

Pacific Northwest ecosystems are adapted to enormous seasonal inputs of salmon eggs, fry and carcasses. Nearly 140 species of vertebrates have ecological relationships with, and 88 routinely interact with salmon (Cederholm et al. 2001). The significant reduction or loss of salmon in our streams causes a vast reduction in nutrients available in the water and on the land, with the potential to alter entire ecosystems. Salmon conservation will be necessary to recover and preserve the health and ecological integrity of the Pacific Northwest.

Large woody debris

Large woody debris (LWD), such as branches, logs, uprooted trees, and root wads, is an important component of aquatic habitats in the Pacific Northwest, both as a structural element and as cover from predators or protection from high streamflows. Large woody debris helps form channel features such as point bars, pools, riffles, runs, eddies, side channels, meanders, hydraulic complexity (e.g., variation in streamflow) and instream cover (e.g. overhanging vegetation, undercut banks) (Beschta 1979; Booth et al. 1997; Spence et al. 1996). Stream complexity is essential for salmon because at various life cycle stages they require different types of habitat. According to May et al. (1997b), LWD is the most important structural component to salmonid habitat.

Large woody debris also controls the routing of water and sediment, dissipates stream energy, protects streambanks, stabilizes streambeds, helps retain organic matter, and acts as a surface for biological activity (Swanson et al. 1982a; Harman et al. 1986; Bisson et al. 1997; Sedell et al. 1988; Bilby and Ward 1989; Gregory et al. 1991; Naiman et al. 1992; FEMAT 1993; Spence et al. 1996; May et al. 1997b). Large woody debris enters streams either directly from the adjacent riparian area or from hillslopes through a variety of mechanisms including toppling of dead trees, windthrow, debris avalanches, undercutting of streambanks and redistribution from upstream (FEMAT 1993; Spence et al. 1996; Naiman et al. 2000).

Over time, the influence of LWD may change, both in terms of its function and location within the watershed, but its overall importance is "significant and persistent" (May 2000). The characteristics of riparian vegetation determine the age, species, diversity, and size of the wood entering the stream, which in turn influences the persistence of LWD in the channel. For example, hardwoods decompose more quickly than conifers (Keim et al. 2000; Naiman et al. 2000). Conifers, therefore, have a greater ability to form and maintain structural features over time (Knutson and Naef 1997).

In steep headwater streams, large woody debris is generally located where it initially fell and is typically large enough to span the entire channel, affecting hydraulic processes by physically obstructing the streamflow and creating pools, riffles, rapids and waterfalls (Naiman et al. 1992). This results in less erosion to the streambed and banks, more sediment storage in the channel, and slower downstream movement of organic debris. By delaying transport of sediment downstream, rapid changes in sediment loading can be avoided (Swanson et al. 1982a; Bilby and Ward 1989; Naiman et al. 1992; Spence et al. 1996). The delayed transport of organic material downstream enhances its use as either a nutritional resource or habitat by aquatic organisms (Swanson et al. 1982a; Bilby and Ward 1989; Gregory et al. 1991). The ability of the stream to retain organic matter is enhanced when small woody debris, such as branches, sticks, and twigs accumulates, trapping leaves and other organic matter (Gregory et al. 1991).

Large woody debris becomes increasingly important in creating salmonid habitat in mid-section zones where it is a dominant channel-forming feature. In streams where LWD spans the width of the channel, it redirects the flow of water and alters water velocity, creating complexity and a number of pool types that are used by juvenile salmonids during summer (Beschta 1979; Naiman et al. 1992; Nickelson et al. 1992). Large woody debris in low-gradient zones is less of a channel-forming feature than in mid-section zones. In areas where LWD commonly accumulates, such as along outside bends of riverbanks and on upstream ends of islands, it influences meander cutoffs, provides cover for juvenile salmonids, and serves as habitat for invertebrate production (Naiman et al. 1992).

Riparian contributions to terrestrial habitat

Natural riparian areas are biologically diverse and complex ecosystems that contain more plant, mammal, bird, and amphibian species than the surrounding upland areas (Kauffman et al. 2001). Wildlife use riparian corridors more than any other type of habitat (Thomas et al. 1979). Riparian areas provide several functions important to wildlife, including:

- Food, cover and water

- Movement corridor
- Microclimate

Food, cover and water

Wildlife are attracted to riparian areas because of the abundance of food sources, cover, and proximity of drinking water. Access to water is critical for both riparian-dependent wildlife and for many upland species, especially in urban areas where access can be a limiting factor. Riparian areas are especially important areas during breeding season and provide wildlife with an energy-efficient habitat for rearing young due to the close proximity of food, water and cover, thereby minimizing energy expenditures by the adults and young.

The greater availability of water to plants in riparian areas increases plant biomass production, providing a complex and highly productive food web. Seeds, herbaceous vegetation and fruits, aquatic and terrestrial insects, and fungi are plentiful (Thomas et al. 1979; Mitchell 1998; Johnson and Ryba 1992). Riparian areas also provide predators with an abundance of prey species (Knutson and Naef 1997). In addition, spawning salmon and salmon carcasses also provide a seasonal high-energy food source to many wildlife species. A recent study conducted by Johnson et al. (cited by Cederholm et al. 2000) found that 137 species of birds, mammals, amphibians and reptiles common to Washington and Oregon consume salmon at one or more stages of a salmon's life cycle.

Riparian vegetation in the form of grasses, shrubs, trees and other plants provides wildlife habitat for reproduction, nesting, roosting, foraging and protection from the weather and from competitive and predatory species. Riparian areas often contain unique plant communities, both in composition and structural complexity (Kauffman et al. 2001; O'Neil et al. 2001). Structural complexity exists when there is a diversity of plant species, multiple canopy layers (e.g., deciduous vs. coniferous; shrubs vs. trees), and snags and downed woody material (Thomas et al. 1979; Knutson and Naef 1997; FISRWG 1998).

Many wildlife species are associated with specific plant communities; some require a certain age (e.g., old growth or pioneer species). Some species of invertebrates, birds and mammals rely on snags (standing dead trees) and downed and dead wood for a portion of their life history (see *Riparian Habitat Types And Species Associations*). Downed and dead woody material in various stages of decay provide diversity in the environment and are of varying significance for wildlife habitat (Thomas et al. 1979). Much of the biodiversity and productivity of the riparian area would disappear without this woody debris accumulation (Naiman et al. 1992).

The linear nature of riparian areas maximizes the development of edge habitat, an area where two different plant communities, successional stages, or vegetative conditions meet (Thomas et al. 1979). Some species benefit from the availability of edge habitat because edges contain plant communities that are characteristics to each adjoining habitat (Knutson and Naef 1997). Although edge habitat can promote high wildlife diversity, it can also have a negative impact on some species associated with interior portions of the riparian area (see *Impacts of Urbanization* section).

Movement corridors

Many wildlife populations rely on their ability to move between different types of habitat along riparian corridors, especially for species that would not otherwise cross large openings (Palone and Todd 1997). Riparian corridors, because of their linear shape, enable movement of wildlife between habitat patches (Thomas et al. 1979; Beier and Noss 1998; Palone and Todd 1997). Dispersal and establishment of new territories for feeding and breeding is important for many species. This allows for an exchange of genetic material between species populations and is critical for resilience to disease and other negative impacts (Cohen 1997). At least 95 percent of all terrestrial species in North America depend on corridors (Cohen 1997).

Riparian corridors also play a potentially important role within landscapes as corridors for plant dispersal and, according to Gregory et al. (1991), may be an important source of most colonists through the landscape.

Microclimate

Riparian and upland vegetation create a microclimate in riparian areas as described in *Riparian Contributions to Aquatic Habitat.* The microclimate of riparian areas is generally more moist and mild (cooler in summer and warmer in winter) than the surrounding area (Knutson and Naef 1997). This creates diverse habitat characteristics that are desirable to many species, particularly for amphibians year-round and for ungulates and other large mammals during hot, dry summers and severe winters (Knutson and Naef 1997).

The importance of seasonal streams and wetlands

Some reviewers question why Metro included seasonal water sources, such intermittent streams and wet-season wetlands, in the riparian corridor inventory. Extensive empirical evidence indicates that these habitats should be included as vital components of the region's natural resource inventories. Seasonal streams and wetlands exert important ecological controls on riparian ecosystems, support unique wildlife communities and greatly increase wetland and water connectivity. These functions are likely to profoundly influence aquatic ecosystems and wildlife.

Control and mediation of ecological processes

Seasonal streams and wetlands exert important ecological controls that influence wildlife by moderating hydrology and downstream inputs including water, nutrients, and sediments.

Seasonal wetlands. Seasonal wetlands moderate hydrology and reduce flooding by providing surface water storage, flood desynchronization, groundwater recharge and discharge, and shoreline stabilization (Winter 1988; FEMAT 1993; Hicks and Larson 1997). Wetlands also protect instream habitat by maintaining stream base flows via temporary surface water storage during storm events and groundwater recharge. Thus seasonal wetlands help maintain natural hydrologic parameters and, therefore, channel conditions (Richter and Ostergaard 1999).

Seasonal wetlands produce substantial amounts of plant materials, and also process a variable but important amount of organic matter produced elsewhere. This large amount of organic material provides the foundation of the food web; behind that follows invertebrates, amphibians, reptiles, birds and mammals (Harris 1988; FEMAT 1993). In New York, researchers compared four different wetland types ranging from temporary to permanent, and found that all demonstrated extensive nutrient cycling; rather than period of inundation, they found that hydrology and organic matter controlled nutrient uptake and processing (Groffman et al. 1996). Researchers in Massachusetts and Rhode Island found similar results (Duncan and Groffman 1994).

Seasonal wetlands improve water quality by removing excess nutrients, sediments, and chemical contaminants (FEMAT 1993; Hicks and Larson 1997; Whigham 1999; Thompson-Roberts and Pick 2000). Wetlands trap sediments and prevent them from silting streambeds (Braskerud 2002). This is important not only for maintaining instream habitat such as riffle-pool sequences, but also because nutrients such as phosphorus, heavy metals and other toxins typically bind to soil particles, and wetland storage prevents eroded soil particles from entering streams (Moore et al. 2000; Cooper and Gillespie 2001). Wetlands have excellent potential for denitrification and phosphorus removal (Zurayk et al. 1997; Kang et al. 1998; Tanner 2001; Dierberg et al. 2002). For example, seasonal alder-dominated wetlands in California removed substantial amounts of nitrogen and phosphorus (Busse and Gunter 2002). In North Carolina, wetlands removed 80% of nitrogen, 91% of sediment, and 59% of total phosphorus inputs during a storm event (Kao and Wu 2001).

Seasonal streams. Small headwater streams often comprise up to 85% of total stream length within a drainage network and collect most of the water and dissolved nutrients from adjacent terrestrial ecosystems (Harr 1976; Peterson et al. 2001; Meyer et al. 2003). Small and often ephemeral headwater streams are critical determinants of the integrity of downstream water and habitat quality (Vannote et al. 1980; Swanson et al. 1982b; Naiman et al. 1992). Headwater streams throughout North America exert control over nutrient exports to rivers, lakes, and estuaries (Peterson et al. 2001), and largely establish the basic chemical composition of unpolluted streams draining a landscape (Meyer et al. 2001). For example, the most rapid uptake of inorganic nitrogen occurs in the smallest headwater streams (Peterson et al. 2001).

In their natural state ephemeral streams typically contain dense growth and numerous debris dams that trap sediments, slow flow, and provide important habitat structure and sites for metabolic activity (May et al. 1997a; Meyer et al. 2001). The result is reduced flooding and less "flashiness" downstream – that is, the storm hydrograph peak is lower and water duration is longer. Thus more water is available over a longer period to grow riparian vegetation and maintain stable streams; instream and near-stream habitats remain more capable of supporting native wildlife when seasonal streams are protected.

Wildlife use of seasonal water resources. Seasonal water resources provide water, food sources and predator protection during critical life-history phases for many wildlife species, including amphibians, reptiles, birds and macroinvertebrates.

Seasonal wetlands. Seasonal wetlands provide critical amphibian habitat. Many amphibians migrate to ephemeral wetlands for breeding (Pechmann et al. 2001). Permanent wetland amphibian communities differ from those found in temporary wetlands (Snodgrass et al. 2000; Pechmann et al. 2001), probably relating to species' natural history requirements as well as predator influences. Researchers throughout the US have found that introduced fish or bullfrogs, which are associated with permanent wetlands, adversely affect native amphibian populations

(Lawler et al. 1999; Kupferberg 1997; Richter 1997; Kiesecker and Blaustein 1998; Zampela and Bunnell 2000). In the Puget Sound Lowlands ecoregion, Red-legged frog occurrence was negatively associated with the presence of exotic fish, and the spread of exotics was correlated with a shift toward greater permanence in wetland habitats regionally (Adams 1999). In addition, Red-legged frog and Pacific treefrog larvae experienced lower survival in permanent than in seasonal wetlands (Adams 2000). In the Puget Sound, Richter and Azous (1995) found that high amphibian species richness was related to low velocity flow and low water fluctuation, but not to seasonal persistence of water; although altered hydrology negatively impacted amphibians, species richness did not depend on whether the wetland was seasonal or permanent. Snodgrass et al. (2000) found no relationship between amphibian species richness and wetland size or seasonality, but found that seasonal wetlands support a unique group of species. "Short-hydroperiod wetlands," state the researchers, "are important in maintaining biological diversity across a landscape because they are likely to support species not found in longer-hydroperiod wetlands." Semlitsch (2000) commented that the loss of small, temporary wetlands may be especially harmful to amphibians because of their abundance and high species diversity in those habitats.

Seasonal wetlands are also very important to turtles, birds and the invertebrates that feed them. Western Pond Turtles regularly use seasonal wetlands (Hays et al. 1999). Overwintering Coho salmon use seasonal wetlands as off-channel rearing habitat (Richter and Ostergaard 1999). In northern California, Mallards preferentially selected seasonally flooded wetlands for brood-rearing and experienced higher fledging success than in permanent wetlands (Mauser et al. 1994). Shorebirds and waterfowl use seasonal wetlands for foraging; wintering waterfowl obtain a significant portion of nutrient reserves used for reproduction from macroinvertebrates during the overwintering period (Mauser et al. 1994; de Szalay and Resh 1997; de Szalay and Resh 2000; Isola et al. 2000). Given that the majority of waterfowl species in the Portland metro region use the region's wetlands for overwintering and migratory stopover (see Metro's Vertebrate Species List), seasonal wetlands in our urban region may be key to these species' reproductive success elsewhere.

Part of the importance of these wetlands is their rich invertebrate communities. Invertebrate communities are quickly established after flooding, with highly variable composition and abundance of species assemblages adding to biological diversity and food resources for other wildlife. Invertebrates are a foundation of riparian food webs, comprising significant portions of the nutritional requirements of amphibians, birds and small mammals (de Szalay and Resh 1997; Richter and Wisseman 1997). Invertebrates in seasonally flooded wetlands can produce a greater biomass of aquatic invertebrates than permanent wetlands – that is, they sometimes actually produce more pounds of invertebrates per unit area, per year compared to permanently flooded wetlands (Mauser et al. 1994).

Wetland preservation and mitigation programs across the country have typically focused on permanent wetlands, often assuming that bigger is better (Richter and Azous 1995; Snodgrass et al. 2000). Smaller, seasonal wetlands are generally afforded less (or no) protection by federal or state agencies (Whigham 1999; Naugle et al. 2001). Whigham (1999) states:

> "The most striking weakness in the current national wetlands policy is the lack of protection for 'dry-end' wetlands that are often the focus of debate for what is and what is not a wetland. From an ecological

> perspective, dry-end wetlands such as isolated seasonal wetland and riparian wetlands associated with first order streams may be the most important landscape elements. They often support a high biodiversity and they are impacted by human activities more than other types of wetlands...they may be more valuable than other types of wetlands because of important landscape and biodiversity functions that they perform."

Seasonal streams. Empirical evidence also clearly points to the importance of seasonal streams to wildlife. The Northwest Forest Plan, which provides protection for seasonal, or intermittent, streams, defines intermittent streams as "...any nonpermanent flowing drainage feature having a definable channel and evidence of annual scour or deposition" (Waters et al. 2001). Headwaters are typically intermittent, and comprise a high proportion of all intermittent streams in a drainage (Labbe and Fausch 2000; Peterson et al. 2001). Meyer et al. (2001) comment that headwater streams provide unique habitats for numerous species, and that their degradation and elimination from the landscape increases extinction vulnerability for aquatic invertebrate, amphibian, and fish species.

In the Pacific Northwest, juvenile Chinook salmon rely on intermittent streams for rearing habitat (Maslin et al. 1999). In Colorado, Labbe and Fausch (2000) found that the dynamics of intermittent streams exert important, multi-scale controls on a threatened fish population. In order of increasing spatial scale the key variables relating to the threatened fish were pools; temperature regime; flow variability and seasonality; and predation by nonnative fish. The importance of different variables at different spatial scales suggests that the entire system of intermittent streams is important to the species' survival.

Amphibians comprise the majority of vertebrates in western Oregon headwater streams, and are more abundant in streams with rocky substrate and wide forested buffers (Stoddard and Hayes 2004). Forest loss plus impervious surfaces alter hydrology, and altered hydrology typically causes streams to lose their rocky substrate. This implies that amphibians are at risk in urban areas, where damaged streams have narrow buffers and muddy bottoms. In western Oregon, Corn and Bury (1989) found that small headwater streams harbor significant amphibian communities, and that removal of vegetation has a long-lasting negative effect on all species.

In northwestern California, Waters et al. (2001) found significant differences between vegetation along intermittent streams and upland vegetation, with many more herbaceous species along the intermittent stream channels. They also found that a variety of riparian- and upland-associated vertebrate species relying on intermittent streams, including a number of species known to inhabit the Portland metro region. Also in northwestern California, Seidman and Zabel (2001) found significantly increased bat foraging activity along intermittent streams compared to upland sites. Bats eat flying insects, therefore the implication is a substantial increase in flying insects along intermittent streams compared to uplands. In Arkansas, Townsend's big-eared bats (which occur in the Portland metro region and are on the state Sensitive Species List, critical category) preferentially used intermittent streams for foraging during the breeding season (Clark et al. 1993). In South Dakota, Wood ducks regularly used emergent vegetation along intermittent streams for breeding areas (Granfors and Flake 1999).

Seasonal streams provide habitat for surprisingly diverse, sometimes unique macroinvertebrate communities (Bottorff et al. 1990; Gagen et al. 1998; de Szalay and Resh 2000; Euliss et al. 2001). Alabama researchers found little difference between invertebrate communities when comparing intermittent and perennial streams (Feminella 1996). In northern California streams, the subsurface macroinvertebrate communities for both perennial and intermittent streams had high density and taxa richness during the dryest summer months (del Rosario and Resh 2001). In coastal British Columbia headwater streams, researchers found that even the smallest streams with intermittent flow harbored true aquatic insects with 1-year life cycles, even during periods with no detectable flow (Muchow and Richardson 2000). There was no difference in macroinvertebrate species richness between intermittent and perennial streams, but intermittent streams produced as much as twice the number of adult stoneflies as continuous streams. Thus, intermittent streams may provide an ongoing source of riparian insects to other wildlife living near them, even when the streams are apparently dry.

However, headwater streams currently receive little protection at the national scale and as a result, many areas (including the Portland metro region) have experienced very substantial reductions in drainage density. Meyer et al. (2001) state, "This loss of headwater streams has profoundly altered the structure and function of stream networks, just as eliminating fine roots from the root structure of a tree would reduce its changes of survival."

Landscape-scale connectivity. Seasonal streams and wetlands add important connectivity to landscape-scale wetland assemblages and to the entire watershed (Semlitsch 2000). This hydrologic connectivity extends longitudinally from upper watershed reaches to downstream areas; laterally from stream channels to wetlands; and vertically to groundwater. Loss of hydrologic connectivity disrupts water-mediated transfer of matter, energy, and organisms within or between elements of the hydrologic cycle (Pringle 2001). Gibbs (1993) simulated loss of small, seasonal, unprotected wetlands and estimated an average increase in between-wetland distance of 67%, even though total wetland area would only decrease by approximately 19%. Thus, the loss of small wetlands across a landscape can have a disproportionately large effect on wetland connectivity.

Amphibians rely on wetland connectivity. For example, most Puget Sound amphibians migrate and disperse during wet conditions (December through May), when seasonal wetlands are likely to be present and providing important connectivity (Richter 1997). Studies in Minnesota demonstrate reduced amphibian species richness with greater wetland isolation at all spatial scales (Lehtinen et al. 1999; Lehtinen and Galatowitsch 2001). Salamanders are capable of moving several hundred meters per day (Richardson and Neill 1998; Semlitsch 1998); existing seasonal wetlands in the Portland metro region probably provide key connectivity during spring amphibian breeding and movement periods. Richter and Azous (1995) suggest that steps to prevent isolation of wetlands within the urban landscape will reduce losses of amphibian species.

Waterfowl also rely on the presence of small connecting wetlands. In the Prairie Pothole region of South Dakota, small seasonal wetlands were shown to influence habitat suitability of larger wetlands, with more waterfowl species in areas that were less fragmented by removal of such wetlands (Naugle et al. 2001). Partial loss of wetlands can have a dramatic negative impact on nesting birds (Weller 1988). Research in the Lower Klamath National Wildlife Refuge showed that Mallards prefer seasonally flooded wetlands for breeding, and suggested that survival of newly hatched ducklings was negatively impacted by reduced wetland connectivity (Mauser et al. 1994).

Thus it appears that these small, often seasonal streams and wetlands are key to maintaining or increasing regional biodiversity because they provide water resources, feeding areas rich with macroinvertebrates, and connectivity during critical life-history stages for many species. Large-scale retention of these resources may help prevent local, and ultimately regional, species extirpations.

In summary, seasonal streams and wetlands provide unique and critical ecological services that strongly influence hydrology, water quality, connectivity, and therefore, vegetation and wildlife communities. Their cumulative influence on the region's watershed health is profound. Empirical research offers compelling reasons to include seasonal water sources as part of the riparian corridor and as unique and important wildlife habitat. The entire stream/wetland network functions as a system, and severing the connection between intermittent and perennial water sources will compromise the long-term physical and biological integrity of the region's ecosystems.

Riparian habitat types and species associations

We have described, in general terms, the natural disturbance regime and the geomorphology, hydrology, and vegetative interactions that make riparian areas so biologically rich and variable. In this section we describe the riparian habitat types found in the Metro region and the wildlife species associated with them.

Each type of habitat is unique in terms of the specific functions and values it provides to wildlife. In turn, each wildlife species has its own set of requirements, thus different habitats and structural conditions are important to different species. To gain a better understanding of how wildlife in the Metro region uses various habitats, Metro compiled a list of all vertebrate species (Metro's Species List, Appendix 1) and their associations with habitat types and structural conditions that occur in the region. The following sections describe the number of species associated with each habitat type, and Table 1 provides an overview of riparian habitat use by wildlife in the region. The end of this section describes specific at-risk or extraordinarily valuable habitat areas, known as Habitats of Concern.

Table 1. Analysis of the importance of the three water-associated habitats (riparian, wetlands, and open water) for each major group of animals (29 total existing native species; based on Metro's Species List, Appendix 1).

Group	# Native Species	Riparian Dependent	Uses Riparian	Total % Using Riparian
Amphibians	16	11 species 69%	4 species 25%	15 species 94%
Reptiles	13	3 species 23%	6 species 46%	9 species 69%
Birds	209	103 species 49%	96 species 46%	198 species 95%
Mammals	54	15 species 28%	34 species 64%	49 species 91%
TOTAL	292	132 species 45%	140 species 48%	271 species 93%

Note: Fish were excluded because they are 100 percent water-associated. "Riparian Dependent" species are closely associated with at least one of the three habitats; "Uses Riparian" species are generally associated with or known to use at least one of the three habitats. Habitat types and species-habitat associations are based on Johnson and O'Neil's (2001) classification system.

Habitat classification scheme

To provide a general description of habitats in the Metro region we selected the habitat classification system described in *Wildlife-Habitat Relationships in Oregon and Washington* (Johnson and O'Neil 2001). Based on wildlife in our region, the book provides species-habitat relationships and cross-references other widely used habitat classification systems. Johnson and O'Neil (2001) describe wildlife habitat as a concept related to a particular wildlife species. Specifically, **habitat** is "an area with the combination of the necessary resources (e.g., food, cover, water) and environmental conditions (temperature, precipitation, presence or absence of predators and competitors) that promotes occupancy by individuals of a given species (or population), and allows those individuals to survive and reproduce" (Johnson and O'Neil 2001). This habitat scheme is provided as a tool to describe habitats and their relationships with species; Metro is not committed to the sole use of this scheme and will use other systems if they are deemed more appropriate. We have included Johnson and O'Neil's cross-references to other well-known schemes for water-associated habitats.

The broadest classification within this scheme is Habitat Type (e.g., Westside Lowlands Conifer-Hardwood Forest, Urban, etc.). There are five upland and three water-associated habitats (including riparian forest) in the Metro region. Each habitat type can be subdivided into structural conditions. For example, forested habitat structural conditions are based on average tree diameter at breast height (dbh), percent canopy cover, and number of canopy layers in the forest (described below). This yields 26 possible structural conditions within each of three forest types, or a total of 78 potential forest/structure combinations. Shrubland and grassland (grasslands have less than 10 percent shrubs) structural conditions include 20 possibilities. Agricultural lands may be cultivated cropland, improved pasture, orchards/vineyards/nursery, modified grasslands, or unimproved pasture. Urban habitats are divided into three categories based on urbanization intensity.

Habitat types and structural conditions constitute the level of detail in this paper, addressed through habitat descriptions and Metro's Species List (Appendix 1). The habitat types are sufficiently broad categories to be feasible in large-scale land use planning. Structural conditions provide a wide variety of finer level descriptions of conditions within each habitat type, and these may be useful for future on-the-ground habitat and species conservation, as well as an aid to determine restoration goals and priorities.

The utility of Johnson and O'Neil's habitat scheme is greatly enhanced by species-habitat/structural relationships for all species in the Metro region except fish. Johnson and O'Neil provide further information on what they term "Habitat Elements," those components of the environment believed to most influence wildlife species' distribution and success. Habitat Elements include attributes such as downed wood and leaf litter, shrub layers within forest stands, fungi, and snags (including decay classes for downed wood and snags); Johnson and O'Neil relate each vertebrate species to this level of detail. Thus, within the context of Johnson and O'Neil's habitat classification scheme, the full complement of wildlife habitats (we only address the first two here) would include:

Wildlife Habitats = Habitat Type(s) + Structural Condition(s) + Habitat Element(s)

Below we describe habitat types and each major group of associated species, based on the scientific literature. Upland habitat and wildlife descriptions are based on the same system and follow a similar format, but are discussed in the ***Upland Habitat*** section. Plant species that typically dominate each habitat type are listed in Johnson and O'Neil (2001). Other habitat classification schemes for riparian may also provide useful or more detailed approaches (e.g., Franklin and Dyrness 1973; Cowardin et al. 1979; Diaz and Mellen 1996; U.S. Fish and Wildlife Service 1997b; Adamus 1998).

Open water (lakes, rivers and streams)

This habitat type, including ponds and reservoirs, is widely distributed in the Metro area and contains four distinct zones: (1) the **littoral zone** is at the edge of lakes and is the most productive of the zones, with diverse aquatic beds and attached emergent wetlands (part of Herbaceous Wetland habitat). (2) The **limnetic zone** is deep open water dominated by **phytoplankton** and freshwater fish, extending to the limits of light penetration. (3) The **profundal zone** is below limnetic zone, and is devoid of plant life and dominated by **detritivores**. (4) The **benthic zone** includes bottom soil and sediments. Ponds and lakes are typically adjacent to Herbaceous Wetlands, while streams and rivers are often adjacent to Westside riparian wetlands or Herbaceous wetlands. Streams and rivers in the Willamette Valley are productive and typically contain high species diversity (Johnson and O'Neil 2001).

This habitat is called riverine and lacustrine in Anderson et al. (1998), Cowardin et al. (1977), Washington Gap Analysis Project (Cassidy 1997), Mayer and Laudenslayer (1988), and Wetzel (1983). However, this habitat is referred to as Open Water in the Oregon Gap II Project (Killsgaard 1999) and Oregon Vegetation Landscape-level Cover Types (Killsgaard and Barrett 1998).

Flooding is a major natural disturbance in these systems. In the Willamette Valley, floods are influenced by precipitation (rather than snowmelt runoff) and thus tend to be short duration events, although their influence on this habitat is profound. Seasonal and decadal trends in precipitation also influence water habitats. In the Metro region beavers played a historic role in creating many ponds and marshes, and are still present in reduced numbers. Human disturbances that negatively influence this habitat type include hydrologic changes, excess nutrient inputs, toxins, loss of habitat and water quality and quantity, and others (see *Impacts of urbanization*). Non-native species, including plants, fish and mollusks, pose a major threat to native organisms in this habitat. Management activities that would improve this habitat include planting and/or retaining vegetative buffers along streams to reduce toxins and sediments, reducing pollutant sources, managing stormwater and maintaining or restoring natural flow regimes, and decreasing impervious surfaces (particularly in close proximity to the stream).

Water is clearly an important resource in the Metro region, and a large number of **species at risk** depend on this habitat. Seventy-five Metro region vertebrate species, excluding fish (which are all dependent on this habitat), are closely associated with Open water habitats, second only to Herbaceous wetlands. Ten non-fish vertebrate species closely associated with this habitat are state- or federally-listed species at risk, plus two Canada Goose subspecies and two **extirpated** species. Twenty native fish species or subspecies are at risk (Appendix 1).

Herbaceous wetlands

Herbaceous wetlands are declining locally and nationally. These wetlands (including marshes, and wet sedge meadows) are sometimes termed "freshwater aquatic beds," "emergent wetlands," or "palustrine" habitats. Herbaceous wetlands are permanently, semi-permanently, or seasonally flooded. Patches of this habitat may be found adjacent to all habitats discussed in this section, although most frequently in valley bottoms and high rainfall areas such as the Willamette Valley. These wetlands occur in flat terrain and are typically, but not always, associated with a stream, river channel, or open water. In Willamette Valley riparian corridors, this habitat commonly forms a pattern with Westside riparian-wetlands habitats. Johnson and O'Neil do not make it clear whether springs, seeps and vernal wetlands are included, but our intention is that they be included in this habitat type.

In their widely used wetlands classification system, Cowardin et al. (1979) classify this habitat type as palustrine emergent wetlands. The Oregon Gap II Project (Killsgaard 1999) and Oregon Vegetation Landscape-Level Cover Types (Killsgaard and Barrett 1998) that would represent this type are wet meadow, palustrine emergent, and National Wetland Inventory (NWI) palustrine shrubland.

Herbaceous wetlands include a mixture of emergent herbaceous and grass-like plants, and may include floating or rooting aquatic forbs. A variety of hydrologic regimes limit or exclude woody plant invasion, but in drier areas of the Willamette Valley fire suppression can lead to invasion by Oregon Ash. As with other aquatic habitats, beavers play an important disturbance role in creating and maintaining this habitat. Direct alteration of hydrology (stormwater inputs, channeling, draining and damming) or indirect alteration (road building, vegetation removal, beaver removal) alter the amount and patterns of this habitat.

Excluding fish, 79 vertebrate species in the Metro region are closely associated with this habitat, more than any other habitat. Of these, seven are state or federal at-risk species, plus another two Canada Goose subspecies and one extirpated species. This habitat type also provides important off-channel habitat to salmonids.

Westside riparian-wetlands

Westside riparian-wetlands are patchily distributed along streams and water bodies in lowlands and foothills of the Willamette Valley, and have declined significantly through conversion to urban and agriculture land covers. This habitat often occurs as patches or linear strips within Westside lowlands conifer-hardwood habitats, although Urban and mixed environs is another common habitat within which Westside riparian-wetlands are nested. Herbaceous wetlands and Open water habitats are often nearby. In natural conditions large woody debris is abundant, but tree removal reduces woody debris inputs to terrestrial and aquatic systems.

This habitat includes all palustrine, forested wetlands and scrub-shrub wetlands at lower elevations on the westside, but drier portions of this habitat in riparian floodplains may not qualify as wetlands according to Cowardin's (1979) definition. Much of this habitat is probably not mapped as distinct habitat types by the Gap projects due to the relatively small scale on the landscape and difficulty of distinguishing forested wetlands (Johnson and O'Neil 2001). A portion of this habitat is mapped as the Oregon Gap II Project (Killsgaard 1999) and Oregon Vegetation Landscape-Level Cover Types westside cottonwood riparian gallery, palustrine forest, palustrine shrubland, NWI (National Wetland Inventory) palustrine emergent, and alder/cottonwood riparian gallery (Killsgaard and Barrett 1998).

Riparian plant communities in the Pacific Northwest typically include scattered patches of grasses and herbs on exposed portions of the active channel, with mosaics of herbs, shrubs and deciduous trees in the floodplain (Gregory et al. 1991). Conifers may dominate where surfaces have been stable for long periods of time, such as on old floodplain benches or along lower hillslopes. Forested riparian habitats contain much greater plant volume than non-forested habitats, and quantity and composition of the plants growing along water exert strong influences on animals living in the water and on the land. Much of this remaining habitat in the Metro region is degraded due to human-induced changes in hydrologic and nutrient cycles, but it is nonetheless of primary importance to wildlife in the region.

Riparian habitats are naturally dynamic, formed and regulated to a large extent by natural disturbance regimes. Flood frequency and intensity varies considerably with natural hydrologic regime and geomorphology. Other natural disturbance agents include debris flows, tree windthrow, beavers, and grazing by wild herbivores. Human changes to vegetation along waterways, as well as the addition of impervious surfaces, alter hydrology and otherwise modify this habitat (see *Impacts of urbanization*). Reed canarygrass is an abundant non-native invader in this habitat, along with other non-natives.

This valuable wildlife habitat has more closely associated species (64, excluding fish) than any other terrestrial habitat type, including many amphibians and birds. Eleven of these are species at risk in Oregon and/or nationally; two more are now extirpated from this region. The native turtles appear particularly vulnerable to habitat loss, degradation, fragmentation, and pressure by non-native turtles and bullfrogs (bullfrogs eat young turtles) (Adams 1999; Adams 2000).

Special Habitats of Concern

The Goal 5 Rule for Wildlife Habitat 660-23-110 (2) states that:

> "...local governments shall obtain current habitat inventory information from ODFW and other state and federal agencies. These inventories shall include at least the following: (a) Threatened, endangered, and sensitive wildlife species habitat information;(b) Sensitive bird site inventories; and (c) Wildlife species of concern and/or habitats of concern identified and mapped by ODFW..."

Habitats of Concern and areas vital to sensitive, threatened, or endangered animal or plant communities are an important component of a regional wildlife inventory. Habitats of Concern may include both riparian and upland habitats. A Habitat of Concern is a unique or unusually important wildlife habitat area, described as follows:

- **Priority conservation habitats.** ODFW identifies grasslands, deciduous oak and riparian forests, aquatic habitats, and urban natural area corridors as the top four Willamette Valley habitats at risk. The Oregon Biodiversity Project, in which ODFW and USFWS are partners, identifies native prairie grasslands, oak habitats, wetlands, and bottomland hardwood forest as conservation priorities in the Willamette Valley. The Oregon-Washington chapter of Partners in Flight (ODFW and USFWS are partners) considers grassland-savanna, oak woodland, and riparian forests to be priority conservation habitats. From these sources we conclude that native oak habitats, native grasslands, wetlands, and bottomland hardwood forests are priority conservation habitats. Less than one percent of historic Willamette Valley native oak and grassland habitats still exists. Over 70 percent of the bottomland hardwood forests have been lost. In the Willamette Valley, various sources document wetland losses between 40-57 percent of original, with continuing losses of more than 500 wetland acres per year.

- **Riverine islands and deltas.** Riverine islands and deltas provide unique habitat for shorebirds, waterfowl, nesting terns and gulls, and other wildlife through enriched food resources, sand and mudflats, and protection from predators and disturbance. Macroinvertebrate communities are denser and more diverse around river islands and deltas. Bald eagles winter, breed, and forage on islands in our area. Channel complexity and large wood, which are linked to island formation, have been substantially reduced from historic levels.

- **Habitat patches providing unique or critical wildlife functions.** Patches providing unique or critical wildlife functions should be considered on a site-by-site basis. Such habitats include migration corridors or stopover areas such as grassy hilltops, inter-patch connectors, biologically or geologically unique areas such as rocky outcrops or talus slopes important to many herptiles and bats. Habitat vital for a sensitive species or habitats that support at-risk plants fall into this category.

Impacts of urbanization

Aquatic habitats in urban and urbanizing areas of the Pacific Northwest are the most highly altered of any land use types (R2 Resource Consultants 1996). Habitat loss, alteration, and significant increases in the amount of impervious land cover characterize the Metro region. The

Metro region has lost approximately 400 miles of streams (about 30 percent of the original) (Metro 1997a). In addition, 213 miles are listed by the Department of Environmental Quality as water-quality limited (Oregon Department of Environmental Quality 1996). Ninety-six percent of the land in the Willamette basin under 500 feet in elevation is privately owned and has been converted to agricultural or urban use (Willamette Urban Watershed Network 2000). A recent study of tree cover in the Willamette/Lower Columbia Region found a reduction in tree canopy cover from 46 percent in 1972 to 24 percent at present (American Forests 2001). Average tree cover in the region's urban areas is only 12 percent, down from nearly 21 percent in 1972. Eleven percent of the Metro region's natural areas were lost between 1989-1999, with accompanying adverse effects on watershed hydrology and wildlife habitat. Groundwater volume is also declining (McFarland and Morgan 1996).

A relatively large body of scientific literature documents effects due to urbanization that are similar regardless of study area, and some of these studies are summarized in Appendix 2. Most of urbanization's adverse impacts originate from changes in the amount and timing of water runoff, loss of natural vegetation, or both. Often changes in one result in changes in the other.

Relevance of science in rural forested landscapes to urban systems

Urban ecology is a relatively new scientific field. The question arises as to whether the use of scientific data from non-urban ecosystems (e.g., natural forested habitats) is appropriate in an urban setting, where conditions are significantly different from relatively undisturbed systems. The City of Portland raised this issue to their peer review science panel (City of Portland 2000); reviewers concluded that applying science developed within non-urban forested settings was appropriate in urban habitats, provided that urban research was incorporated as available.

However, urban research is sparse. Scientists know a fair amount about impacts of urbanization on waterways and fish, but resulting ecosystem changes and the cascading effects on other wildlife species and habitats may be subtle and complex. Also, unlike naturally forested ecosystems, in urban ecosystems the removal of vegetation and other consequences to riparian and aquatic habitats are often permanent (Booth 1991).

Nonetheless, all of the natural structures, functions and processes occurring in non-urban settings also occur, mediated by human activities, in urban ecosystems. For example, the discussion of impervious surfaces below was founded on knowledge of the natural hydrologic cycle, augmented by regionally specific urban research. The concept of habitat simplification leading to simplified wildlife communities is well understood in non-urban settings, and can be applied to urban ecology. The impacts of nonnative species on native wildlife relate to competition, predation, and changes in **trophic** levels; these foundations in community ecology are not unique to urban environs. Thus scientific research conducted outside urban systems provides a theoretical framework for urban research, as well as providing **reference conditions** against which the differences between relatively undisturbed and human-altered systems can be compared.

Cumulative impacts

It is critical to recognize the cumulative nature of human impacts within a watershed. Watershed condition is a result of the cumulative effects of past and present human activities (May and Horner 2000). The Oregon Watershed Assessment Manual describes this effect (Watershed Professionals Network 1999):

> Cumulative effects can be defined as the changes to the environment caused by the interaction of natural ecosystem processes with the effects of land use and other human activities distributed through time and over the landscape...Individual actions that by themselves are relatively minor may impact resources when combined with other modifications that have occurred in the watershed. The current habitat condition at any location in a stream is a function of the watershed activities that currently occur upslope and upstream, added to the effect of historical activities. For example, in a typical managed forest, historical streamside timber harvest combined with stream cleaning, splash damming, and use of streams as transportation corridors have resulted in a legacy of low LWD frequency. Downstream in an agricultural area, streams were often channelized and riparian forests were removed. These historical changes combined with present-day expansion of suburban areas, for example, resulted in altered channel conditions throughout the watershed. (page 37)

Thus, accounting for cumulative effects remains one of the greatest challenges for managing wildlife habitats in an urban setting. A local example of cumulative effects follows.

The portion of the Willamette River running through the Metro region is influenced not only by the intensity of urbanization within its own watersheds, but also by the cumulative effects from land use and activities upstream. In December 2000, the Portland Harbor was listed as an EPA Superfund Site (U.S. Environmental Protection Agency 2001a). This six-mile reach of the Willamette River between the southern tip of Sauvie Island and Swan Island exemplifies the difficulties in balancing environmental and economic concerns. The harbor is an international commerce and industry portal contributing substantially to the regional economy, but it also provides a critical migratory corridor and rearing habitat for endangered salmonids and other wildlife (U.S. Environmental Protection Agency 2001a). Industrial facilities line the banks on both sides of the river, private and municipal wastewater outfalls add effluent, and sediments and toxins are input from upstream tributaries. Sediments in this reach of the Willamette contain high levels of many contaminants, including PCBs, heavy metals, arsenic, petroleum hydrocarbons, and pesticides such as DDT. A *Remedial Investigation and Feasibility Study* is the next step, designed to determine how much contamination is present, its location and extent, related threats to the public, and potential cleanup alternatives (U.S. Environmental Protection Agency 2001b). A binding agreement to proceed on this step has been signed by parties that voluntarily came forward to participate in the cleanup process; the EPA has not yet determined all potentially responsible parties.

Impervious surfaces and altered hydrology

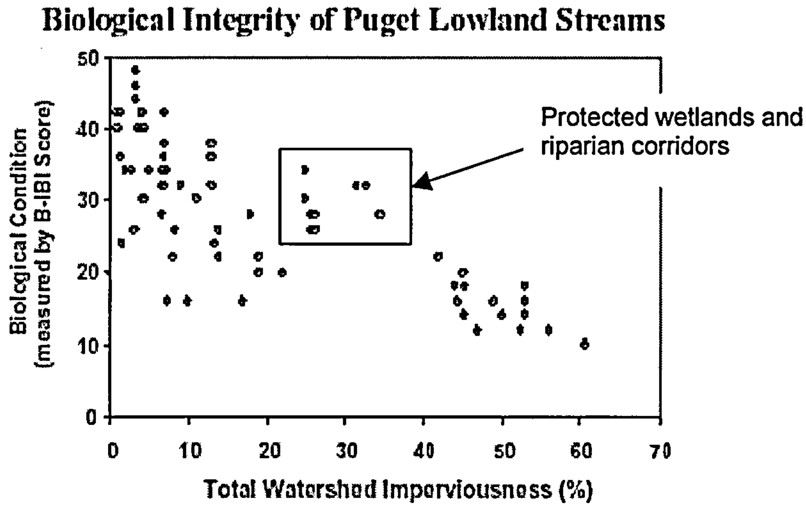
One of the most ubiquitous influences of urbanization on the functions and values of a watershed is the replacement of the natural landscape with pavement and other water-impervious (impenetrable) material such as roads, parking lots, driveways, sidewalks, and rooftops (May et al 1997a; Wilcove et al 1998; Booth 2000). Increased levels of impervious surfaces interrupt the hydrologic cycle, alter stream structure, and degrade the chemical profile of the water that flows through streams. These changes to water storage and delivery harm the environment in a variety of ways, and are cumulative within watersheds (McCarron et al. 1997; May and Horner 2000).

As Metro's (1997) Title 3 white paper indicates, the amount of rainwater that runs off the land rather than infiltrating increases with imperviousness. For example, in areas covered completely with natural vegetation approximately 15 percent of the rainwater runs directly off. In a typical single family home scenario (35-50 percent imperviousness), about 35 percent of the rainwater runs off. In a fully urbanized setting ($\geq$ 75 percent imperviousness), 61 percent of the water may run off the land. Local streams are adapted to local, native conditions; during storm events, all that water running quickly into streams acts like a giant corkscrew augering right down the stream channel. Streams are **incised** and the beds are widened, more sediments, toxins and water enter the system, and much of the wildlife that once lived in the stream disappears.

The percent of impervious surfaces within a watershed can indicate the intensity of urbanization and associated negative ecological impacts, but there is evidence that these effects can be mitigated. Research in the Pacific Northwest and in other regions indicates that when a watershed's **imperviousness** reaches approximately 5-10 percent, stream ecosystems and biotic communities show measurable evidence of degradation (Schueler 1994; Arnold and Gibbons 1996; Spence et al. 1996; May et al. 1997a); adverse ecological effects typically become quite severe when imperviousness reaches approximately 25-30 percent. Some researchers consider 10 percent imperviousness to be the lower end of an ecological threshold (the "65/10" rule, in which imperviousness targets are <10 percent and forest cover targets are 65 percent; see Booth 2000). However, recent evidence suggests that in fact, there is no lower threshold, and that degradation can occur at any level of imperviousness; further, it appears that activities such as protecting wetlands and riparian areas help lessen the impacts of urbanization (Figure 5) (Booth 2000). Thus, mitigating the effects of imperviousness, combined with maintaining relatively high levels of forest canopy cover, are probably keys to maintaining or improving ecological conditions in an urban setting (see *Restoration section* for some mitigation examples).

In general, the reason for the harmful effects of imperviousness is a combination of factors affecting the quality, quantity, and timing of stormwater delivered to the stream. Impervious surfaces prevent precipitation from infiltrating the soil and moving slowly to the stream, thereby reducing the "sponge" area in a watershed. Water may move quickly from impervious surfaces to the stream overland, or across the surface, carrying with it sediment and pollution; or it may be routed via pipes directly to the stream. The natural patterns of water delivery and filtration are either modified or completely bypassed. Stormwater from pipes is particularly damaging because it is discharged at high volumes and velocities, harming stream channels and altering the wildlife capable of living in or near the stream. The primary concept is that impervious surface and piping effects are highly detrimental to hydrology and waterways, but these effects may be decreased through some mitigation approaches (Figure 5).

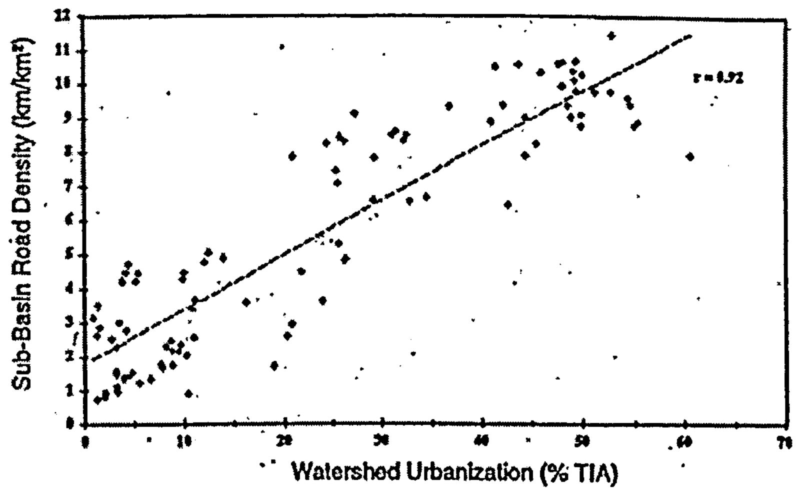
Figure 5. The influence of protecting wetlands and riparian corridors on aquatic biological integrity.



Compilation of biological data on Puget Lowland watersheds, reported by Kleindl (1995), May (1996), and Morley (2000). The pattern of progressive decline with increasing imperviousness is evident only in the upper bound of the data; significant degradation can occur at *any* level of human disturbance (at least as measured by impervious cover). Modified from Booth 2000 (the "protected wetlands and riparian corridors" portion of this graph was obtained from a talk given by James Karr at the 2001 At Water's Edge conference).

Imperviousness is typically quantified through two methods. The most common method is to measure the proportion of the basin area covered by imperviousness, or the **total impervious area** (TIA) (Schueler 1994). TIA may be measured directly through aerial photos, GIS layers or satellite data. An alternative TIA measure is to use GIS data to calculate the amount of "natural" surfaces (e.g. vegetation and soils), then subtract the proportion of natural surfaces from the total to estimate TIA. Transportation systems (streets and parking lots) typically comprise a majority of impervious surfaces, and road density is sometimes used as a proxy for TIA in jurisdictions lacking better data (Schueler 1995; May et al. 1997b). In the Puget Sound region, roads and parking lots account for over 60 percent of basin imperviousness in suburban areas and is strongly correlated with TIA (May et al. 1997b) (Figure 6). Ideally, however, TIA should be used rather than road density because it provides a more accurate measure of imperviousness.

Figure 6. Sub-basin road density vs. watershed urbanization (percent TIA).



Source: May et al. 1997.

The second method of measuring imperviousness is **effective impervious area** (EIA), referring specifically to the area where there is no opportunity for runoff from an impervious surface to infiltrate into the soil before it reaches a conveyance system (pipe, ditch, stream, etc.) (Washington State Department of Ecology 2000). In other words, impervious surfaces may not be considered part of EIA if the water has a chance to soak in. Table 2 provides an estimate of TIA versus EIA (without impervious mitigation measures) under various development intensities. To illustrate how EIA differs from TIA, consider a building with a driveway and roof, where stormwater runs off these surfaces and is routed through curbs and gutters to a storm drain, flowing directly to the stream. In this case, TIA would be the same as EIA. If the roof gutters were instead routed to a vegetated area, then the EIA would be less than the TIA. EIA could be further reduced by removing curbs along the driveway and allowing water to infiltrate into vegetation, soils or gravel, but TIA would remain the same unless impervious surfaces were removed.

Table 2. Presumed relationship between land use, TIA and EIA.

LAND USE	TIA (%)	EIA (%)
Low density residential (1 unit per 2-5 acres)	10	4
Medium density residential (1 unit per acre)	20	10
"Suburban" density (4 units per acre)	35	24
High density (multi-family or 8+ units per acre)	60	48
Commercial and industrial	90	86

Source: Booth and Jackson (1997)

Currently, EIA may be the most appropriate estimate of human influence on hydrology because it incorporates measures to mitigate adverse impacts. However, EIA may be difficult to measure, in part because the extent to which such mitigation efforts actually work is unknown. When EIA is significantly less than TIA, there is little doubt that imperviousness exerts a weaker influence on the environment than if the two were equal. The magnitude of this difference is unknown, but reducing effective imperviousness is clearly an important strategy in urban ecosystems.

The result of greater stormwater volumes traveling over impervious surfaces and being delivered too rapidly to streams is increased stream **flashiness** (Figure 7) and a reduction in summer base flows, sometimes causing perennial streams to turn intermittent or dry up completely (Harbor 1994). As a result, urbanized watersheds are prone to more frequent and bigger floods (Sovern and Washington 1996). For example, in King County, Washington, downstream from urbanized watersheds the largest floods were two to three times bigger than in nearby natural systems, while the frequency of smaller floods increased as much as tenfold (Booth 2000). Wigmosta et al. (1994) estimate that Pacific Northwest areas covered by impervious surfaces typical of suburban development have 90 percent less water storage capacity than naturally forested areas of the same size.

Local jurisdictions' code may impede low-impact development solutions designed to reduce stormwater impacts. In 2004, the Audubon Society of Portland produced a useful report entitled *Stormwater/Pavement Impacts Reduction (SPIR) Project Report* (Audubon Society of Portland 2004).

Floodplain and wetland alterations

Floodplains play a critical role in transporting high flows and moderating the effects of peak floods. Wetlands are usually part of the floodplain system. Stream degradation through incision and artificial barriers such as dams, floodwalls and levees, as well as wetland draining and alteration, may render a stream incapable of dispersing water, soil and nutrients to the floodplain (Rosgen 1993; Spence et al. 1996; Poff et al. 1997).

Recent research in Great Britain indicates that planting trees in the floodplain helps moderate floods a great deal, even while the trees are still young (The Economist, 21 October 2004). Comparing water infiltration, researchers measured nearly none in heavily grazed pastures. Ten cm per hour infiltrated into less heavily grazed pastures. But in areas planted with young (7-year-old) broad-leaved trees, 80 cm per hour soaked in.

In 1992, Holland et al. (1995) found that 40% of wetlands identified by the National Wetland Inventory in 1981/1982 had disappeared, with conversion to urban land the most common cause. A quarter of the remaining wetlands they studied were severely degraded by human activities.

Dams

Although dams provide many societal benefits including power generation, water storage, flood control, agricultural irrigation, and recreation, they influence watershed functions in fundamental ways (FISRWG 1998). Ecological problems associated with dams include erratic water volume and velocity (altered hydrology), increased streambank erosion, loss and fragmentation of riparian habitat, altered water chemistry, altered instream habitat, and blocked fish and instream wildlife passage (see also Tables 3 and 4). More than 85 percent of the inland waterways within the continental United States are now artificially controlled through dams (National Research Council [NRC] 1992), including all major Metro-region rivers. All salmon and steelhead in the Columbia Basin are affected to some degree by damming activities (Federal Caucus 2000).

Floodwalls and levees

Floodwalls and levees, installed to control floodwater and limit the access of a stream to its floodplain, cause hydrologic fragmentation by disrupting lateral and downstream stream-floodplain interactions. The floodwalls along Portland's downtown area provide a local example. Floodwalls and levees tend to eliminate riparian vegetation, increase flood heights and water velocities, and reduce sinuosity (Poff et al. 1997). In headwater and midsection stream zones, this leads to increased bank and channel erosion and channel incision. In lower reaches where velocity is slower, sediments drop out of the water, leading to excessive sedimentation. Thus in addition to onsite soil, vegetation and water loss due to these artificial barriers, fish and wildlife habitat is degraded in the area near the structure and downstream (Riley 1998).

Wetland loss and alteration

Natural wetland functions are adversely impacted by urban development when wetlands are fully or partially filled, drained, relocated, or otherwise substantially altered. Altered hydrology modifies wetlands in fundamental ways, including a shift toward upland plants and wildlife (Ehrenfeld and Schneider 1993; Ehrenfeld 2000). Urbanization is implicated in wetland loss in most U.S. watersheds and may account for as much as 58 percent of total wetland loss nationwide (Opheim 1997). Over half of the wetlands in the contiguous U.S. have been lost since the 1780's, and recent research indicates that wetland mitigation programs designed to result in "no net loss" are not working (Whigham 1999; National Academy of Sciences 2001).

In the Willamette Valley, various sources document wetland losses between 40-57 percent of original (Philip Williams and Associates, Ltd. 1996; Morlan 2000). Between 1982 and 1994 alone, 6,549 acres (9.9 square miles) of wetlands were lost in the Willamette Valley, with 28 percent of the total loss due directly to urbanization (Daggett et al. 1998). This excludes small wetlands <0.25 acres, which could not be assessed but may be critical to large-scale amphibian population dynamics (see Gibbs 1993) and surely experienced losses. The Willamette Valley continues to lose more than 500 wetland acres per year (Morlan 2000). For salmon, this translates to loss of off-channel winter salmonid habitat, summer rearing diversity, cool water sources for summer rearing, and flow buffering (Martin 1998). For wetland-dependent species such as amphibians and some bird species, loss of half of the total habitat over time is a severe consequence.

It is important to recognize that not all wetlands are created equal. Whigham (1999) notes, "From an ecological perspective, dry-end wetlands such as isolated seasonal wetlands and riparian wetlands associated with first order streams may be the most important landscape elements. They often support a high biodiversity and they are

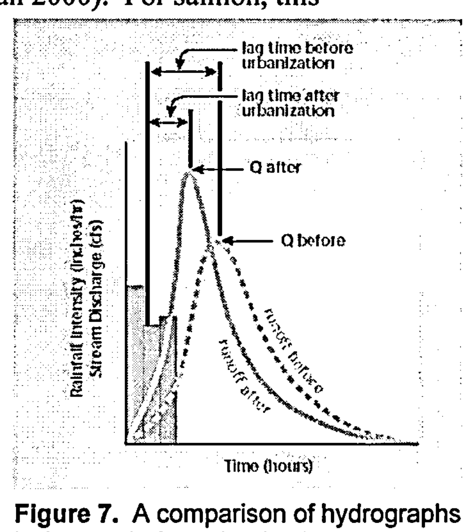


Figure 7. A comparison of hydrographs before and after urbanization. The discharge curve is higher and steeper for urban streams than for natural streams. (Source: FIRSWG 1988)

impacted by human activities more than other types of wetlands." Further, created wetlands may differ quite markedly from natural wetlands, thus achievement of "no net loss" may nonetheless result in substantially reduced wetland ecological functions (Brown and Lant 1999; Whigham 1999).

The vegetation unique to wetland areas is frequently removed as a result of urbanization, and altered stream channels (discussed next) effectively disconnect the stream from the wetlands and natural floodplain. Impervious surfaces such as buildings and parking lots aggravate the problem by causing rapid water runoff, altering the **hydrograph** by affecting the frequency, duration and magnitude of flood events, and reducing wetland infiltration and water storage (Figure 7) (Booth and Jackson 1997). As Figure 7 illustrates, the hydrograph's peak is taller and occurs sooner (a bigger flood that quickly overwhelms water storage) and the shape of the peak is narrower (shorter lag time, e.g., the water is not retained on the land). Many other adverse effects are documented, and some of these are listed in Table 3.

Table 3. Some effects of urbanization on wetland hydrology, geomorphology, plants and animals. Most of these effects also occur in or influence streams and riparian areas.

Hydrology:
Decreased stormwater storage results in increased surface runoff (= increased surface water input to wetland)
Increased stormwater discharge relative to baseflow discharge results in increased erosive force within stream channels
Changes in water quality (increased turbidity, increased nutrients, metals, organic pollutants, decreased O_2, etc.)
Culverts, outfalls, etc. result in more variable baseflow and low-flow conditions
Decreased groundwater recharge results in decreased groundwater flow, which reduced baseflow and may eliminate dry-season streamflow
Increased flood frequency and magnitude result in more scour of wetland surface, physical disturbance of vegetation
Increase in range of flow rates (low flows are diminished; high flows are augmented) may deprive wetlands of water during dry weather
Greater regulation of flows decreases magnitude of spring flush
Geomorphology:
Decreased sinuosity of wetland/upland edge reduces amount of ecotone habitat
Decreased channel sinuosity results in increased stream water discharge velocity to receiving wetlands
Alterations in shape of slopes (e.g., convexity) affects water gathering or water-disseminating properties
Erosion along banks from increased flood peak flow increases cross-sectional area of stream channels
Vegetation:
Large numbers of exotic species present; large and numerous sources for continuous re-invasion of exotics
Large amounts of land with recently disturbed soils suitable for weedy, invasive species
Depauparate species pool
Restricted pool of pollinators and seed dispersers
Chemical changes and physical impediments to growth associated with the presence of trash and pollutants
Small remnant patches of habitat not connected to other natural vegetation
Human-enhanced dispersal of some species
Trampling along wetland edges and periodically unflooded areas
Fauna:
Loss of critical habitat
Benefits species with small home ranges, high reproductive rates
Large predators virtually non-existent; increased small mammal abundance for some species, while others are susceptible to extirpation due to fragmentation and isolation
"Edge" species benefit, to the detriment of forest-interior species
Absence of wetland/upland zones of transition
Human presence and noise disrupt normal behaviors

Source: Modified from Ehrenfeld, 2000.

Stream channel modification

The hydrologic changes discussed above modify the stream channel. Rapid runoff associated with increased stormwater velocity and volume quickly erode and incise (**entrench**) the stream channel and banks. Channels widen and straighten (or are intentionally modified in these ways) to accommodate higher flows. This circumvents the natural evolution process of the channel; LWD, ponds, pools, riffles, streambanks and sandbars are simplified or washed away, eliminating critical habitat for fish, waterfowl, and other species (Arnold and Gibbons 1996; Spence et al. 1996; Prichard et al. 1998). For example, Coho salmon are extremely sensitive to alterations in channel characteristics because of their need for smaller streams, relatively low velocity niches, and large pools typical of undisturbed conditions in the Pacific Northwest. As impervious surfaces increase, fish species diversity and Coho abundance in the Pacific Northwest tend to decline (Lucchetti and Fuerstenberg 1993b).

Piping and culverting

Development practices such as piping and culverting caused the loss of about 400 miles of streams in the Metro Region (Metro Disappering Streams Map 1999). For example, in the City of Portland, the majority of streams that once existed on the inner east side of the Willamette River, as well as significant westside streams, were piped underground, resulting in a loss of the majority of the stream's ecological functions. Water is also frequently piped from rooftops, storm drains, and impervious surfaces. Piping water directly to the stream bypasses natural stream/vegetation interactions such as transport of organic material and sediments, erosion control, and filtration of toxins and excess nutrients; in addition, piping causes high volume, high velocity flows that directly enter the stream channel, altering channel form and functions (Booth 1991; R2 Resource Consultants 2000).

Piped streams and culverts also create impassable fish barriers that block entire stream reaches to migratory fish species and isolate remaining species, putting these populations at risk of reduced genetic diversity and/or extinction (Warren and Pardew 1998; May et. al 1997a; Schueler 1995; R2 Resource Consultants 2000). Fish barriers are addressed further in the ***Restoration*** section.

Channel straightening and armoring

Streams in urban settings are often intentionally widened, deepened, straightened, and sometimes armored with hard materials in order to confine flows, stabilize streambanks and increase a stream's capacity for localized flood control (R2 Resource Consultants 2000). In truth, such activities simply result in moving water more quickly downstream, disconnecting the stream from its floodplain, degrading riparian habitat and creating more problems elsewhere (e.g., Griggs 1981). These changes, accompanied by increased flood frequency and magnitude, result in a loss of stream complexity and off-channel fish and wildlife habitat (Booth 1991; Beechie and Sibley 1997).

Local examples

Johnson Creek watershed

The Johnson Creek watershed, a 135-km (52-square mile) area draining urbanized portions of Clackamas and Multnomah Counties, provides a local example of a watershed profoundly influenced by urbanization, but where important positive changes are taking place. This stream has been altered through clearing of riparian vegetation, damming, widening, deepening and armoring of the channel, and floodplain and upland development. Salmonids were once sufficiently abundant to support a small commercial fishery near SE 45th Avenue and Johnson Creek Boulevard (City of Portland 2000). However, steelhead were ESA-listed in 1998 and a coastal cutthroat trout listing is pending. In most reaches within the Johnson Creek watershed, physical habitat complexity normally associated with salmonid streams has been simplified, modified or eliminated. Water temperatures and fecal coliform levels make this stream among the most polluted in the Metro region (Environmental Quality 1998; Cude 2001). Flood frequency and severity have increased substantially over the past century.

The City of Portland's Bureau of Environmental Services has mapped the impervious surfaces for sub-units within the watershed using three classes: "sensitive" (0 to 10 percent impervious), "impacted" (11-25 percent), and "non-supporting" (26-100 percent impervious) (Meross 2000). A fourth classification delineates areas where no overland or piped water flows into the stream or its tributaries because water drains to sumps or a combined sewer system. Although the watershed's overall TIA is not provided, road densities suggest a TIA of approximately 35 percent (see Figure 6). However, 35 percent of the watershed is not piped directly to the stream but instead infiltrates groundwater through sump pumps, is directed to Portland's Combined Sewer System, or is hydrologically disconnected (see Map 6 in Meross 2000). Thus, EIA is probably substantially lower than TIA, but the disconnection of a third of the watershed's surfaces from the stream surely alters hydrologic patterns. Development near and within Johnson Creek's floodplains, combined with cumulative effects throughout the watershed, influence the stream system's water quality and hydrologic patterns. These issues illustrate the complex nature of urban effects on natural systems.

Multi-jurisdictional efforts to restore function to the Johnson Creek watershed are currently underway, including small dam removal, reconnecting floodplains and backwater channels to the stream, increasing sinuosity, and adding wetlands, vegetation and LWD. Houses within the floodplain are being purchased and removed from the floodplain in a "willing seller" program. Watershed-scale restoration efforts such as this have a better chance of success than site-specific restoration because they address the cumulative impacts of adjacent land use.

Pleasant Valley area

The Pleasant Valley area is a relatively rural watershed currently under study by the City of Portland and others. The watershed contains seven subwatersheds, including three below 10 percent TIA and four in the 11-25 percent range. All but one of these subwatersheds have been assessed (through GIS modeling and field data) as ecologically impaired, primarily due to past and current agricultural activities. Planners for this developing watershed are exploring whether sufficiently aggressive design standards for reducing EIA may make it possible to approach relatively high levels of TIA (e.g., up to 40 percent) in a subwatershed, yet still maintain properly functioning conditions similar to those typical at much lower TIA levels.

Some uncertainties arise when planning developments to reduce impervious surface impacts. For example, what will the TIA and EIA be at full build-out? How do we urbanize in the most ecologically sound way, and what is the EIA threshold below which it is possible to sustain ecological functions? The precise amount of impact reduction (mitigation) that reducing EIA might have is unknown and probably depends on the particular mitigation activity. Research into this question would benefit land use planning.

Impact of other land uses on stormwater runoff

Urbanization is not the only land use influencing watersheds in the Metro region. Other human activities, such as rural development and agriculture, road and dam building, and forestry, also routinely occur near and upstream of urban areas. Table 4 lists some of the typical negative effects on waterways caused by urbanization and other human-associated activities.

Table 4. 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					
	Urbanization	Agriculture	Recreation	Roads	Dams	Forestry
Riparian Habitat:						
Altered microclimate	X	X	X	X	X	X
Reduction of large woody debris	X	X	X	X	X	X
Habitat loss/fragmentation	X	X	X	X	X	X
Removal of riparian vegetation	X	X	X	X	X	X
Soil compaction/deformation	X	X	X	X		X
Loss of habitat connectivity	X	X	X	X		X
Reduction of structural and functional diversity	X	X	X	X		X
Stream Banks and Channel:						
Stream channel scouring	X	X	X	X		X
Increased stream bank erosion	X	X	X	X	X	X
Stream channel changes (width, depth)	X	X	X	X	X	X
Stream channelization (straightening)	X	X		X		X
Loss of fish passage	X	X		X	X	X
Loss of large woody debris	X	X	X	X	X	X
Reduction of structural and functional diversity	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
Increased surface water flows	X	X	X	X		X
Reduction of water storage capacity	X	X		X		X
Water withdrawal	X	X	X		X	
Increased sedimentation	X	X	X	X	X	X
Increased stream temperatures	X	X	X	X	X	X
Water contamination	X	X	X	X		X

Source: Knutson and Naef 1997.

Riparian vegetation loss and alteration

Habitat loss

Streams form the backbone for some of the most lush and diverse habitats available in the Metro region because they are highly productive and naturally collect nutrients, seeds, soil, and high quality food resources such as insects. In addition, all animals require water to live. As such, riparian areas are fundamentally important to wildlife (as Metro's Species List demonstrates). Loss of access to these habitats through removal, fragmentation or degradation harms wildlife. Riparian habitat loss is well documented in the region (e.g., Metro 1999; Yeakley et al. 2005). Habitat fragmentation is described in the ***Upland Habitat*** section, but also applies to riparian habitats. We described the functions of riparian vegetation above; here we focus primarily on the impacts of riparian habitat loss and hydrologic changes in a watershed.

Severely altered and unpredictable hydrologic regimes may strip riparian vegetation and prevent naturally adapted floodplain plants from colonizing sandbars and streambanks (Booth 1991; Schueler 1995). Groundwater levels may also become less predictable in urbanized watersheds, and riparian-specialist plants such as black cottonwood depend on relatively predictable groundwater levels to become established (Scott et al. 1999; Law et al. 2000). Riparian vegetation filters sediments and soil, slows runoff and stabilizes streambanks; without vegetation, stream banks and channels become damaged. Hydrology and riparian vegetation are linked, and changes in one create changes in the other. Ideally, native riparian vegetation should be present in some amount along every stream in the region.

Altered microclimate

Riparian vegetation creates an instream microclimate that maintains relatively constant water temperatures; when a riparian forest is removed, the monthly mean maximum temperature along smaller streams may increase 7-8° C (Budd et al. 1987). Vegetation also influences microclimates on the land by blocking wind, moderating temperatures, and increasing humidity. Widespread microclimate alterations change plant and animal communities (Saunders et al. 1999; Gehlhausen et al. 2000; Laurance et al. 2000). In terrestrial habitats, microclimate is influenced by edge effects (see also ***Riparian area width***), thus habitat fragmentation, including patch size and shape, influences local riparian microclimates.

Altered forest structure and composition

Forests in an urban setting are prone to structural simplification and invasion by nonnative species, and these effects are exacerbated in narrow forests (Marzluff et al. 1998; Pimental 2000). Local research provides some guidance on riparian corridor widths needed to control these influences (Hennings 2001; Hennings 2003; Hennings and Edge 2003; see also ***Riparian area width***.)

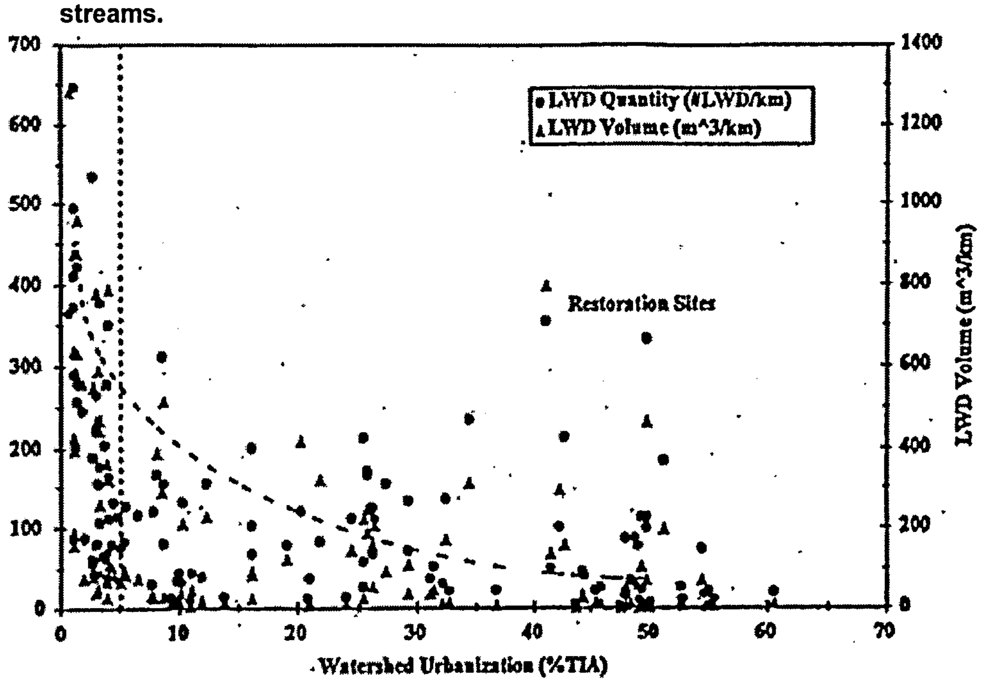
Loss of large woody debris and organic matter

Woody debris and vegetation both in the stream channel and in the floodplain add structural complexity and provide organic matter that becomes part of the food chain (Adams 1994; Prichard et al. 1998). These structures are often intentionally removed; for example, between 1867 and 1912, 88 km (55 miles) of the Willamette River above Albany, Oregon were improved for navigation by removing an average 61 snags per kilometer (Sedell et al. 1990). Large wood may also be removed from streams in an attempt to reduce flooding. In urban streams of the Pacific Northwest, large wood is significantly depleted through washout, downcutting, and direct removal (Booth et al. 1997). In the Puget Sound region, the amount of large woody debris in the channel is related to TIA (Figure 8), and drops off significantly after approximately five percent TIA (May et al. 1997a). The removal of riparian vegetation also results in loss of terrestrial LWD critical to soil health and wildlife habitat (Maser and Trappe 1984; FEMAT 1993). Retention of these materials is vital to a watershed's capacity to support fish and wildlife.

Beyond the structural importance of LWD, other, smaller organic debris provides carbon, the basic fuel for aquatic and terrestrial food webs (Allan 1995). Removing riparian vegetation also removes the primary source of these materials, reducing the stream's **carrying capacity** for organisms (Brown and Krygier 1970). In addition, when flow rates increase and channels are simplified, the retention time of organic debris is decreased because it quickly washes downstream (Webster and Meyer 1997). Thus urbanized streams tend to contain less food than undisturbed watersheds.

Spawning salmon and salmon carcasses provide marine-derived nutrients to many aquatic and terrestrial wildlife species. According to Cederholm et al. (2000): "The loss or severe depletion of **anadromous fish** stocks could have major effects on the population biology (i.e., age-class, longevity, dispersal ability) of many species of wildlife and thus on the overall health and functioning of natural communities..."

Figure 8. LWD quantity and watershed urbanization (percentTIA) in Puget Sound Lowlands streams.



Source: Horner and May 1998.

Pollution – thermal, physical and chemical

Thermal pollution: water temperature and dissolved oxygen

Water temperature is influenced by a variety of factors including streamflow, elevation, amount of shade, surface/groundwater interactions, undercut embankments, surface area, depth, and stream velocity (Budd et al. 1987). Urban streams tend to be warmer than non-urban streams; during warmer months, water flowing over impervious surfaces is often heated to 10 or 12 degrees above the temperature of water that passes through fields and forests (Budd et al. 1987; Schueler 1994). Warmer water cannot hold as much oxygen as cold water. Higher stream temperatures also increase metabolic rates, thus an organism living in warmer water needs more oxygen than the same species in cold water, yet less oxygen is available in warmer water (Spence et al. 1996).

Reduced dissolved oxygen levels can adversely affect salmon egg incubation, growth and development of juveniles, and behavior and physiology of adult fish (Pauley et al. 1986; Spence et al. 1996). For example, a slight increase in temperature at the low end of the optimal temperature range for incubation can cause early emergence of fry from the gravel, increasing exposure to high-flow events and flushing them downstream, in addition to other problems discussed earlier. Most salmon cannot tolerate temperatures above 23-26° C (73-79°F) for an extended period of time (Beauchamp et al. 1983; Pauley et al. 1989).

Physical pollution: sediments and sedimentation

Hydrology, geomorphology and vegetation influence the size and amounts of sediments (including gravel) delivered to the stream system. In urbanized watersheds, fine sediments are increased and approximately two-thirds of all sediments delivered into the stream originates from channel erosion, with the remainder arriving from upland (see Pollution discussion below) and upstream (Trimble 1997; Wood and Armitage 1997). Bank erosion is 30 times more common on non-vegetated streambanks exposed to currents than on vegetated banks (Beeson and Doyle 1995). Construction sites, although somewhat temporary in nature, cause significant erosion and transport of fine sediments to the stream (Spence et al. 1996), and each year in the U.S. an estimated 80 million tons of sediment are washed from construction sites into water bodies (Goldman et al. 1986).

Upon delivery to streams, these sediments are either suspended in the streamwater (creating increased turbidity) or deposited on the streambed (creating sediment build-up and embeddedness). High turbidity clogs fish gills and makes it hard to breath, and adult migrating salmon have been known to stop movement when encountering excessive turbidity (Pauley et al. 1986; Pauley et al. 1989). However, deposited sediments generally have a greater impact on fish than suspended sediments. Salmon, salamanders and many aquatic insects need relatively sediment-free gravel beds with suitable gravel in which to reproduce (Hawkins et al. 1983; May et al. 1997a). Fine sediment deposited on gravel can smother developing salmon eggs, inhibit fry emergence from spawning gravel and limit the production of benthic invertebrates, an important food source for fish and other aquatic species (Beauchamp et al. 1983).

At the same time, storage of sediments in the streambed is an important part of healthy stream function. For example, instream LWD plays an important role in sediment storage; the removal of large organic debris obstructing anadromous fish passage in an Oregon Coast Range stream accelerated downcutting of previously stored sediments, resulting in erosion of more than 5,000 cubic meters of sediment along a 250 m reach the first winter after debris removal (Beschta 1979). Problems occur when the volume of sediments entering waterways overload the stream system's natural capacity to store and transport the sediments.

Chemical pollution

Urban areas are where human population densities are highest. Humans are the primary source of pollutants, thus urbanized watersheds virtually always have pollution and water quality issues. Pollution can destroy food webs within stream systems. Impervious surfaces collect and concentrate pollutants from different sources and deliver these materials to streams during storms, and prevent percolation and natural filtering by soil and vegetation (Booth 1991; Arnold and Gibbons 1996; May et al 1997a). Concentrations of pollutants in streams increase with TIA (Schueler 1994; May et al. 1997a), and data collected in the Pacific Northwest suggest that pollution from urban areas is harming anadromous salmonids (Spence et al. 1996). Common urban pollutants include nutrients such as phosphorus and nitrogen, pesticides, bacteria, and miscellaneous contaminants such as PCBs and heavy metals. Development type influences the pollutants imposed on the stream system; for example, E. coli and phosphorus tends to be contributed from residential developments, whereas industrial areas tend to contribute high quantities of heavy metals (Table 5) (Arnold and Gibbons 1996; Morrisey et al. 2000).

Table 5. Typical urban pollutants. Surfaces exhibiting highest levels of runoff-borne pollutants, out of twelve surface types sampled in selected urban areas in Wisconsin.

	SURFACE		
POLLUTANT	**Highest levels**	**Second highest levels**	**Third highest levels**
E. coli (bacteria)	Residential feeder streets	Residential collector streets	Residential lawns
Solids (sediment)	Industrial collector streets	Industrial arterial streets	Residential feeder streets
Total phosphorus	Residential lawns	Industrial collector streets	Residential feeder streets
Zinc	Industrial roofs	Industrial arterial streets	Commercial arterial streets
Cadmium	Industrial collector streets	Industrial arterial streets	Commercial arterial streets
Copper	Industrial collector streets	Industrial arterial streets	Residential collector streets

Source: Arnold and Gibbons 1996

Pesticides

Farming and urban landscaping practices over the last half-century have resulted in an extraordinary increase in pesticide use, but effects on wildlife are not well known. Pesticides in urban areas originate primarily from lawn and garden care (Stinson and Bromley 1991). On a per-acre basis, urban land use contributes more pesticides than agriculture.

Aquatic organisms are particularly susceptible to water-borne toxins and typically have low tolerance levels; for example, low levels of **neurotoxic** pesticides such as Diazanon impair Chinook salmon's defensive olfactory responses and homing behaviors (Scholz et al. 2000). On land, the effects of pesticides have been studied most extensively for birds. Various pesticides have been responsible for numerous bird kills, and non-lethal and indirect exposure of terrestrial species to pesticides can lead to increased susceptibility to predation as well as changes in avian egg incubation behavior. Repeated pesticide exposure also adversely affects nutrition, reproduction and growth of animals such as gamebirds and waterfowl (Bennett 1992).

Some pesticides **bioaccumulate** in the organism and may remain in the environment for many decades. For example, DDT, a highly toxic form of **organochlorine pesticide** that was banned in the 1970's, is still routinely detected in Willamette Valley farm fields and organisms. For example, in the Tualatin Basin concentrations of organochlorine compounds in fish tissue usually exceeded those in streambed sediment concentrations by at least 10-fold (Bonn 1999). In the Portland/Vancouver area of the Columbia River, River otters have abnormally high concentrations of organochlorine and dioxin compounds (McCarthy and Gale 1999). Bald eagle eggs in the Columbia Slough area have been found to contain unsafe levels of DDE (a metabolite of DDT), PCBs, and dioxins and other toxins; the productivity of lower Columbia River eagles is well below levels of other eagle populations in the area (Lower Columbia River Estuary Program [LCREP] 1999).

Fecal coliform

Fecal coliform refers to the group of harmful bacteria present in animal (including human) feces (Pandey and Musarrat 1993). Escherichia coli (E. coli), a common type of fecal bacteria, may be fatal if left untreated (Ries et al. 1992; Carrasco et al. 1997; Oberhelman et al. 1998). In Washington State Taylor et al. (1995) found significant fecal coliform increases in urban wetlands as TIA exceeded 3.5 percent. Urban stormwater discharge, sewer overflows, and sewer pipe and septic system leakage are a primary means of these bacteria reaching urban waterways (Gibson et al. 1998). Fecal coliform may also enter waterways through overland flow, particularly runoff from residential streets, often in the form of pet feces.

The best way to prevent excessive fecal coliform from reaching streams is to remove the source (e.g., direct sewer overflow). Although that fails to prevent contamination from overland flow, appropriate forest buffers may effectively trap fecal coliform arriving through this route. Pennsylvania researchers found greatly reduced fecal coliform levels in areas where at least 50 percent of the riparian vegetation was intact within 100m (328 ft) of the stream (Brenner et al. 1991).

PCBs, heavy metals and other contaminants

Organochlorine compounds such as polychlorinated biphenyls (PCBs), heavy metals, and an assortment of other contaminants harm fish and wildlife (Rutherford and Mellow 1994). Although trace levels of heavy metals occur naturally, higher levels are toxic to fish and wildlife (May et al. 1997a). Metal contaminants increase in proportion with urbanization (Pouyat et al. 1995; Morrisey et al. 2000; Yuan et al. 2001). Industry and automobiles appear to be the primary sources in urban areas. In addition to heavy metals, hydrocarbons (gas and oil), toxins from rooftops, and industrial and household chemicals (e.g., paint, cleaning products) pollute urban streams (Gavens et al. 1982; Ely 1995). In London, Gavens et al. (1982) found a 3- to 10-fold increase in hydrocarbons in river sediments over a 120-year period. Arkoosh et al. (1991) found that juvenile Chinook salmon migrating through an urban estuary contaminated with PCBs bioaccumulated these pollutants and exhibited a suppressed immune response, whereas immune systems of uncontaminated fish in a nearby rural estuary were unaffected.

Nitrogen and phosphorus

Nitrogen and phosphorus exist naturally and provide nourishment to plants and animals. These are also common fertilizer components, and increase with urbanization (Arnold and Gibbons 1996; Corbett et al. 1997). Phosphorus is typically the biggest problem in urban watersheds, whereas nitrogen is the issue in agricultural watersheds. In Portland, groundwater test wells above and below residential developments showed significantly elevated phosphorus levels downslope of the developments (Sonoda et al. 2001). In Washington, total phosphorus levels in wetlands rose significantly when TIA exceeded just 3.5 percent (Arnold and Gibbons 1996). Increased quantities of nutrients delivered to the stream in the form of wastewater effluent, landscaping runoff, and agricultural runoff can lead to unrestricted instream plant growth (algae blooms); the process of plant decay consumes most of the oxygen in the stream, greatly reducing the quality of aquatic habitat (Arnold and Gibbons 1996; R2 Resource Consultants 2000). Riparian forests act as short- and long-term nutrient filters and sinks (Lowrance et al. 1984; Peterjohn and Correll 1984; Lowrance et al. 1997).

Local examples

Streams such as Fanno Creek appear on DEQ's list of 303(d) water quality-limited streams due to low levels of dissolved oxygen and above-normal temperatures and levels of coliform bacteria and chlorophyll. In the Clackamas River, although oxygen levels are high and nitrogen levels are low, temperatures are elevated. In the Columbia Slough, high nitrogen levels are deteriorating water quality. Johnson Creek makes the list due to high summer temperatures and elevated levels of fecal coliform bacteria found throughout the year, among other problems (Oregon Department of Environmental Quality 1998).

Bonn (1999) found elevated levels of lead and other contaminants locally in Ash Creek, Fanno Creek, and McKay Creek. The most urban site (Beaverton Creek at Cedar Hills Boulevard) contained the most contaminated bed sediments, including very high levels of organochlorines, arsenic, cadmium, lead and mercury.

In 1998 the United States Geological Survey completed a 5-year study of the Willamette River basin as part of a larger national study on water quality and stream ecology. The study showed that fish communities and stream habitat in the Willamette basin were among the most degraded of the 19 basins in which data was collected. Occurrence of parasites and external lesions on fish were five to ten times above normal in the Willamette basin, and pollution-intolerant fish species (e.g., trout and sculpin) were rare or absent. Elevated phosphorus concentrations in streams promoted nuisance plant growth. Concentrations of nearly 50 pesticides or pesticide breakdown products were found, ten of which exceeded federal guidelines for protection of freshwater aquatic life. Groundwater quality in the Willamette basin was better than surface water quality, but pesticides were detected in about one third of wells sampled. Volatile organic compounds such as fuel additives or degreasing solvents were also detected in groundwater below urban areas.

Wildlife use of urban riparian corridors

The previous discussion outlined some of the major effects of urbanization on natural ecosystems. This section addresses the general life history requirements and impacts of urbanization specific to each wildlife group (e.g., birds, mammals, etc.). When major changes occur within an ecosystem, the plants and animals depending on that system are altered, either directly or indirectly. Direct effects include altered ecosystem processes, habitat and food supply (Spence et al. 1996; Knutson and Naef 1997; Marzluff et al. 1998). Indirect effects include altered competition and predation patterns, which influence wildlife communities in fundamental ways, and indirect effects caused by urbanization such as disturbance. Thus urbanization causes changes in habitat quality and availability, with ensuing changes in food webs and predator and prey associations, simplification of habitat and wildlife communities, and loss of native biodiversity (May et al. 1997a; Marzluff et al. 1998; May and Horner 2000).

Urbanization affects some species positively, and some negatively. Species that thrive in urban habitats take advantage of abundant food and water, moderated temperatures (cities absorb heat during the day and release it at night), and abundant nesting sites that allow for prolonged breeding seasons, increased survival, and improved reproductive success (Knutson and Naef 1997; Marzluff et al. 1998; May and Horner 2000). However, other species are unable to thrive in areas with scarce natural habitat, reduced habitat quality and intense human activities. These species are out-competed by generalist and/or invasive species that dominate the urban landscape.

Invertebrates

General requirements

Invertebrates are one of the most diverse groups of life on the planet, and although influenced by human activities, can be surprisingly abundant in urban areas (Frankie and Ehler 1978; Dreistadt et al. 1990). This is reflected in Metro's invertebrate species list, which includes more than 425 species and is admittedly incomplete. Examples of this diversity include 119 butterfly species, 40 dragonfly species, and 56 kinds of bees. At least 84 are important prey species for salmonids and other fish (Xerces Society 2001). Nearly 100 are important predators on other species. Forty-nine are known to be important pollinator species, and these insects help form and maintain healthy riparian and upland plant communities. In addition, many aquatic invertebrates eventually emerge as flying terrestrial insects, thus they form a direct link between aquatic and terrestrial ecosystems. Over 150 species of terrestrial snails and slugs have been identified in moist forests of the Pacific Northwest; most have limited geographic ranges because they are poor dispersers (LaRoe et al. 1995). The number of non-native species living in the Metro region is unknown, nor is their potential influence on native species and habitats.

Invertebrates have a spectacular array of life history characteristics, and this adds to their diversity. For example, a given species of dragonfly may hatch in a headwater stream and feed on woody and organic debris. Moving downstream and undergoing several metamorphoses, its feeding strategy may change depending on the predominant food resources available in that stream reach. Finally, near the mouth of the river, the insect emerges from the stream, flies back to the headwaters, and breeds again to begin the cycle anew; this process may take seven years. That is, of course, if it is not eaten by a fish or bird on its way down- or upstream. Thus this species' life history revolves around the longitudinal and lateral flow of energy and resources in the stream system. This is just one invertebrate species; when one considers spiders, snails, beetles, butterflies, fleas and flies, the possibilities are vast. Variety at the base of the food web provides for biodiversity at higher levels. Also reflecting the variety of invertebrate species, their environmental needs are many, but water quality, vegetation, woody debris, and other organic matter are important (Schueler 1994; Spence et al. 1996).

Impacts of urbanization

Along with plants, insects form the base of aquatic and terrestrial food webs, thus reduced insect populations lower the land's carrying capacity for wildlife species that rely on insects as a major food source (or other species that rely on those species that prey on insects; ripple effect). Insects are also critically important pollinators that help create habitat. In the Pacific Northwest, watershed imperviousness between 5-10 percent causes macroinvertebrate diversity to drop sharply as pollution- and change-intolerant species are replaced by more resilient species (Schueler 1994; Horner et al. 1996; Spence et al. 1996; May et al. 1997a). Similar findings in the Portland metropolitan region and many other areas document adverse effects of urbanization on aquatic insects (e.g., Klein 1979; Benke et al. 1981; Garie and MacIntosh 1986; Frady et al. 2001; Cole and Hennings 2004).

Because some aquatic insects are highly sensitive to water quality and instream habitat conditions, insects may be used as biological indicators in an **Index of Biological Integrity** (IBI) (Karr and Chu 2000). In southwestern Oregon, an aquatic insect IBI provided a better method of distinguishing disturbed from undisturbed watershed than the Rapid Bioassessment Protocol (RBP) III used by Oregon Department of Environmental Quality (Fore et al. 1996). Numerous studies throughout the country document negative relationships between aquatic insect IBI's and increasing urbanization (e.g., Hachmöller et al. 1991; Kerans and Karr 1994; Elliott et al. 1997; Lerberg et al. 2000; Morley and Karr 2002).

<u>Fish</u>

General requirements

The Metro region provides habitat for 26 native fish species, plus at least one extirpated species. Fifteen more species (37 percent) are nonnative. Seven anadromous Pacific salmonid species (all members of the scientific genus *Oncorhynchus*) are native to Oregon. They include chinook, chum, coho, sockeye, steelhead and cutthroat trout (Brownell, 1999; Cederholm et al. 2000). Salmon survival depends on high-quality, stable environments from mountain streams, through major rivers to the ocean. Thus, salmonid habitat requirements serve as an indicator of the conditions needed for other fish species. Thirteen salmonid runs are federally ESA-listed, with two of these also state Threatened or Endangered. Another run is listed as Endangered only at the state level. Out of the entire genus, only resident rainbow trout are not considered to be at risk.

The Independent Scientific Advisory Board (ISAB) for the Northwest Power Planning Council and the National Marine Fisheries Service produced a recent review of agency salmon recovery strategies for the Columbia River Basin (ISAB 2001). Although the review found these documents to be basically scientifically sound, the ISAB concluded that, "...the overall answer to the question of whether the four documents will lead collectively to salmon recovery actions that have a high chance of succeeding is probably no." Their reasons included a lack of important scientific data necessary to resolve critical uncertainties, lack of clear institutional arrangements to carry the program out, and the fact that the status of many native salmonid stocks has become very grave.

Anadromous fish are born in fresh water but spend a large part of their lives in the ocean before returning to the rivers of their birth to reproduce. Their complex life cycles, or distinct stages of growth and development, are highly variable depending on the particular species and the run within the species. A general description of a salmonid's life cycle includes five stages: (1) spawning and incubation, (2) juvenile rearing in freshwater, (3) seaward migration, (4) growth and maturation, and (5) return migration to freshwater to spawn (Steelquist 1992; National Research Council 1992; Cederholm et al. 2000).

Salmon require cool, clean flowing water with a high level of dissolved oxygen; clean gravel in the streambed for reproduction, a variety of in-stream cover, a sufficient food source, and unimpeded access to and from spawning areas and the ocean. Four important factors influence streams as habitat for salmon: water quality (temperature, dissolved oxygen level, turbidity), streamflow, physical structure of the stream and food supply. For example, in Bellevue, Washington, environmental disturbances, including habitat alteration, increased nutrient loading, and degradation of the intragravel environment had strong, negative effects on coho salmon (Scott et al. 1986).

Water temperature is probably the most crucial environmental factor influencing salmon and other aquatic species. Essentially all biological processes in a salmon's life cycle are affected by water temperature including the timing of spawning, incubation and emergence from gravel, appetite, metabolic rate, development and growth rate, timing of smoltification and ocean migration (Spence et al. 1996). In general, salmon require cold water ranging in temperatures between 4 C and 17 C (39 F and 63 F) for spawning, incubation and rearing (Beauchamp et al. 1983; Pauley et al. 1986; Laufle et al. 1986; Pauley et al. 1988; Pauley et al. 1989).

Salmon prefer clear water with low concentrations of suspended sediments. The level of dissolved oxygen (DO) is also important for survival. Fish have elaborate gill structures to allow the uptake and use of oxygen needed for reproducing, feeding, growing and swimming (Spence et al. 1996). Salmon also need a variety of streamflow conditions that create a mix of habitat types (e.g., deep pools, riffles). According to Spence et al. (1996), optimum streamflow requirements vary by species, life cycle stage, and season.

The physical structure of a river or stream is important in determining the quality of fish habitat. Structural components include macrohabitat such as pools, eddies, riffles, runs, and side channels, and microhabitat such as cover (e.g., overhanging vegetation, undercut banks), boulders, coarse streambed material, and water velocity and depth. Large woody debris provides critical cover for salmonids (Dooley and Paulson 1998; May et al. 1997b). Stream complexity is essential for salmon because at various life cycle stages they require different types of habitat. Adult spawning salmon use pools for resting on their upstream migration. Once at their spawning grounds they require clean gravel of various sizes, depending on the species, with a minimum amount of sediment to build their redds. Juvenile salmon use a mix of habitat types depending on their life stage, the time of year, availability of food and the presence of other salmon. For example, newly hatched fry live in shallow areas until they increase in size and then shift into deeper, faster water. Pool habitats are favorable to many salmonids in the summer whereas side channels or beaver ponds are preferred during the winter (Spence et al. 1996)

Salmon consume a wide variety of organisms during their life stages. Aquatic and terrestrial insects, however, are their primary food source. Fallen insects from riparian vegetation can make up 40 to 50 percent of the diet of trout and juvenile salmon during the summer months (Johnson and Ryba 1992).

Impacts of urbanization

The adverse effects of urbanization on salmonid habitat include increased temperatures, low dissolved oxygen, increased turbidity and sedimentation, changes in streamflow patterns and floodplain **connectivity**, loss of physical habitat (pools, riffles, gravel beds, off-channel habitats, hyporheic flow), and loss of invertebrate prey (see Appendix 1 for some important prey species). Woody debris is the preferred cover for cutthroat trout and other salmonids (May et al. 1997b; Solazzi et al. 1997), and its documented loss in urban streams degrades salmonid habitat quality (Bauer and Ralph 2001). In general, Pacific Northwest salmonid abundance and habitat quality are considerably reduced when TIA reaches 5-15 percent (Booth 1991; Booth et al. 1997; Horner et al. 1996; Booth and Jackson 1997; May et al. 1997a), similar to patterns seen for macroinvertebrates. This results in a reduction in the load of salmon carcasses to nourish organisms in and near the stream (Fuerstenberg 1997). In Seattle, Lucchetti and Fuerstenburg (1993b) documented a marked shift from less tolerant Coho salmon to more tolerant cutthroat trout populations at 10-15 percent TIA. However, cutthroat trout are also susceptible to the impact of land management activities, particularly those that result in changes in pool depth and complexity. This may reduce habitat suitability and, therefore, the stream's carrying capacity for this species; persistence of this and other species may well depend on arresting the decline in quality and quantity of freshwater habitat (Reeves et al. 1997).

At the Salmon in the City conference (American Public Works Association 1998), participants came to several conclusions regarding salmonid issues in urbanized regions of the Pacific Northwest. First, relatively pristine watersheds that currently or potentially support wild salmonids must be protected. This includes maintaining effective impervious surfaces close to zero, retaining 60-70 percent canopy cover, and retaining broad buffers of undisturbed native vegetation along the majority of riparian corridors. In already urbanized watersheds it will be necessary to address the hydrological impacts of development, protect riparian corridors, restore physical habitat, and improve water quality if we are to maintain or improve salmonid populations.

Amphibians

General requirements

Sixteen native amphibian species live in the Metro region, including twelve salamanders and five frogs (plus one extirpated frog species). An additional species, the Bullfrog, is introduced and places considerable pressure on native species. Amphibians and birds are the two groups in our area most dependent on aquatic and riparian habitats. In the Metro region, 69 percent of native amphibian species (salamanders, toads and frogs) rely exclusively on stream or wetland related riparian habitat for foraging, cover, reproduction sites and habitat for aquatic larvae. Another 25 percent use these habitats during their life cycle. Six Metro-region amphibian species are state-listed species at risk; four species are considered at risk at the federal level.

Amphibians require both aquatic and terrestrial habitats to complete their life cycle, thus changes to either ecosystem may interfere with their success (Schueler 1995). Small non-fish bearing streams and beaver ponds may be important because they are free from competition and predation by fish (Metts et al. 2001). As with salmonids, amphibians have specific habitat requirements and are sensitive to environmental change. For example, Tailed Frogs occur only in streams with temperature ranges from 0-16° C, and increase in abundance as temperature declines; tadpoles require smooth, cobble-sized stones to which they attach with sucking mouthparts (Claussen 1973). Clean, relatively sediment-free water, rocky stream beds and woody debris are important to amphibians in western and southern Oregon (Bury et al. 1991; Welsh and Lind 1991; Butts and McComb 2000).

Impacts of urbanization

Amphibians have suffered worldwide declines over the past 20 years, with particularly noteworthy declines in the Pacific Northwest (LaRoe et al. 1995; Richter and Ostergaard 1999; Semlitsch 2000). Thus this may be the group most sensitive to human-induced habitat loss and alteration such as microclimate changes. For example, habitat fragmentation creates edge habitat, and edge habitats tend to have elevated temperatures and reduced humidity (Saunders et al. 1999; Gehlhausen et al. 2000; Laurance et al. 2000). Unlike other species groups, amphibians' skin is not waterproof, nor are their eggs, and such edge-induced changes may be lethal. Fragmentation and wetland isolation is also a problem because amphibians have small home ranges and cannot travel as freely as birds and mammals (Corn and Bury 1989; Richter and Azous 1995).

In the Puget Sound region, Richter and Azous (1995) found that amphibian **species richness** in 19 wetlands declined with increasing water fluctuation and urbanization (the two are linked); the study also found that small wetlands (< 2 hectares) supported surprisingly high species richness, and are often overlooked in conservation planning. This study suggests that stormwater adversely impacts sensitive aquatic-phase amphibians. In Missouri, Ahrens (1997) found a negative relationship between amphibian species richness and development density. Size and spatial isolation from other wetlands were the most important predictors for amphibian species richness in restored Minnesota wetlands; more species were found in larger, less isolated wetlands (Lehtinen and Galatowitsch 2001).

Urbanization, wetland loss and alteration of hydrologic cycles, which can kill larval amphibians through pond drying (altered hydrology and habitat) or increased predation, probably adversely affect amphibians in the Metro region. Removal of riparian forest overstory is known to harm two at-risk species, Tailed frogs and Torrent salamanders, as well as harming other amphibians (Kauffman et al. 2001).

As with salmonids, instream habitat quality and quantity, excessive sedimentation, and reduced woody debris are major issues for amphibians (Hawkins et al. 1983; Corn and Bury 1989; Butts and McComb 2000). Studies in other parts of the country document adverse effects due to wetland isolation, road density and environmental degradation (Delis et al. 1996; Mensing et al. 1998; Lehtinen et al. 1999; Knutsen et al. 2000). Bullfrogs may pose a major threat to native amphibians in the Metro region, where they both out-compete and predate native species (including non-amphibians such as young turtles and waterfowl) (Adams 1999; Adams 2000; Witmer and Lewis 2001). Bullfrogs are relatively insensitive to water quality and habitat fragmentation and can travel long distances overland, unlike most native amphibians.

Reptiles

General requirements

Thirteen native reptile species live in the Metro region, including two turtle, four lizard, and seven snake species. Two more turtle species are non-native. This is the least riparian-associated group; even so, 23 percent of native reptile species depend on water-related habitats and another 46 percent using them during their lives. Although most lizards and snakes are upland-associated, many species use riparian areas extensively for foraging because of the high density of prey species and vegetation. All of the turtle species are riparian/wetland obligates, and rely on large wood in streams and lakes for basking (Kauffman et al. 2001). The two native turtles are state and/or federal species at risk.

Reptiles are cold-blooded animals, and some species have special habitat requirements in order to collect the sun's energy. This translates into surfaces that are efficient heat collectors. For example, most lizard and snake species rely on **talus**, cliffs and rocky outcrops, or other rocky surfaces for gathering heat during cool periods. Crevices within these structures also provide important refuge during hot spells.

The reasons for species' reliance on riparian habitat are varied, and demonstrate the structural and functional diversity provided by riparian forests. For example, Western pond turtles eat a variety of foods such as insects, mollusks, fish, amphibians, and carrion. These animals require about six inches of forest leaf litter in which to overwinter and five or more inches of soil (with high clay content and good sun exposure) and close proximity to water for nesting (Oregon Department of Fish and Wildlife 2000). Riparian forests provide food and generate soil and leaf litter. The common garter snake, another riparian-dependent species, forages for amphibians, small fish, and earthworms and needs riparian denning sites with good cover, such as downed wood and good shrub and understory.

Impacts of urbanization

Little urban-specific information is available for reptiles in the Pacific Northwest, but in Missouri Ahrens (1997) found that reptile species richness was negatively correlated with high density residential and institutional land uses, but not with other land uses such as low density residential, commercial, industrial, recreational and roads. In Oregon, Western pond turtles are in serious jeopardy due to habitat loss and predation on hatchlings, and have dangerously restricted gene pools in the Metro region due to isolation (Gray 1995; Oregon Department of Fish and Wildlife 2000). Habitat connectivity is probably important to lizards and snakes, as well. Losses of LWD and beaver ponds for turtle basking and use by common garter snake are probably detrimental (Metts et al. 2001). The two non-native turtles with established populations (probably from released pets), common snapping turtle and red-eared slider, pose significant threats to native turtles (Gray 1995; Oregon Department of Fish and Wildlife 2000).

Birds

General requirements

Birds often represent a majority of vertebrate diversity in a region, and the 209 native bird species on Metro's Species List represent a full two-thirds (67 percent) of the region's native vertebrate species. An additional four non-native species have established breeding populations in the area. In the Metro region, about half (49 percent) of native bird species depend on riparian habitats for their daily needs, and 94 percent of all native bird species - the same percentage as amphibians - use riparian habitats at various times during their lives. Twenty-two bird species on Metro's list are state or federal species at risk. Nineteen of these are riparian obligates or regularly use water-based habitats. An additional riparian obligate, the Yellow-billed Cuckoo, is extirpated in the Metro region.

Bird abundance, species richness and diversity is typically higher in riparian habitats compared to other habitat types (Stauffer and Best 1980; LaRoe et al. 1995; Kauffman et al. 2001). This reflects greater plant volume and structural diversity (birds are highly 3-dimensional in their habitat use), and food, water and habitat resources associated with riparian vegetation (LaRoe et al. 1995). The occasional study seeming to refute these trends (e.g., McGarigal and McComb 1995; Murray and Stauffer 1995) is typically set in areas where there is little contrast between riparian and upland vegetation. The Oregon-Washington chapter of Partners In Flight offers conservation strategies for landbirds in coniferous forests and lowlands and valleys of western Oregon (Altman 1999; Altman 2000).

Impacts of urbanization

Birds are the most well-studied group of terrestrial urban wildlife. Urban bird communities are characterized by reduced diversity and species richness compared to undisturbed habitats, but increased total abundance due to domination by a few nonnative and urban-associated species (Penland 1984; Blair 1996). There tends to be a loss of species, particularly habitat specialists, over time (Aldrich and Coffin 1980; Hennings 2001). European Starlings, an abundant non-native species, are closely associated with riparian habitats and can comprise 50 percent or more of total birds in the region's narrow riparian forests (Hennings 2001; Hennings and Edge 2003). Neotropical migratory birds appear to respond negatively to development and rely heavily on riparian areas for migratory stopover habitat (Moore et al. 1993; Friesen et al. 1995; Nilon et al. 1995; Theobald et al. 1997; Mancke and Gavin 2000; Hennings 2001).

Breeding Bird Survey data from the Pacific Northwest indicate long-term Neotropical migratory bird declines, particularly for those species relying on older or riparian forests (Sharp 1995-1996). Some bird species, such as Rufous Hummingbirds, Winter Wrens, Brown Creepers and Pacific-slope Flycatchers, may be particularly sensitive to habitat fragmentation in the metro area and appear to need large habitat patches (McGarigal and McComb 1995; Hennings 2001; Hennings and Edge 2003). In Connecticut, Askins et al. (1987) found that for forest interior-dwelling bird species, both reduced patch size and increased patch isolation were detrimental.

At least 13 riparian-occurring breeding bird species that have declined significantly more rapidly in the Metro region than statewide over the past 32 years (Hennings 2001; Table 6). Along with fragmentation-sensitive species, these birds may be at risk in the Metro region and merit further study.

Table 6: Examples of some bird species whose trends differ substantially between the Metro area and all BBS routes statewide (1966-1998).

Metro region vs. Oregon 32-year Breeding Bird Survey

Species	Trend Difference (% per year)	Riparian or ag loss	Ground/low nester	Open-cup nester	Cavity or bag nest	Neotropical migrant	Insectivore
Yellow Warbler	-11.9	X		X		X	X
California Quail	-10.3	X	X				
Olive-sided Flycatcher	-7.6			X		X	X
Common Yellowthroat	-7.6	X	X	X		X	X
Brown-headed Cowbird	-7.3	X		X		X	
Swainson's Thrush	-6.4	X	X	X		X	X
Black-headed Grosbeak	-6.4	X		X		X	X
Bushtit	+3.1				X		X
Vaux's Swift	+6.2				X	X	X
Bewick's Wren	+6.4				X		X
Chestnut-backed Chickadee	+6.9				X		X

Source: Hennings 2001.
Note: Habitat loss is implicit for all species listed. Data compiled from 32-year (1966-1998) Breeding Bird Survey data.

Birds, like insects, can be good indicators of habitat conditions. As a group they are easy to observe, sensitive to environmental changes, and responsive to habitat fragmentation (see the ***Upland Habitat*** section). The Bureau of Land Management (no date) compiled a list of bird species as indicators of riparian vegetation condition in the western U.S., based on geographic area and potential vulnerability of the species. In the Metro region, six species are likely to place over 90 percent of their nests in riparian vegetation (or greater than 90 percent of their abundance occurs in riparian vegetation during the breeding season). These species vary in the vegetation layer used. For example, Common Yellowthroats and Song Sparrows most frequently use understory vegetation. Willow Flycatchers and Yellow-breasted Chats use understory and midstory. Yellow Warblers use midstory and canopy, and Wilson's Warblers use all three vegetation layers. Swainson's Thrush, Lazuli Bunting, Black-headed Grosbeak, and Warbling Vireo also make good indicator species. According to Breeding Bird Survey 32-year trends, each of these species have declined in the Metro region compared to statewide (except Wilson's Warbler and Lazuli Bunting, whose abundance was too low in the Metro region for analysis) (Sauer et al. 2000; Hennings 2001). These species may provide valuable monitoring tools to help assess existing and future riparian habitat conditions in the Metro region.

Mammals

General requirements

Mammals are another diverse group of species in the Metro region, with 54 native species. This is the terrestrial group with the highest number of non-native species (eight species, or 15 percent of total species; most are rodents). Of native species, 28 percent are closely associated with water-based habitats, with another 64 percent using these habitats at various points during their lives. Six out of nine bat species are state or federal species at risk. Three native rodent species are similarly listed.

Riparian resources are important to mammals for many of the same reasons they are important to amphibians and birds, i.e., diverse habitat structure, abundant coarse woody debris, good connectivity, access to water and a wealth of food resources (Butts and McComb 2000; Kauffman et al. 2001). In Pacific Northwest forests, multispecies canopies, coarse woody debris, and well-developed understories (dominated by herbs, deciduous shrubs and shade-tolerant seedlings) were important to small mammal biodiversity across a broad suite of spatial scales (Carey and Johnson 1995). Other Pacific Northwest studies have shown increased small mammal abundance and/or diversity with increasing coarse woody debris (McComb et al. 1993; Butts and McComb 2000; Wilson and Carey 2000). Riparian forests contain high amounts of coarse woody debris, and this may be why some studies document higher small mammal abundance in riparian habitats than in uplands (Doyle 1990; Menzel et al. 1999; Bellows and Mitchell 2000).

Bats in the Pacific Northwest are more abundant and diverse in habitats with increased roost availability and diversity, including a variety of tree, cliff, and cave roosts; canopy cover and structural complexity is very important to this sensitive group (Wunder and Carey 1996). Bats often roost in artificial structures, and bat-friendly habitats can be provided in both new and existing bridges and other structures at little or no extra cost (Tuttle 1997). This may be as simple as specifying appropriate crevice widths of three-fourths to one inch in expansion joints or other crevices. Tuttle (1997) offers designs for retro-fitting bat-friendly habitats into existing structures; one is called the Oregon Bridge Wedge, designed to provide day-roost habitat in bridges and culverts.

Mammals can profoundly influence habitat conditions for other animals. Beaver, a **keystone species** in riparian areas, play a critical role in the creation and maintenance of wetlands and stream complexity, and may have broad effects on physical, chemical, and biological characteristics within a watershed (Cirmo and Driscoll 1993; Snodgrass 1997; Schlosser and Kallemeyn 2000). Beaver can also create nuisance problems due to tree removal and unplanned flooding, but property damage can be minimized by activities such as protecting trees with exclosures (Olson and Hubert 1994; Snodgrass 1997; Oregon Department of Fish and Wildlife 2001). Historically, beavers were nearly extirpated from the Willamette Valley due to trapping, but populations have rebounded somewhat (Oregon Department of Fish and Wildlife 2001). Large herbivores such as deer browse on herbs and shrubs, which can promote vigorous growth (Kauffman et al. 2001). Cattle grazing can have severe detrimental consequences on riparian habitats (Knopf et al. 1988; Grant 1994). Medium-sized **carnivores** keep rodent and small predator populations in check while large carnivores control herbivore populations, with important implications for bird nest success (Berger et al. 2001). Rodents eat Spruce budworm, an insect whose outbreaks can cause significant forest loss (Jennings et al. 1991). Bats help regulate insect populations and may contribute to nutrient cycling, particularly in riparian areas (LaRoe et al. 1995).

Impacts of urbanization

Most mammal research has been conducted outside the urban setting. However, Dr. Michael Murphy's graduate students at Portland State University are providing insights into small mammal needs in the urban area (Murphy 2005). As yet unpublished, their research indicates that the following small mammals may need habitat patches of 10 ha or greater: shorttail weasel, Oregon vole, Northern flying squirrel, shrew-mole, white-footed mouse, Trowbridge's shrew, vagrant shrew, Douglas squirrel, Western gray squirrel, and Townend chipmunk. Conversely, non-native mammals tended to decrease in abundance in larger patches.

Bolger et al. (1997a) found that small mammal extirpation rates increased with fragmentation in urban habitats. The loss of habitat, connectivity, forest structural diversity, and LWD common in urban areas probably harm many mammals. Bats are generally intolerant of human disturbance and in western Oregon, are more abundant in old-growth than other forest types; Townsend's big-eared bat abundance has declined by 58 percent west of the Cascades since 1985 because of habitat alteration and human disturbance (LaRoe 1995). Nutria are the primary nonnative mammals using streams in the Pacific Northwest. Introduced for fur, nutria have established populations in at least 15 states, where they inflict wetland and agricultural damage and compete with beaver and muskrat for resources (Pedersen 1998; Abrams 2000). Pets, especially cats and dogs, can be disruptive and/or lethal to native birds and small mammals (see also Uplands chapter, Nonnative species section).

Riparian area width

The functions and values of riparian corridors with respect to fish and wildlife, as well as the impacts from urbanization, have been explored in the preceding sections. In this section we review the riparian area widths identified in the scientific literature that are necessary to protect habitat for fish and wildlife. Several recent literature reviews have addressed the effectiveness of various riparian area widths for maintaining specific riparian functions for both protecting water quality and preserving the biologic integrity of the riparian corridor (Budd et al. 1987; Johnson and Ryba 1992; FEMAT 1993; Castelle et al. 1994; Spence et al. 1996; Metro 1997; Wenger 1999; May 2000). The biological integrity of the riparian corridor depends, in part, on the width and condition of the riparian area, which dictates stream functions and ultimately the type of species that can live in and around streams.

A riparian buffer is defined as a strip of land established to mitigate the impacts of human activities on the stream ecosystem (Johnson and Ryba 1992; May 2000). Riparian buffers serve to protect natural functions as well as minimizing impacts of stormwater runoff and preventing property loss due to flooding (May 2000). The riparian buffer includes riparian habitat that provides key functions and values for many wildlife species dependent on the unique environment.

The effects of human activities on riparian and aquatic ecosystems are numerous and pervasive in the urban area, as discussed in the previous sections. A riparian buffer alone is not enough to maintain natural aquatic functions; additional efforts in managing stormwater runoff and protection of upland areas are essential in a comprehensive watershed protection plan (Knutson and Naef 1997). The appropriate size of a riparian buffer is likely to vary depending on the position of a stream in the landscape and the intensity of land use nearby (Todd 2000). Wider buffers may be required in urban areas with higher intensity land uses than in a forested or rural landscape (May 2000; Todd 2000). Wider buffers are critical in retaining functions and values for wildlife that utilize riparian areas. When we refer to a riparian buffer width we are referring to the width *on one side* of a stream, river or other water feature. The buffer is then to be applied on *both sides* of the stream or other water feature.

Fixed width vs. variable width buffer

Riparian buffers are commonly implemented to protect a wide range of functions provided by the riparian area, ranging from water quality and flood control to fish and wildlife habitat. The size, or width, of the buffer depends on the function(s) to be protected and the type of land use that occurs outside of the buffer area. Buffers are implemented as either a fixed width or a variable width requirement.

Fixed width buffers are typically based on a single parameter, such as a specific function (Castelle et al. 1994). They are often developed as a political compromise between protecting ecological functions and minimizing the impact on private property rights (May 2000). This type of buffer is relatively easy to enforce, provides for regulatory predictability, and costs less to administer because those applying the regulations do not need specialized skills (Johnson and Ryba 1992). Fixed width buffers, however, do not account for site-specific conditions, thus the riparian corridor may not be adequately protected in some areas, and in others the buffer might unnecessarily restrict development (Fischer and Fischenich 2000; Todd 2000). May and Horner (2000) stated that "...a one-size-fits-all buffer is not likely to work."

Variable width buffer programs account for site-specific conditions, providing a greater level of protection to important resources while reducing the impact on private property in certain instances (Johnson and Ryba 1992; May 2000). However, this type of buffer program is more expensive and difficult to administer and monitor and offers less predictability for land use planning purposes (Johnson and Ryba 1992; Castelle et al. 1994; Todd 2000).

A hybrid of the fixed and variable width buffer could conceivably address several of the problems with both while drawing on each method's strengths. A variable width buffer based on existing conditions and the intensity of the adjacent land use that is generalized to the extent possible might provide the best protection of the riparian corridor while respecting private property rights (Todd 2000).

Management areas vs. setbacks

Just as important as the width are the activities are allowed within the riparian buffer. Some riparian buffers are implemented as setbacks within which no disturbance is allowed, with the exception of restoration activities. Other riparian buffers are considered "management areas" within which a limited amount of activity may occur. This allows for some level of development as long as guidelines are followed so as to retain riparian functions. Human activities within the riparian buffer should be limited to prevent further degradation of riparian and aquatic habitat.

Extent

To the maximum extent possible, all perennial, intermittent and ephemeral streams should be protected from surrounding land use activities by a buffer (Mitchell 1998; May 2000). The effectiveness of a riparian corridor protection program depends on the amount of stream miles that are protected; the more miles protected, the more effective a program will be (Wenger 1999). As stated by Fischer et al. (2000): "Continuous buffers are more effective at moderating stream temperatures, reducing gaps in protection from non-point source pollution, and providing better habitat and movement corridors for wildlife."

Several functions important for fish and wildlife are influenced by the entire system of streams. For instance, nearly half of the large woody debris found in low gradient streams is delivered from upstream sources (Pollock and Kennard 1998). Studies have also found that the temperature of streams is influenced not only by the condition of adjacent forest but also by upland forest conditions and upstream conditions (Pollock and Kennard 1998).

The entire stream network functions as a system, thus removing the connection between intermittent and perennial streams may have detrimental consequences to the physical and biological components of stream ecosystems, particularly in the long term (Mitchell 1998; FEMAT 1993). Naiman et al. (1992) stated that intermittent streams are an important, often overlooked, component of aquatic ecosystems. For example, juvenile Chinook salmon rely on intermittent streams for rearing habitat (Maslin et al. 1999).

Riparian buffers are especially important along the small headwater streams that typically make up the majority of stream miles in any basin

Osborne and Kovacic 1993; Hubbard and Lowrance 1994; Lowrance et al. 1997; May et al. 1997a; Fischer et al. 2000). These smaller streams have more interaction with the land and riparian vegetation plays an integral role in reducing sediment and other pollutants, maintaining temperature regimes, and providing large woody debris and other organic inputs (FEMAT 1993). Riparian buffers along larger streams have less of an impact on water quality, however they often are longer and wider thus providing better wildlife habitat (Fischer et al. 2000).

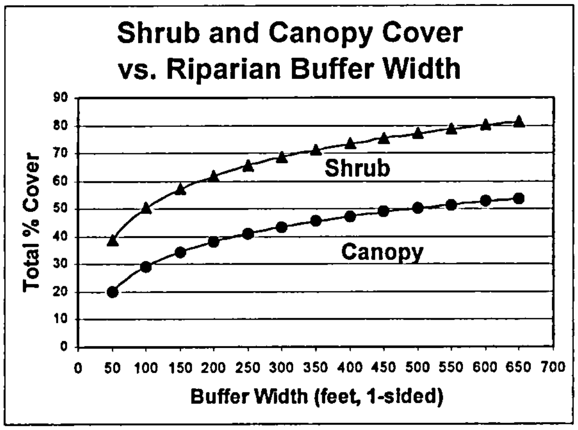
In urban areas the functions of the aquatic ecosystem are altered, as described in the previous section. Increased urbanization causes an increase in negative inputs such as contaminants, stormwater flow, and also reduces the amount of large woody debris and other organic inputs required for the survival of aquatic life (Booth et al. 1997; Todd 2000). Johnson and Ryba (1992) stated that " a large buffer in an area of high-intensity land use...is more essential than in low-intensity land use areas." FEMAT (1993) recommends 91 m (300 ft) on each side of fish bearing streams in a forested landscape, as well as protecting permanently flowing non-fish bearing streams; constructed ponds, reservoirs, and all wetlands greater than one acre; all lakes and natural ponds; and seasonal or intermittent streams, smaller wetlands, and unstable areas to a lesser extent. The protection of all of these areas is crucial to maintaining habitat for aquatic species, with further protection necessary for riparian-associated wildlife. In an urban area, with the greater impacts associated with urbanization, a protection scheme of less than that recommended by FEMAT in the forested landscape may not be sufficient to fully provide fish and wildlife habitat.

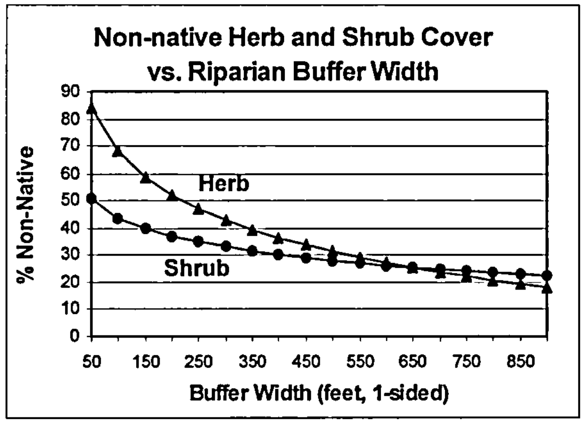
Vegetation

Riparian corridors should consist of native vegetation along the stream where appropriate (May 2000). As described throughout this chapter, native vegetation provides several crucial functions that enable the riparian corridor to provide high value fish and wildlife habitat. The quality of the vegetation in a riparian buffer is crucial to the provision of organic litterfall, large woody debris, shade, and other riparian functions (May 2000).

Forest width plays an important role in urban riparian plant community structure and composition. Watersheds with intact riparian forests are able to retain more riparian functions at higher levels of imperviousness (May et al. 1997b). Within the Metro region, researchers comparing rural versus urban habitats found that riparian forest width was the only significant predictor of native plant species richness (wider forests had more species), while native plant diversity was best explained by perimeter-to-area ratio, a measure of edge (smaller patches had lower diversity) (O'Neill and Yeakley 2000). In another Metro-area study, riparian forest width was the best predictor for nonnative plants along small streams; narrow forests contained higher percentages of nonnative herbaceous, shrub and tree cover than wider sites (Figure 9) (Hennings 2001; Hennings and Edge 2003). In addition, narrow forests were less structurally complex, with reduced shrub and canopy cover.

Figure 9. Relationships between riparian forest width and forest structure and composition measured along 54 small stream sites in the Metro region, surveyed July and August 1999.





Source: Hennings 2001.

Factors that influence buffer width

Several factors should be taken into consideration when determining the size of the riparian buffer. Floodplains, steep slopes, and wetlands are important resources in themselves and strongly influence the ability of the riparian area to provide key functions for fish and wildlife.

Floodplain

One of the important factors determining the width of the riparian area is the presence of floodplains. Unconstrained reaches typically have large floodplains compared to constrained reaches. The linkage between the stream and its floodplain is of critical importance to fish and wildlife (Knutson and Naef 1997; May 2000). The floodplain includes the limits of the stream channel migration zone and also represents the zone of interchange between land and water (Wenger 1999). Stream channels, except for those in steep gullies or canyons, naturally move as the result of seasonal flood events. The floodplain and channel migration zone is the area that could potentially become aquatic habitat, but currently provides riparian habitat (Pollock and Kennard 1998). A buffer zone should be wide enough to permit natural channel migration (Wenger 1999; May 2000).

The entire floodplain plays an important role in contaminant removal. According to the scientific literature, the riparian zone of influence includes the extent of the 100-year floodplain because of the movement of the stream or river across the floodplain through time (Gregory and Ashkenas 1990; Schueler 1995; Spence et al. 1996). It is important to protect the entire width of the floodplain because this area provides essential spawning and rearing habitat for fish and important year round habitat for turtles, beavers, muskrats and other wildlife. Therefore the riparian area width should include the extent of the 100-year floodplain (Wenger 1999; May 2000).

Steep slopes

The slope of the land on either side of a stream is one of the most significant variables in determining the effectiveness of a buffer in trapping sediments, retaining nutrients, preventing contaminants from reaching the stream, and reducing erosion. Steeper slopes have higher velocities of surface water flow, resulting in less time for nutrients and other contaminants to pass through the buffer and reach the stream (Wenger 1999). Mass wasting of unstable slopes contributes to degraded water and riparian habitat quality (Knutson and Naef 1997). Several researchers have observed that very steep slopes are unable to effectively remove contaminants from surface water flow (Wenger 1999). Steep slopes adjacent to all streams should be protected.

Steep slopes often occur on intermittent streams, where it is especially important to protect the slope to prevent increased landslides and erosion and provide habitat for species unique to these areas. FEMAT (1993) recommends buffers ranging from about 12-61m (40-200 ft) on intermittent streams, depending on the stability of the soil.

There is debate as to what constitutes a steep slope. Jurisdictions have defined steep as ranging from 10 to 40 percent slope. Metro defined steep slopes as 25 percent in the Stream and Floodplain Protection Plan (Title 3). May (2000) recommended that for slopes over 25 percent the buffer should be measured from the break in slope to reduce sediment loading from mass wasting events.

Wetlands

Wetland habitats frequently overlap with riparian areas, although some wetlands are isolated from streams or rivers. Isolated wetlands are often small but may have unique characteristics that allow specialized plant species to develop (FEMAT 1993). Wetlands provide many of the same functions as riparian areas, such as maintaining water quality, retaining water and reducing floods. Wetlands comprise a very small proportion of the landscape and yet provide for a significant number of specialized plant and animal species. Thus, riparian wetlands are significant enough to merit automatic inclusion in a protection scheme (FEMAT 1993; Wenger 1999). FEMAT (1993) recommended one site potential tree height or 46 m (150 ft) slope distance for wetlands greater than one acre, and two site potential tree heights or 91 m (300 ft) slope distance for lakes and natural ponds. May (2000) recommended that all riparian wetlands adjacent to the stream channel be protected from disturbance, and that a minimum buffer of 30-50 m (98 – 164 ft) should extend outward from the wetlands.

Site Potential Tree Height

Site potential tree height is often used as a standard of measurement within which several key riparian functions are provided. For example, several studies suggest that in order to supply large woody debris and maintain temperature and streambank stability, the width of the riparian corridor should be at a minimum equal to one site-potential tree height at maturity (FEMAT 1993; Spence et al. 1996; Pollock and Kennard 1998; May 2000). Thus, the term is used to communicate a general riparian standard that allows for the operation of multiple ecological functions; not just the functions directly attributed to trees.

Various definitions for site-potential tree height (SPTH) exist. For example, the Oregon Division of State Lands (DSL) defines the potential tree height as the dominant tree species at maturity. DSL provides a list of common riparian trees in Oregon in their Urban Riparian Inventory & Assessment Guide (Van Staveren et al. 1998) ranging from 15 feet to 120 feet. FEMAT (1993) defines the height of a site-potential tree as the average maximum height of the tallest dominant trees (200 years or more) for a given site class. The NMFS uses a similar definition but considers the tallest dominant trees within 100 years, given site conditions. According to the NMFS definition, these heights range from about 130 feet to over 200 feet for second-growth conifers in riparian areas; second-growth conifers are commonly found in Portland area forests.

Aquatic Habitat

Most anadromous and resident fish require deep pools for cover and to rest; riffles for foraging; and cold, well-oxygenated, gravel-bottomed streams to spawn and reproduce. The width and composition of the riparian area are factors that assist in maintaining habitat needed to support the various life cycles of fish and other aquatic species.

Temperature regulation and shade

An important factor influencing stream diversity and productivity is shade from riparian vegetation, which keeps stream temperatures cool. Elevated water temperature affects its ability to hold the oxygen required for aquatic life, and is particularly detrimental to cold water fish like salmon and trout. Intact riparian vegetation helps regulate water temperature. Beschta and Taylor (1988) found that many factors influence stream temperature in forested watersheds, one of the most important being intact riparian vegetation. Spence et al. (1996) identified site-specific factors that influence the riparian area's ability to provide shade including vegetation composition, stand height, stand density, latitude (which determines solar angle), topography, and stream orientation. Several studies conducted in the Cascade and Coast Ranges of western Oregon examined the effectiveness of riparian area widths for shade and temperature regulation and concluded that riparian area widths of at least 30 m (98 ft) provide adequate shade to stream systems (Spence et al. 1996). In most instances, riparian area widths maintained for other functions such as LWD are likely to be adequate to protect stream shading (Spence et al. 1996).

The temperature of groundwater entering streams also influences stream temperature (Brosofske et al. 1997). Removal of surrounding riparian and upland forest may increase groundwater temperature. However, on small streams shading is likely to be the most important factor in regulating temperature (Wenger 1999). In a literature review, Osborne and Kovacic (1993) found that buffer widths of 10-30 m (33-98 ft) can effectively maintain stream temperatures. However, newer research has found that buffer widths of 21-24 m (70-80 ft) are not sufficient to maintain stream temperatures that approximate natural conditions (Pollock and Kennard 1998). Brosofske et al. (1997) found that a buffer of 76 m (250 ft) is necessary to maintain natural shade levels and reduce the impact of solar radiation. Factors other than riparian vegetation also impact temperature, such as dams and industrial discharge.

Bank stabilization and sediment removal

Riparian vegetation helps to stabilize streambanks, making them less susceptible to excessive erosion. The Forest Ecosystem Management Assessment Team (FEMAT) (1993) concluded that most of the stabilizing influence of riparian root structure is probably provided by trees within a half of a potential tree height of the stream channel. All streams can be subject to channel erosion if the banks are not properly stabilized, and upstream sediments have a large impact downstream. Ensuring stable banks on the entire stream network, including intermittent and ephemeral streams, is important to maintaining a functioning aquatic system. In their natural state ephemeral streams typically contain dense growth and trap surface water sediment and slow flow, but they can provide a large quantity of in-stream sediment during storm events in disturbed areas. Clinnick (1985) proposes a minimum of a 20 m (66 ft) wide buffer on ephemeral streams.

As described in the *Impacts of Urbanization* section, sedimentation can be very detrimental to fish (particularly salmonids) and other aquatic organisms (Hicks et al. 1991). Riparian vegetation helps to control excess sediment from entering streams. In a study on California streams, Erman et al. (1977) found that a 31-meter (100-foot) vegetated buffer was successful in preventing sedimentation and thus maintaining background levels of benthic invertebrates (aquatic insects) in streams adjacent to logging activity. Moring (1982) assessed the effect of sedimentation following logging with and without buffer strips of 30 m (98 ft) and found that increased sedimentation from logged, unbuffered streambanks clogged gravel streambeds and interfered with salmonid egg development.

According to Belt et al. (1992), "Research suggests four things about buffer strip design to trap sediments and nutrients: 1) buffer strips should be wider where slopes are steep, 2) riparian buffers are not effective in controlling channelized flows originating outside the buffer, 2) sediment can move overland as far as 300 feet through a buffer in a worst case scenario, and 4) removal of natural obstructions to flow – vegetation, woody debris, rocks, etc. – within the buffer increases the distance sediment can flow." For a more detailed discussion of buffer widths for sediment see Metro's **Policy Analysis and Scientific Literature Review for Title 3** (1997).

Pollutant removal

In 1998 Metro adopted a plan for protecting water quality and floodplain management, but it did not specifically address wildlife issues. However, excess nutrients, metals, pesticides and other contaminants also impact the quality of habitat for fish and wildlife. Therefore, we revisit these issues briefly here, but for a more detailed discussion see Metro's **Policy Analysis and Scientific Literature Review for Title** *3* (1997).

Excess levels of phosphorous common to urban areas cause eutrophication in the stream system, as described in the *Impacts of Urbanization* section. Most phosphorous is carried to the stream attached to sediment, thus buffer widths that are sufficient to retain sediment should also prevent phosphorous from reaching the stream (Wenger 1999). However, riparian vegetation can only retain phosphorous over a short time period, after which the vegetation becomes oversaturated and actually releases phosphorous into the stream.

Nitrogen also contributes to eutrophication in aquatic ecosystems. A vegetated buffer along a stream is able to remove nitrogen through uptake by vegetation and by denitrification. Several studies have found that total nitrogen removal efficiencies in surface water flow increase with buffer width (Dillaha et. al 1988; Dillaha et. al 1989; Magette et. al 1989). Denitrification occurs under conditions of reduced oxygen availability, which correlates with soil moisture. Wetlands and hyporheic zones play an important role in denitrification. According to Wenger (1999), a minimum width of 15 m (50 ft) is necessary to reduce nitrogen levels, but wider buffers of 30 m (100 ft) or more would be more likely to include areas of denitrification.

Pesticides are meant to be deadly. When pesticides enter the stream they can cause direct mortality to many organisms as well as an array of sublethal effects (Cooper 1993). Pesticides used in landscaping commonly find their way to streams and rivers. Riparian vegetation plays an important role in preventing direct contamination of streams. Buffers can help to remove pesticides from surfacewater flow, but we were unable to locate current research to identify specific widths necessary to prevent them from reaching the stream (Wenger 1999).

Large woody debris and litter inputs

Large woody debris

As discussed previously, large woody debris (LWD) is an important structural component in Pacific Northwest streams west of the Cascade Range. Forested riparian areas are necessary to provide regular inputs of LWD; removal of trees and vegetation can have long-term negative effects (Booth et al. 1997; May et al. 1997b; Wenger 1999). The potential for trees or portions of a tree to enter the stream channel is primarily a function of distance from the stream channel in relationship to tree height and slope angle (FEMAT 1993). A review of the scientific literature shows that the probability that LWD will enter the stream channel is generally low at greater than one site-potential tree height, or the height of the dominant tree species at maturity (McDade et al. 1990; FEMAT 1993; Spence et al. 1996; Wenger 1999).

Sometimes seemingly conflicting science makes management decisions difficult. For example, the literature review for Washington State's Forests and Fish Report (CH2MHILL 2000) stated that, "Of all the inputs from riparian zones to streams, LWD delivery requires the widest riparian management zone (RMZ)." However, the same review showed McDade's (1987) data from small streams of the Cascade and Coast Ranges of Oregon and Washington, in which over 70 percent of the total LWD delivered to the channel originated within 50 feet of the channel, and over 90 percent within 100 feet of the channel. Spence et al. (1996) reviewed the literature and found that most recent studies suggest buffers approaching one site-potential tree height are needed to maintain natural levels of recruitment of LWD. Streams naturally migrate within the valley floor or floodplain, and LWD is also delivered to streams by flooding and landslides. The additional importance of LWD to terrestrial wildlife, as well as the importance of all organic matter to healthy soils (and, therefore, healthy riparian forests), argue for LWD buffers of at least one SPTH.

The Independent Multidisciplinary Science Team's (IMST) 1999 report to the Governor John Kitzhaber stated:

> Sharp demarcations between riparian forest and upslope forest, and between fish-bearing and nonfish bearing streams are not consistent with the historic pattern...Most models of large wood recruitment focus on riparian areas as the source, ignoring the important contributions made by upslope sources, especially from landslides. There is a critical need to restore the ecological processes that produce and deliver large wood to the streams from riparian as well as upslope areas.

In addition to lateral LWD inputs to the stream, studies show that up to half of the large woody debris found in lower gradient streams is transported from upstream sources (Pollock and Kennard 1998). This emphasizes the importance of protecting the entire stream network to allow for a sufficient level of large wood. Management activities such as forest thinning within a buffer also may reduce the amount of large woody debris that is provided to the stream; when possible, removal of large woody debris in riparian areas should be avoided.

Small woody debris and organic litterfall
Branches and other woody material play an important role in providing aquatic habitat. Smaller wood helps to create and maintain pools in smaller streams, often backing up against large wood (Pollock and Kennard 1998). Pollock and Kennard (1998) found that the majority of small woody debris is delivered to small and mid-sized streams from trees further than 31 m (100 ft) from the edge of the stream.

Smaller pieces of organic litter (e.g., leaves, needles and twigs) and terrestrial insects, important food sources for aquatic species, enter the stream primarily by direct leaf or debris fall (Spence et al. 1996). The effectiveness of riparian forests in the delivery of small organic debris decreases at distances further than one-half of a site potential tree height (FEMAT 1993). Benthic invertebrates rely on a supply of organic litter to maintain healthy communities. Erman et al. (1977) found that the composition of benthic communities in streams with buffers of 31 m (100 ft) were basically the same as streams in unlogged watersheds.

Terrestrial Habitat

Riparian areas provide essential life needs – food, water and cover – for many terrestrial species. Each species has unique habitat requirements; therefore, widths to protect wildlife can vary greatly. Riparian buffers established for water quality and to protect aquatic habitat may not meet the habitat requirements of terrestrial wildlife (Gregory and Ashkenas 1990). Narrower buffers may support a limited number of species, but wider buffers – at least in some places – will support a more diverse range of wildlife species. Connections to upland wildlife habitat can be especially important for many species.

Large woody debris and structural complexity

Large woody debris (LWD), both standing and fallen, is an important source of foraging, cover and nest sites for birds, mammals, reptiles, and amphibians. LWD provides nesting habitat for cavity nesting birds such as woodpeckers, chickadees and wrens. Downed logs provide cover for a number of amphibians common to riparian corridors, such as Long-toed salamanders and Torrent salamanders. The greater the width of the riparian area, the more wood that is potentially available for snag and downed wood habitat. The more snags present in the riparian area, the greater the wildlife species diversity tends to be (Cline and Phillips 1983). Just as the ability of forests to contribute LWD to aquatic habitat decreases at distances further than one site potential tree height, the effectiveness of upland forests to contribute snags and downed wood decreases at greater distances (FEMAT 1993).

Edge effect

One of the main reasons interior forest dwelling species do not survive successfully in narrow buffers is because of increased edge habitat (edge habitat is more fully discussed in the ***Upland Habitat*** section). Edge habitat occurs when two different habitat types meet, which provides opportunities for some species but also can lead to an increase in competition and predation, reducing interior habitat specialists. Studies in Virginia showed that interior forest birds only occurred in riparian corridors of at least 50 m (164 ft) wide (Tassone 1981), and another study showed that a minimum buffer of 100 m (328 ft) was recommended to support area-sensitive Neotropical migrants (Keller et al. 1993). In eastern forests the edge effect has been shown to extend up to 600 m (2,000 ft) from the edge (Wilcove et al. 1986).

Noise frequently impacts the ability of wildlife to carry on their natural functions within the urbanized landscape. Harris (1985) found that a mature evergreen buffer of 6.1 meters (20 feet) provides the same level of noise reduction as removing the source of the noise three times farther from the habitat without the vegetation. Groffman et al. (1990) found that a forested buffer of 32 meters (100 feet) would reduce the noise of commercial activity to background levels.

Movement corridors

Riparian buffers often may serve as movement corridors for wildlife and plants. Riparian corridors serve as travel and dispersal habitat even in undisturbed areas, due to the connectivity of streams and the diverse food sources available. Riparian areas and isolated wetlands often provide some of the only habitat available in urban areas, buffers around these features allow wildlife to travel through the urban environment with some level of protection (Castelle et al. 1994). There has been much debate over the functionality of corridors for terrestrial wildlife as a means of conservation, but the general consensus is that corridors are a valuable aspect of any wildlife protection plan (for more details on the pros and cons of corridors, see the ***Upland Habitat*** section).

Riparian corridors provide a logical base for a network of corridors allowing movement between upland habitat patches and riparian habitat. Naiman et al. (1988) found that there are some wetland-dependent birds and animals that require an adjacent upland area to meet their needs. Some amphibians, while they only require riparian habitat for a short time period, are unable to complete their life cycle without it (Castelle et al. 1994). In order to serve the needs of interior habitat specialists, movement corridors should be as wide as possible to provide at least some interior habitat and reduce the edge effect.

Microclimate

Riparian areas have a unique microclimate differentiated from upland habitat by a diversity of vegetation, leading to complex structure in the forest canopy, which impacts the amount of light, heat, and wind that penetrates the area. Moist soils help to keep temperatures lower than in surrounding areas as well. The stream channel width and topography of a riparian area influence the extent of the microclimate (FEMAT 1993). Brosofske et al. (1997) found that a buffer of about 76 m (250 ft) would be needed to approximate natural conditions at the stream. However, as stated in Pollock and Kennard (1998), a 76-m (250-ft) buffer will not maintain the microclimate in the riparian forest itself, which is important for riparian dependent plants and animals. Chen et al. (1995) found that changes in relative humidity could be measured 30-240 m

(98-787 ft) into the forest interior from the edge of a clearcut, while changes in soil temperature extended 60 m (197 ft) into the interior. Based on this information, FEMAT (1993) recommended a buffer width of approximately three tree heights in order to preserve most microclimate functions.

An important consideration with forested riparian buffers is the ability of the forest to withstand the force of high winds (Broderson 1973; Steimblums et al. 1984). For example, in northwest Washington, windthrow (uprooting of trees or tree trunk breakage) averaged 33 percent in riparian forest buffers within 1 to 3 years after clearcut harvest of adjacent timber (Grizzel and Wolff 1998). In a review of several studies, Pollock and Kennard (1998) determined that over 75 percent of buffers less than 24 m (80 ft) wide experienced significant blowdown, while only 14 percent of wider buffers lost a significant number of trees. They concluded that the minimum buffer width to maintain minimal windthrow losses over the long-term is 23 m (75 ft). In Mendocino County, California, researchers found that the prescribed 30-m buffers were inadequate to protect trees from greatly increased mortality (primarily through uprooting via windthrow) (Reid and Hilton 2001). Treefall rates were abnormally high for a distance of at least 200 m from clearcut edges, and these rates persisted for six years with somewhat lesser (but still unnaturally high) tree mortality from 6-12 years after clearcutting.

Wildlife needs

The U.S. Fish and Wildlife Service has published numerous scientific papers and a series of habitat suitability index (HSI) models regarding buffer widths for a variety of wildlife species (e.g., Raleigh 1982; Sousa and Farmer 1983; Doyle 1990; Darveau et al. 1995). These models have demonstrated a need for buffer widths ranging from 3 to 106.7 meters (10 to 350 feet) depending on the particular species (Castelle et al. 1994).

Studies recommending riparian corridor widths sufficient to meet the needs of many wildlife species are scarce, because species have different habitat requirements and may respond differently to the same width. FEMAT (1993) recommends a range of widths based on categories of streams, for example for fish-bearing streams the recommended width is two site-potential tree heights, or 91-m (300-ft) buffers on each side of the stream, and non-fishing bearing streams would have a buffer of 46 m (150 ft) on each side. Oregon's Division of State Lands (Van Staveren et al. 1998) recommends one site-potential tree height [ranging from 5-37 m (15-120 ft), depending on the habitat]. Johnson and Ryba (1992) found that the range of recommended width for terrestrial habitat was 67-200 m (220-656 ft). Wenger (1999) reviewed the scientific literature and determined that a 100-m (328 ft) minimum was required to protect diverse terrestrial riparian wildlife communities, but commented that some wider and larger blocks should be preserved to protect area-sensitive species.

The buffer widths discussed here were based primarily on non-urban habitats. In urban habitats edges may be unnaturally abrupt, biological communities such as predator-prey relationships are altered, and human disturbances are routine. It is possible that wildlife using urban riparian areas need wider buffers compared to non-urban habitats. Studies comparing urban and non-urban buffers in similar habitats would help elucidate such differences. Until more urban information is available, the empirical evidence for buffer widths discussed below provides valuable information, but may underestimate the needs of wildlife in urban ecosystems. Urban areas include concentrations of high intensity land use; thus urban stream buffers often are increased to account for future risk of encroachment and to mitigate for the impacts of adjacent land use (Todd 2000).

Fish

The reliance of fish on LWD and clean, cold water suggest that buffers to protect fish at least meet the minimum buffer widths for these two criteria. Several Pacific Northwest studies offer buffer width recommendations specific to salmonid protection. One salmonid run (Columbia River coho) is state-listed as endangered but not federally listed. In western Washington, Castelle et al. (1992) recommended 61-m buffers (200-ft) to protect the zone of habitat influence for salmonids. Knutson and Naef (1997) recommended 15–61 m (50-200 ft) buffers for Cutthroat trout, Rainbow trout and Steelhead.

In species-specific HSI's, the U.S. Fish and Wildlife Service recommended 30-m (98-ft) buffers for Cutthroat trout, Rainbow trout and Chinook salmon (Hickman and Raleigh 1982; Raleigh et al. 1984; Raleigh et al. 1986). However, these HSI's are old and were typically developed for specific projects. The reference to the 30m (98-foot) buffer was for erosion control and to maintain undercut stream banks characteristic of good trout habitat. Many of the other parameters that get used in the model (such as water temperature, dissolved oxygen, substrate size, percent pools, base flow, stream shading, etc.) require properly functioning conditions. The HSI does not state that these habitat conditions will be present if there is a 98 foot riparian width, and it does not address the broader upstream and upland impacts that may affect site-specific habitat conditions. HSI models are typically used to evaluate the impacts of a specific project and measure the effectiveness of associated mitigation. HSI models are often modified for specific projects to incorporate current and local (the models are used nationwide) information.

Insects

Little is known about buffer widths and terrestrial insects, but several studies have examined riparian corridor width and benthic insects. Erman et al. (1977) studied streams in northern California and commented, "stream invertebrates were far more effective in discerning logging impacts than the physical and chemical parameters measured." This study recommended 30 m (100 ft) as the minimum buffer width for maintenance of benthic communities typical of undisturbed conditions. In Western Oregon, Gregory et al. (1987) recommended a minimum of 30-m (100-ft) buffers to maintain instream macroinvertebrate diversity. Benthic insects are highly dependent on organic debris, and these numbers generally match the range within which the majority of organic debris is contributed from riparian vegetation (Erman et al. 1977; McDade et al. 1990). However, certain species are highly sensitive to water quality and urbanized regions are pollution-prone (see *Impacts of Urbanization*). Although 30-m (100-ft) buffers may suffice for organic matter in urban habitats, wider buffers may be necessary to protect water quality important to aquatic insect communities.

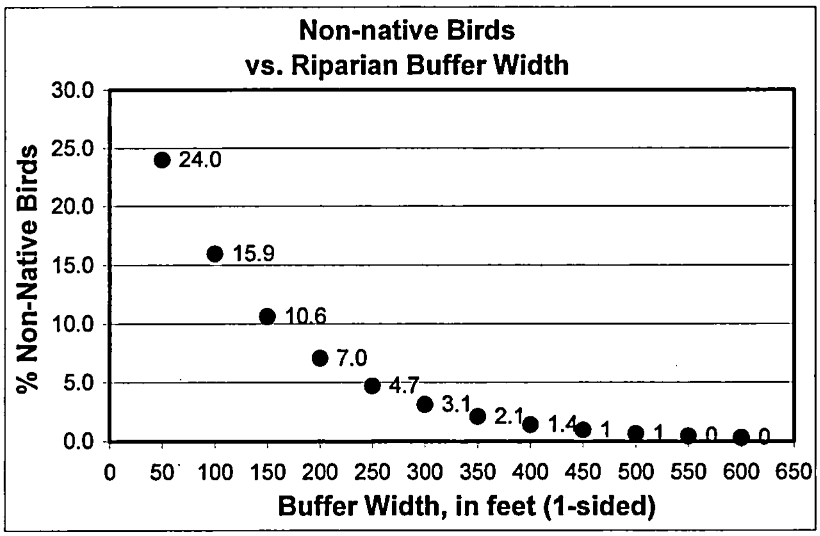
Birds

A relatively large body of literature is available to suggest buffer widths for various single species or groups of birds. In western Oregon, the abundance of four forest-associated bird species (Pacific-slope Flycatcher, Brown Creeper, Chestnut-backed Chickadee, and Winter Wren) increased with increasing buffer width through 70 m (230 ft); four species (Hammond's

Flycatcher, Golden-crowned Kinglet, Varied Thrush and Hermit Warbler) that were relatively common in unlogged sites, rarely occurred even in the widest (70 m) buffers in logged sites (Hagar 1999). These species may be area-sensitive in this region and vulnerable to habitat fragmentation.

As a group, Neotropical migratory songbirds appear to require wider forests or larger habitat patches than resident and short-distance migratory species (Hennings 2003; Murphy 2005). It is unclear whether this is due to numerous area-sensitive species, other habitat requirements such as native shrubs, an aversion to human disturbance, or some combination of these and other variables. However, local data suggests that human disturbance and native shrubs are influential to this group, but that certain species (e.g., Winter Wren, Brown Creeper, Swainson's Thrush and Pacific-slope Flycatcher) may be area-sensitive (Hennings 2001). The data also shows that non-native bird density decreases with greater corridor widths, reducing predation and competition effects on native birds, as shown in Figure 10 below.

Figure 10. Relationship between riparian buffer width and percentage of non-native birds.



Source: Hennings 2001.

Neotropical migrants are often riparian-associated during the breeding season (Gates and Giffen 1991). In Pennsylvania, Croonquist and Brooks (1993) found that sensitive Neotropical migrant bird species did not occur in riparian zones unless undisturbed buffers greater than 25 m (82 ft) per side were present. Hodges and Krementz (1996) document 100 m (328 ft) as the minimum buffer width to support area-sensitive riparian NMB in Georgia. In Maryland and Delaware, Neotropical migratory species richness increased with corridor width, especially between 25-75 m (82-328 ft), while resident and short-distance migrant species remained stable regardless of buffer width (Keller et al. 1993).

In northern boreal forests, forest-breeding birds were sensitive to corridor width and required at least 60 m (197 ft) wide corridors (30 m – 98 ft – on each side of the stream) to maintain their numbers (Darveau et al. 1995). In southeastern British Columbia, 70-m buffers (230 ft) were necessary to accommodate riparian-associated birds (Kinley and Newhouse 1997). Studies in Vermont showed that 90 percent of forest-dwelling bird species were present when buffer widths reached 150-175 m (492-574 ft) (Spackman and Hughes 1995). Jones et al. (1988) recommended 75-200 m buffers (246-656 ft) to maintain native bird communities. In eastern Texas, 30-95 m (98-312 ft) buffers were necessary to maintain bird abundance and retain species preferring mature forest (Dickson et al. 1995).

Reptiles and amphibians

Little is known about buffer width requirements for reptiles and amphibians, but a few studies add important information. For example, Western Pond Turtles appear to need 100-m (330-ft) buffers for nesting (Knutson and Naef 1997), an important consideration because this species is state-listed species at risk and a Federal **species of concern** (Oregon Department of Fish and Wildlife 2000; U.S. Fish and Wildlife Service 2001). In the Carolina Bays, Burke and Gibbons (1995) found that 275-m (902-ft) buffers were required to protect all nesting and hibernation sites for certain freshwater turtle species. In western Oregon, 75-100 m (246-328 ft) may be necessary to protect riparian-dependent reptiles and amphibians (Gomez and Anthony 1998). The NRCS (1995) recommended minimum 30-m (98-ft) buffers to protect frogs and salamanders, and Rudolph and Dickson (1990) recommended the same buffer width for the full complement of reptiles and amphibians. The dependence of amphibians on LWD suggests a minimum of 30-m buffers (100 ft). In addition, connectivity between habitat patches is likely to be of particular importance to this relatively immobile group.

Mammals

Information about buffer width is scarce for this diverse group. However, as with amphibians, small mammals relying on woody debris probably require buffers sufficiently wide to provide woody debris. Jones et al. (1988) recommend minimum 67-93 m (220-295 ft) buffers to support many small mammal species, and similar widths were suggested by Allen (1983). In southwestern Oregon, Cross (1985) found riparian zones in mixed conifer forests supported a higher diversity and density of small mammals than uplands, and 67 m (200 ft) buffers supported small mammal communities comparable to nearby undisturbed sites. For American Beaver the NRCS (1995) recommended 91-m (300-ft) buffers, while Allen (1983) recommended 30-100 m (98-328 ft) buffers.

Less is known about large mammals, but it is likely that some species such as elk require wider buffers to meet food and other natural history needs such as movement, predator and disturbance avoidance (Phillips and Alldredge 2000). The NRCS (1995) suggested 61-m (200-ft) buffers for deer habitat, and Knutson and Naef (1997) proposed 183-m (600-ft) buffers to provide fawning habitat. Jones et al. (1988) recommended 100-m (328-ft) buffers to support large mammal populations.

Range of functional buffer widths

While studies result in a variety of recommended buffer widths for the riparian area, all recommend some level of protection for this important resource for fish and wildlife. If riparian buffers of sufficient width are maintained along streams in the urban area they can provide good quality habitat within an altered landscape (Knutson and Naef 1997). Table 7 below summarizes the range of riparian area widths recommended in the scientific literature to protect fish and wildlife habitat. In an urban area restoration is likely to play an important role in addition to protection of habitat that is currently in good condition (May 2000).

Table 7: Range of functional riparian area widths for fish and wildlife habitat

AQUATIC HABITAT			
Function		Reference	Functional width *(each side of stream)*
Temperature regulation and shade	Shade	FEMAT 1993	100 ft
	Shade	Castelle et al. 1994	50-100 ft
	Shade	Spence et al. 1996	98 ft
	Shade	May 2000	98 ft
	Shade	Osborne and Kovacic 1993	33-98 ft
	Shade/reduce solar radiation	Brosofske et al. 1997	250 ft
	Control temperature by shading	Johnson and Ryba 1992	39-141 ft
Bank stabilization and sediment control	Bank stabilization	Spence et al. 1996	170 ft
	Sediment removal and erosion control	May 2000	98 ft
	Ephemeral streams	Clinnick et al. 1985	66 ft
	Bank stabilization	FEMAT 1993	½ SPTH
	Sediment control	Erman et al. 1977	100 ft
	Sediment control	Moring 1982	98 ft
	Sediment removal	Johnson and Ryba 1992	10 ft (sand) – 400 ft (clay)
	High mass wasting area	Cederholm 1994	125 ft
Pollutant removal	Nitrogen	Wenger 1999	50-100 ft
	General pollutant removal	May 2000	98 ft
	Filter metals and nutrients	Castelle et al. 1994	100 ft
	Pesticides	Wenger 1999	>49 ft
	Nutrient removal	Johnson and Ryba 1992	33 – 141 ft
Large woody debris and organic litter	Large woody debris	Spence et al. 1996	1 SPTH
	Large woody debris	Wenger 1999	1 SPTH
	Large woody debris	May 2000	262 ft
	Large woody debris	McDade et al. 1990	150 ft
	Small woody debris	Pollock and Kennard 1998	100 ft
	Organic litterfall	FEMAT 1993	½ SPTH
	Organic litterfall	Erman et al. 1977	100 ft
	Organic litterfall	Spence et al. 1996	170 ft
Aquatic wildlife	Cutthroat trout	Hickman and Raleigh 1982	98 ft
	Brook trout	Raleigh 1982	98 ft
	Chinook salmon	Raleigh et al. 1986	98 ft
	Rainbow trout	Raleigh et al. 1984	98 ft
	Cutthroat trout, rainbow trout and steelhead	Knutson and Naef 1997	50 – 200 ft
	Maintenance of benthic communities (aquatic insects)	Erman et al. 1977	100 ft
	Shannon index of macroinvertebrate diversity.	Gregory et al. 1987	100 ft
	Trout and salmon influence zone (Western Washington)	Castelle et al. 1992	200 ft

Table 7 (continued) - TERRESTRIAL HABITAT			
Function		**Reference**	**Recommended width *(each side of stream)***
	Willow flycatcher nesting	Knutson and Naef 1997	123 ft
	Frogs and salamanders	NRCS 1995	100 ft
	Full complement of herpetofauna	Rudolph and Dickson 1990	>100 ft
	Belted Kingfisher roosts	USFWS HEP Model	100 – 200 ft
	Deer	NRCS 1995	200 ft
	Smaller mammals	Allen 1983	214 – 297 ft
	Birds	Jones et al. 1988	246 – 656 ft
	Beaver	NRCS 1995	300 ft
	Minimum distance needed to support area-sensitive Neotropical migratory birds	Hodges and Krementz 1996	328 ft
	Western pond turtle nests	Knutson and Naef 1997	330 ft
	Pileated woodpecker	Castelle et al. 1992	450 ft
	Bald eagle nest, roost, perch Nesting ducks, heron rookery and sandhill cranes	Castelle et al. 1992	600 ft
	Pileated woodpecker nesting	Small 1982	328 ft
	Mule deer fawning	Knutson and Naef 1997	600 ft
	Rufous-sided towhee breeding populations	Knutson and Naef 1997	656 ft
	General wildlife habitat	FEMAT 1993	100-600 ft
	General wildlife habitat	Todd 2000	100-325 ft
	General wildlife habitat	May 2000	328 ft
Edge effect	Interior bird species	Tassone 1981	164 ft
	Neotropical migrants	Keller et al. 1993	328 ft
	Effect of increased predation	Wilcove et al. 1986	2,000 ft
	Noise reduction of a mature evergreen buffer	Harris 1985	20 ft
	Reduce commercial noise	Groffman et al. 1990	100 ft
LWD and structural complexity	Snags and downed wood	FEMAT 1993	1 SPTH outside the buffer
	Width necessary to minimize non-native vegetation	Hennings 2001	650 ft
	Travel corridor for red fox and marten	Small 1982	328 ft
	Minimum to allow for interior habitat species movement	Environment Canada 1998	328 ft
Microclimate	Maintain microclimate	May 2000	328 ft
	Prevent wind damage	Pollock and Kennard 1998	75 ft
	Approximate natural conditions	Brosofske et al. 1997	250 ft
	Maintain microclimate	Knutson and Naef 1997	200-525 ft
	Maintain humidity and soil temperature	Chen et al. 1995	98 – 787 ft

Acronyms:

SPTH: site potential tree height
NMFS: National Marine Fisheries Service
NRCS: National Resource Conservation Service
USFWS: U.S. Fish and Wildlife Service
FEMAT: Forest Ecosystem Management Assessment Team

Summary

Riparian areas are "hot spots" of biological diversity and productivity. While they occupy a relatively small proportion of the landscape, they provide a multitude of functions vital to fish and wildlife, watershed health, and society. The word "riparian" is derived from Latin "riparius" which means "of or belonging to the bank of a river." This paper uses the term "riparian corridor" to include the area of open water (stream channel, wetland, or lake), the adjacent riparian vegetation, and the area of direct interaction between the terrestrial (land) and aquatic (water) environment.

Beyond their essential importance to aquatic life such as salmon, riparian areas and adjacent water habitats contain more plant, mammal, bird, and amphibian species than do surrounding uplands.

Urbanization has resulted in the impairment of many of these functions and values provided by healthy riparian corridors. Some of the effects of urbanization include riparian loss, habitat alteration and fragmentation; changes in basin hydrology; filling and damaging of floodplains and wetlands; stream channel modification; and reduced water quality. These effects are cumulative from upstream and within a watershed. For example, studies show that ecosystem impairment begins as watersheds become more heavily urbanized (that is, where total impervious surfaces [pavement, rooftops] exceed 5-10 percent of the watershed area). In the Metro region, most watersheds exceed this level of impervious cover.

This section provides a review of riparian widths identified in the scientific literature that are necessary to protect habitat for fish and wildlife. Many animal species, from invertebrates to fish to mammals, depend on the riparian area for all or part of their life cycles. Deciding on appropriate widths for protection and restoration of riparian areas for fish and wildlife is complex. The literature provides the following guidelines in addressing this issue:

- Due to the pervasive effects of human activities in an urban environment, riparian area protection and restoration is not sufficient in itself to maintain healthy watershed function. Management of stormwater runoff and protection of upland intact forest areas is essential to protect and restore the ecological health of riparian systems for fish and wildlife and other values. Wider riparian corridors may be needed in urban areas with higher intensity land uses than compared to a rural landscape.
- To the maximum extent possible, all perennial, intermittent and ephemeral streams should be protected from surrounding land use activities. The entire stream network functions as a system, and removing the connection between intermittent and perennial streams will compromise the long-term physical and biological functioning of stream ecosystems.
- Riparian corridors should be wide enough to permit natural stream channel migration, and should maintain connectivity within the 100-year floodplain.
- Riparian corridors should consist of native vegetation where possible. Forest widths along streams, wetlands, and rivers play an important role in urban riparian community structure and composition. Urban research within the Metro region found that wider riparian forests had greater native plant diversity and abundance. Narrow forest widths were more likely to contain higher percentages of nonnative plants.

- Stream-associated wetlands, off-channel habitats and oxbows are valuable for fish and wildlife and should be included in protection programs.
- A range of riparian widths is recommended in the scientific literature to protect multiple riparian functions and values (see Table 7).

A comprehensive protection and restoration program should be based on the widths needed to provide for the long-term integrity of these complex and productive ecological systems.

UPLAND HABITAT

Introduction

In the Metro region we are fortunate to have retained some important natural areas such as Forest Park, the East Buttes, Cooper Mountain and other habitat that is essential for maintaining a diversity of wildlife species within the urban area. While some wildlife species that once inhabited our region are no longer found, remaining natural areas still provide habitat for many wildlife species, as well as recreational opportunities for humans (Houck and Cody 2000).

Metro's Regional Urban Growth Goals and Objectives (RUGGOs), adopted in 1995, state that: "A region-wide system of linked significant wildlife habitats should be developed. This system should be preserved, restored where appropriate, and managed to maintain the region's biodiversity." Also in 1995, citizens of the Metro region passed a $135.6 million bond measure to acquire natural areas within the Portland metropolitan region. Metro has since acquired over 6,000 acres of key habitat. Residents of the region have access to numerous parks and open spaces that provide habitat for a number of wildlife species. This system of parks, riparian corridors, and upland habitat has been called by some "greenfrastructure" and many consider it to be essential in maintaining a high quality of life in an urban area while providing for over 500,000 additional people projected to live in this region within 20 years (Metro 2000).

In this chapter we discuss the importance of upland habitats in the Metro region, including the following topics:

- Ecological definition of upland habitat
- Functions and values of upland habitat
- Upland habitat types in northwestern Oregon
- Impacts of urbanization on upland habitats
- Buffers and surrounding land use
- Upland habitat connectivity and patch size recommendations

Ecological definition of upland habitat

Upland habitat refers to all wildlife habitats that are not riparian, wetland, or open water habitats. However, it should be noted that wetlands are a natural component of upland areas and such wetlands are important for many species, especially during periods of drought (National Academy of Sciences 2001). A habitat can be described as the integration of the landscape and the essential resources of food, water and cover found within it (Linehan et al. 1995). While most species associated with upland habitats use riparian areas, they are dependent on upland areas for key aspects of their life history such as breeding, food, or shelter. Habitat types found in upland areas include grassland or meadow, shrubs, coniferous or deciduous forests, and rocky slopes. These land types provide crucial functions and values for many wildlife species.

Functions and values of upland habitat

All wildlife species depend on the surrounding environment to meet their needs, both long-term and short-term. Some wildlife species live in the Metro region all year round, while others migrate through and some use this region as wintering grounds. For example, elk migrate between upland areas in the summer and lowland areas in the winter. Other species are here only during the breeding season.

Breeding, foraging, dispersal, wintering habitat

All of the upland habitat types described below provide key functions for wildlife at different life stages. Wildlife must have access to areas in which to find food, water, and shelter, and numerous birds spend the winter in the Metro region taking advantage of the relatively mild climate (ODFW 1993). They need foraging habitat that provides food sources such as fruits and berries, or that can support sufficient prey to sustain carnivores. Wildlife species also require habitat suitable for breeding and rearing young. Some upland habitats provide essential areas for breeding species; others are crucial for foraging in both summer and winter. Upland habitat fragments may provide key connections between a variety of other upland and riparian habitats, allowing species to disperse for breeding, foraging, or shelter purposes.

Habitat may be considered in terms of vertical structure that runs the continuum from bare ground to grasses, other herbaceous plants, shrubs, small trees, and tall trees (Forman and Godron 1986). Wildlife species may be vertically stratified, some using the upper canopy, others reliant on the forest floor. Each part of this ecosystem provides important functions and values, both separately and as part of the sum of the whole. Most wildlife species utilize more than one type of habitat in the course of their life cycle (Forman and Godron 1986). Certain plant communities play key roles during specific life events, such as breeding or sheltering young.

Important functions of forested habitats

Forest communities provide essential habitat for wildlife in the Willamette Valley. Douglas-fir is the dominant tree found in this region. In areas that have been burnt, either historically by Native Americans or due to forest fires, Oregon white oak and big-leaf maple may precede forests of Douglas-fir (Larsen and Morgan 1998). Several other trees, while not dominant, provide important food sources for wildlife, including the Pacific madrone, hawthorn, cascara, red-osier dogwood and Pacific dogwood (ODFW 1993). In urban areas forests are frequently made up of second growth trees – trees that have grown after an area has been logged.

A healthy forest contains a multi-story canopy that includes a herbaceous layer, a shrub layer, and an upper canopy of native trees (Forman and Godron 1986). This vegetative community naturally contains downed wood and snags that provide key functions for wildlife such as food and nest cavities. Forests are essential for numerous species of wildlife in the Metro area (see Appendix 1 for species associated with forests in the Metro region). Both coniferous and deciduous forest communities are important. Native trees provide breeding, foraging, dispersal, and wintering habitat for a number of wildlife species. Forest strips may also provide dispersal corridors for interior habitat species.

Three-dimensional structure

The structure of a forest is crucial in terms of the level of function it is able to provide as habitat for wildlife (Guthrie 1974; Goldstein et al. 1986; Short 1986; Germaine et al. 1998). Each layer of the healthy forest multi-story canopy is important to different wildlife species at various life history stages. The horizontal spacing and density of foliage provides cover for protection and escape routes. Vertical layers provide places for perching, roosting, nesting, and feeding. The presence of a multi-story canopy can serve as an indicator for the types of species able to use a forest. For example, most Pileated Woodpecker nests are found in mature or old-growth forests with two or more canopy layers (Marshall et al. 1996). However, in urban areas Pileated Woodpeckers have been found to use second growth forests. The extent to which the canopy is open or closed also impacts the type of vegetation that grows in the forest. An open canopy allows more light lower to the ground, which in turn allows for a more diverse and abundant shrub layer. A healthy understory of native shrubs provides important woody structure for many bird species for nesting purposes.

Snags and downed wood

Dead and downed wood in forests serves a variety of functions for wildlife (Maser et al. 1988). Hollows and cavities in standing dead trees as well as logs and stumps provide shelter for many wildlife species. Over 100 wildlife species in the Pacific Northwest use snags, and about 53 of those species are dependent on cavities in the snags (Brown 1985; Neitro et al. 1985). These species include woodpeckers, owls, bats, small mammals, and amphibians. Many species of birds and small mammals use cavities in standing snags for nesting, roosting, feeding, and overwintering (Maser et al. 1988). Burrowing species use stumps, logs and large tree roots for burrow sites. Soft decaying logs provide habitat for some amphibians and reptiles, and also provide food for other species that eat fungi or invertebrates dependent on decaying wood (Maser and Trappe 1984). Coarse woody material on the forest floor provides moist sites for amphibians to find shelter from predators, foraging areas, and breeding habitat. Downed woody material provides habitat in the winter, catching snow and providing warm, dry areas for shelter (ODFW 1993).

Fallen trees provide opportunities for new plants to become established in the forest, by creating holes in the canopy to allow sunlight to reach the forest floor and by providing nutrients through the process of decay (Maser et al. 1988). Many old-growth trees started life as a seedling nourished by a rotting downed log, often called a "nurse log." Decaying wood is a major source of organic material in the soil (Maser and Trappe 1984). A decomposing fallen tree provides a variety of habitat functions as it proceeds through the stages of decay to finally become part of the forest floor. Woodpeckers and other wildlife species routinely forage for insects on downed logs.

Upland interactions with surrounding landscape

Upland habitat in urban areas is typically fragmented and intermingled with other land uses. Some land uses are more compatible for the functions and values important for wildlife than others. For example, in some cases low-density residential areas may have less of an impact on a habitat patch, depending on the species, than other land uses (Nilon et al. 1995). The type (native vs. nonnative) and abundance of species tends to change across the urban gradient, as the landscape changes from undeveloped, rural land to high intensity land uses in the downtown areas (Blair 1996). Habitat areas provide more functionality to wildlife if they are situated near other patches of similar habitat with some amount of connectivity between the fragments (Soulé 1991a,b; Duerkson et al. 1997).

Corridors and connectivity with surrounding habitat

Habitat corridors provide connections among various habitat patches within a fragmented landscape. Major functions provided by corridors include: habitat for some species within the corridor, opportunity to move between habitat fragments, and a source of environmental and biotic inputs on the surrounding habitat (Forman and Godron 1986). The value of connectivity has been debated in the scientific literature (Duerkson et al. 1997). While corridors provide many benefits, they also allow exotics, including mammals, birds, and plants, to more easily invade native habitats. Another potential downside of corridors is that they may provide opportunities for predation that would not otherwise occur, especially when they are narrow and lacking in vegetative cover. However, the benefits of corridors, particularly in preventing local extinctions, likely outweigh the risks (Soulé 1991a). (See *Impacts of Urbanization, Habitat Fragmentation* for more discussion on corridors).

Connectivity is important to wildlife for several reasons. Many species must migrate seasonally to meet basic needs for food, shelter and breeding, and connections between habitat patches allow this migration to occur (Duerkson et al. 1997). In addition, wildlife populations that are connected to each other are more likely to survive over the long term than an isolated population (Duerkson et al. 1997; Beier and Noss 1998). A population that exists on a connected system of habitats will be more likely to survive a catastrophic event on one patch, and the surviving population may be able to repopulate or revive an area that is in trouble. Finally, connectivity between habitats allows populations to interbreed, which aids in the vigor and survival of the overall population by reducing genetic inbreeding (Duerkson et al. 1997).

Connectivity with riparian areas

Prior to modern land use patterns, the landscape provided fish and wildlife habitat in an interconnected mosaic of habitat types (Forman and Godron 1986). Upland areas were functionally and physically connected with the streams, rivers, wetlands and lakes (riparian areas) that wended their way through valleys.

Most species of wildlife utilize riparian areas at some point in their life history. Many mammals must use riparian areas for water, food, and shelter. Because riparian areas frequently serve as corridors through an urbanized landscape, these areas also provide places for movement and dispersal. Over 60 percent of mammal species in the Northwest use riparian areas for breeding and feeding (Kauffman et al. 2001). In the Metro region, nearly half of all birds, and 45 percent of all non-fish vertebrate species are dependent on water-associated habitats. Nearly all vertebrates (93 percent, excluding fish) use these habitats (see Table 1), yet riparian areas comprise only a small fraction of the landscape. Thus, connections between upland habitats and riparian areas are very important for most wildlife species. Upland habitats that are physically connected to riparian areas will likely be more valuable for wildlife.

Local wildlife data affirms the importance of connectivity to water and riparian areas. In 1999, Oregon State University (OSU) conducted spring bird surveys along small streams in the Portland area (Hennings 2001; Hennings and Edge 2003). Concurrently, Metro (Parks and Greenspaces Department) developed a model to predict key habitats of interest for future conservation using four variables: size of habitat patch, proximity to other habitat patches, proximity to water resources, and species richness.[1] At Metro's request, OSU analyzed their bird data based on model criteria scores. Each of the four model variables appeared important to bird communities, and analyses suggested that habitat patches with more nearby water resources had higher bird diversity (Hennings 2001).

Upland habitat types in Northwestern Oregon

Prior to settlement by Europeans, the Willamette Valley consisted of a mosaic of large patches of riparian forests and wetlands, open white oak savannas and prairies, and hills of oak, Ponderosa pine and Douglas-fir (LaRoe et al. 1995). Native Americans historically set controlled fires that maintained the prairies, savannas, and oak woodlands throughout much of the valley for many years (ODFW 1993). Settlers were attracted to the Willamette Valley due to the fertile soils and abundant rainfall, providing ideal agricultural conditions. Most of the prairies have since been converted to farmland, and the original forests have almost all been logged (LaRoe et al. 1995; Oregon Natural Heritage Advisory Council 1998). The greatest change in vegetation type has been the loss of grassland and oak savanna; current estimates are that less than one percent of the historic extent still exists in small, scattered patches (Partners in Flight 2000).

Historic vegetation

Using data from land surveys for the General Land Office between 1851 and 1895, the Oregon Natural Heritage Program created a historical vegetation map for Oregon (Christy 1993). The data coverage was created at 1:24,000 scale using survey notes for township and section lines, with standard USGS 7.5-minute topographic maps as a base. This map shows that the Metro region was covered predominantly by closed and open canopy forest interspersed with prairie and savanna habitats especially in the lowlands of the Tualatin, Willamette, and Columbia River basins (see Figure 11 "Historical Vegetation of the Metro Region").

[1] An index of species richness was determined by the Oregon Natural Heritage Program and applied to the natural areas identified by the model.

Figure 11. Historical vegetation of the Metro region (from Christie et al. 1993).

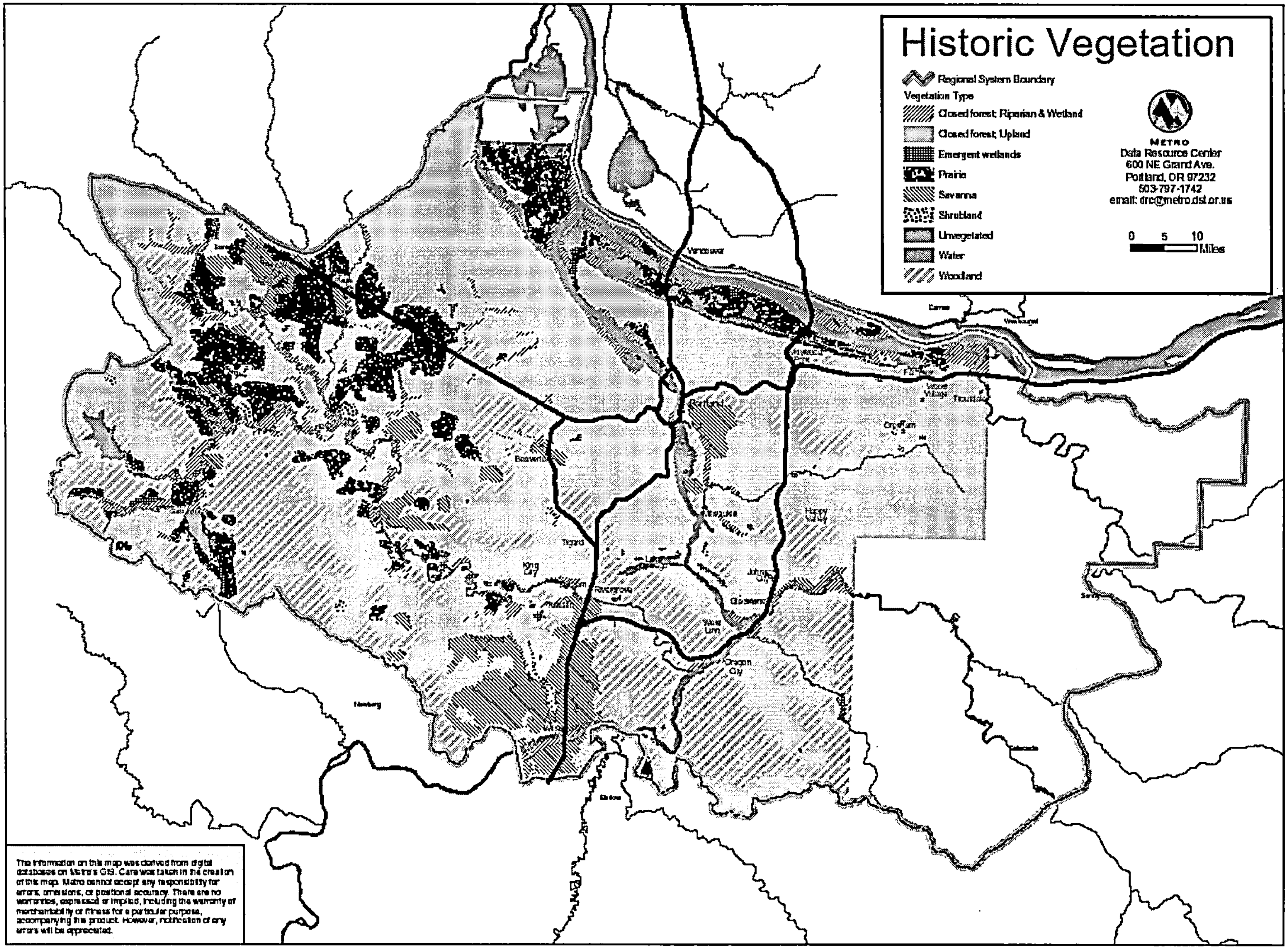


Table 8 gives the percentage breakdown for the types of vegetation that once covered the Metro region compared to current land cover data. The data show that forest canopy covered more than three fourths of the Clackamas, Sandy, Tualatin, and Willamette River basins within the Metro region. The Columbia River and Multnomah Channel contained significant amounts of riparian forest, wetland, dry prairie and savanna, and open water. The Tualatin River basin contained significant amount of dry prairie and savanna habitat.

Table 8. Percentage of vegetation cover for the Metro region: historical versus current

Vegetation Type	WATERSHED						
	Clackamas River	**Columbia River**	**Multnomah Channel**	**Sandy River**	**Tualatin River**	**Willamette River**	**All**
	Percent historic/current	*Percent historic/current*	*Percent historic/current*	*Percent historic/current*	*Percent historic/current*	*Percent historic/current*	*Percent historic/current*
Barren/Urban	<1 / 27	<1 / 52	0 / 3	0 / 45	<1 / 17	<1 / 29	<1 / 24
Upland closed forest canopy	68 / 28	40 / 3	53 / 32	82 / 8	47 / 23	52 / 25	49 / 22
Upland open forest canopy	16 / 9	4 / 10	1 / 3	0 / 16	28 / 8	30 / 15	25 / 10
Riparian/ wetland forest	11 / 2	16 / 2	10 / 2	12 / 4	6 / 1	3 / 2	6 / 1
Wetlands and wet prairies	<1 / <1	4 / 2	8 / 2	<1 / 1	3 / 1	<1 / <1	2 / <1
Dry prairie, savanna, and shrubland	2 / 6	14 / 10	21 / 17	0 / 10	16 / 6	10 / 5	14 / 6
Ag riparian/ wetland	0 / <1	0 / <1	0 / 2	0 / <1	0 / 1	0 / <1	0 / <1
Ag Upland	0 / 25	0 / 2	0 / 35	0 / 10	0 / 43	0 / 19	0 / 31
Water	2 / 2	22 / 19	7 / 3	6 / 6	<1 / <1	4 / 4	4 / 4
Total Acres	14,053	47,252	22,481	6,892	289,985	166,356	547,017

Source: Christy 1993, Metro 1998 land cover data.

Notes:

1) The Urban category underestimates the amount of land covered with urban development because it excludes urban uses that are also intermingled with open and closed forest canopy cover.
2) The table shows a 43 percent decline in forest cover from historic levels. Forest composition has also changed due to loss of old growth forests and white oak woodlands.
3) Current riparian/wetland forest is only 17 percent of historic levels. However, the difference is probably much greater due to the assumptions used to calculate current riparian/wetland forest cover. This cover type was estimated using 200-foot buffers along streams and wetlands. This significantly overestimates the actual amount of riparian forest given existing development patterns.
4) Historic dry prairie, savanna, and shrubland have been converted to non-native grasslands and shrublands.
5) Agriculture and urban categories comprise 55 percent of the land area in the region, representing a total conversion from the original land cover.

Another source of historical data for the metro region is the First Federal Township Survey Map of 1852 (Munch *No date*). This map gives an interesting overview of the region – its first settlement patterns of roads, platted lands, and cultivated fields, as well as natural features such as location of prairies, wetlands, and general topography. It shows that most of the cultivated fields were located in the prairies and savannas that characterized the lowlands of the Tualatin and Willamette valleys. The map shows lakes located in the Willamette River floodplain, now known as the Northwest Industrial District of Portland, and Sucker Lake, which has been renamed Lake Oswego.

The following types of vegetation communities have been particularly impacted by the change in the landscape over the past hundred years (summarized from Christy 1993, Johnson and O'Neil 2001).

Prairies included both wet and dry grasslands. Wet prairies were subject to seasonal floods and were found on poorly drained soils in valley bottoms. Dry prairies were found primarily along the edges of valleys and on well drained soils, and were dominated by perennial grasses. Savanna habitat was similar to dry prairies but also included widely scattered trees with some open tree groves. Trees typically were Oregon white oak, but also included Douglas fir or Ponderosa pine. In prairie habitats, canopy cover was generally less than 25 percent.

Oak woodlands consisted of a relatively open understory and were typified by a canopy of 50 percent or greater Oregon white oak. Other species included Big-leaf maple, Douglas-fir and Pacific madrone. The understory was predominantly poison oak, California hazel, snowberry, oceanspray, serviceberry, and sword fern. Historic distribution of oak woodlands was limited to low elevation dry areas with limited conifer competition. For example, oak woodland and oak savanna habitat once covered approximately 21 percent of the Tualatin Valley within the metro region.

Current Vegetation

Current vegetation in the Willamette Valley has changed dramatically from historic patterns as a result of human alteration of the landscape (Table 8). Key factors include agricultural cultivation, urban development, livestock grazing, exotic species introduction, suppression of natural fires, logging, drainage of wetlands, and **channelization** of streams and rivers (Partners In Flight 2000).

Native grassland has been reduced to only one percent of historic land coverage. Oak woodland habitat has been impacted by conversion of land to agriculture and invasion by exotics due to fire suppression, and current distribution is patchy. Conifer and deciduous forests have overtaken former grassland habitat. These forests are typically dominated by Douglas-fir, often with an understory of exotics such as Himalayan blackberry (Partners in Flight 2000). Riparian associated forests and shrub habitats have been radically changed from pre-settlement conditions. Over 70 percent of the bottomland hardwood forests have been lost.

While land cover data in Table 8 documents the historical loss of native habitats in the Metro region, recent data confirms the loss of habitat is ongoing due to the continuing conversion of land for development and other uses. For example, Metro conducted a study to document the loss of natural areas occurring between 1989 and 1997. The study documented a loss of 12 percent of the original 131,167 acres of natural areas inventoried in 1989 (Metro 1997a). With projected population increases of 500,000 people in the metro region over the next twenty years, habitat loss is likely to continue.

Mapping landcover types

One of the difficulties in large-scale ecosystem management is a lack of consistent data at scales fine enough to be biologically meaningful. Detailed habitat characterization over a large area requires a substantial amount of on the ground fieldwork to identify specific vegetative communities across the landscape. The cost of such an effort is prohibitive. To overcome the obstacle of identifying habitat to enable management and protection of wildlife, conservationists and planners have turned to data sources better suited for collecting information consistently on a large scale.

O'Neil et al. (1995) identify three components necessary to accurately assess ecological functionality of a habitat (vegetation composition, vegetation structure, and critical habitat components such as snags and water), but acknowledge that vegetation composition is the only component that is currently measurable. The authors state that "vegetation reflects many abiotic and biotic characteristics of an area...and has therefore been used as a surrogate for ecosystems in conservation assessments." The use of **coarse** (applicable on a large scale) data is appropriate for identifying important habitat areas, rather than focusing on protecting a specific wildlife species (O'Neil et al. 1995). Vegetation composition is measurable at a large scale, based on remote sensing and aerial photography.

One such data source is the Landsat Thematic Mapper (TM) images. In 1999, Metro Parks and Greenspaces Department contracted with Ecotrust to develop several digital products from the Landsat TM images for use in identifying regional natural areas and producing an urban forest canopy map. The Landsat TM data was chosen for several reasons: 1) the entire region is captured in a single scene, 2) the type of spectral information is ideal for classifying vegetation, and 3) Metro had previously used Landsat TM data in 1991, thus comparisons in vegetation changes over time are possible (Ecotrust 1999). Metro and Ecotrust developed a land cover classification scheme for categorizing the data based on the Anderson classification scheme, including 17 mutually exclusive classes (shown in Table 9 below). A two-acre minimum mapping unit was used. Ecotrust utilized digital orthophotos to support the Landsat TM data.

The land cover types contained in the data layer provide a basis for identifying the types of habitat found in the Metro region. The land cover data identifies open versus closed canopy forests, deciduous versus coniferous forests, various types of shrub habitats, and distinguished between agricultural and meadowlands. A limitation of the land cover data is the inability to identify detailed quality aspects of the habitat for wildlife, such as structure and critical habitat components. For example, the land cover data allows the identification of a coniferous closed canopy forest, but does not show if ivy or another invasive species has invaded the understory of that forest.

Ideally the land cover data would be ground-truthed to further identify specific habitat types and thus enable the association of species with mapped areas. However, when working at a regional scale many conservation efforts have chosen to utilize the coarse data in developing habitat protection plans (Robinson et al. 1995). There are several habitat classification schemes that could be used to further refine the land cover data based on fieldwork. As an example, we chose to use a habitat classification scheme developed by Johnson and O'Neil (2001). Although the habitat types described in this biologically based classification scheme cannot currently be mapped at a scale useful in the Metro region; the information provides additional detail on the types of vegetative communities to be found in this region. The scheme also provides species associations with each habitat type. Table 9 below describes the land cover types and provides a crosswalk to show how Johnson and O'Neil's classification scheme fits within Metro's existing data.

Table 9. **Land cover types and crosswalk to Johnson and O'Neil's classification scheme**

Land Cover Types	Description	Johnson & O'Neil's classification scheme
Water	Major rivers, lakes, ponds, reservoirs, and other standing water (from Metro's existing hydrology data)	Open water – lakes, rivers, streams
Barren and sparsely vegetated	Bare ground, sand, gravel, asphalt, structures, rock with less than 15% vegetated cover and less than 10% trees (no agriculture)	Urban and mixed environs
Agriculture		
Low structure	Pasture and other cultivated cropland with limited vegetative structure	Agriculture, pasture and mixed environs
High structure	Areas with high degree of vegetative structure such as orchards, groves, vineyards, canes, nurseries, Christmas trees	Agriculture, pasture and mixed environs
Forest		
Closed canopy = 75% tree crown closure		
Deciduous closed canopy forest	70% total crown closure deciduous	• Westside lowlands conifer-hardwood forest • Westside oak, dry Douglas-fir forest, woodlands
Mixed closed canopy forest	<70% total crown closure deciduous; <70% total crown closure coniferous	• Westside lowlands conifer-hardwood forest • Westside oak, dry Douglas-fir forest, woodlands
Conifer closed canopy forest	70% total crown closure coniferous	• Westside lowlands conifer-hardwood forest • Westside oak, dry Douglas-fir forest, woodlands
Open canopy = <75% tree crown closure		
Deciduous open canopy forest	70% total crown closure deciduous	• Westside lowlands conifer-hardwood forest • Westside oak, dry Douglas-fir forest, woodlands
Mixed open canopy forest	<70% total crown closure deciduous; <70% total crown closure coniferous	• Westside lowlands conifer-hardwood forest • Westside oak, dry Douglas-fir forest, woodlands
Conifer open canopy forest	70% total crown closure coniferous	• Westside lowlands conifer-hardwood forest • Westside oak, dry Douglas-fir forest, woodlands
Scattered canopy = <25% tree crown closure		
Deciduous scattered canopy forest	70% total crown closure deciduous	• Westside lowlands conifer-hardwood forest • Westside oak, dry Douglas-fir forest, woodlands
Mixed scattered canopy forest	<70% total crown closure deciduous; <70% total crown closure coniferous	• Westside lowlands conifer-hardwood forest • Westside oak, dry Douglas-fir forest, woodlands
Conifer scattered canopy forest	70% total crown closure coniferous	• Westside lowlands conifer-hardwood forest • Westside oak, dry Douglas-fir forest, woodlands
Shrub		
15% woody canopy cover, <10% crown closure of trees		
Closed canopy	75% total shrub/tree crown closure	No applicable habitat type
Scattered canopy	25% to <75% total shrub/tree crown closure	Westside grasslands
Open canopy	10% to <25% total shrub/tree crown closure	Westside grasslands
Meadow/grass	15% vegetative cover, <15% woody canopy cover, <10% tree cover	Westside grasslands

Source: Metro 2001.

As discussed in the *Aquatic and Riparian Habitat* section, Johnson and O'Neil (2001) describe eight habitats present in significant amounts in the Metro region. Of these, three are water-based classifications and are discussed in the *Aquatic and Riparian Habitat* section. The remaining five habitats include Westside Lowlands Conifer-Hardwood Forest, Westside Oak and Dry Douglas-fir Forest and Woodlands, Westside Grasslands, Agriculture Pasture and Mixed

Environs, and Urban and Mixed Environs, and comprise the majority of upland habitats available to native wildlife in this region. Trees, shrubs and herbaceous species common to each of these habitats are listed in Johnson and O'Neil's (2001) book. All scientific names (genus and species) and species-habitat associations are included with the species list (Appendix 1). Eighty-nine percent of all terrestrial species in the Metro region are associated with upland habitats, with at least 28 percent depending on these habitats to meet their life history requirements, as shown in Table 10 below. In this section, we provide an abbreviated list of **species at risk** closely associated with each habitat based on state and/or federal status, as described in Appendix 1 (species list).

Table 10. Analysis of the importance of terrestrial habitats within each major group of animals (292 total existing native species; based on Metro's Species List, Appendix 1).

Group	# Native Species	Upland Dependent	Uses Uplands	Total % Using Uplands
Amphibians	16	2 species 13%	13 species 81%	15 species 94%
Reptiles	13	0 species 0%	13 species 100%	13 species 100%
Birds	209	61 species 29%	120 species 57%	181 species 86%
Mammals	54	18 species 33%	32 species 59%	50 species 92%
TOTAL	292	81 species 28%	178 species 61%	259 species 89%

Notes:

1. "Upland Dependent" species are closely associated with at least one of the four upland habitats; "Uses Upland" species are generally associated with or known to use at least one of the four habitats.
2. Note that although the total percent *using* uplands was only 4 percent lower than water-associated habitats, the percent *dependent* upon uplands was considerably lower than water-associated habitats (28 percent versus 45 percent, respectively; see Table 1 in Riparian chapter). Water-associated habitats comprise only 10-15 percent of the land at most, and clearly represent critical wildlife habitat. However, uplands also provide connectivity to water and other natural areas, as well as unique habitat types to habitat specialists throughout the region.

Habitat types

Upland habitat types may include Habitats of Concern (see Special Habitats of Concern section under Aquatic and Riparian Habitat).

Westside lowlands conifer-hardwood forest

This habitat is widespread and prevalent in the Metro region. Historically and currently the most extensive of all natural habitats west of the Cascade Mountains, it often forms the matrix within which other habitats occur as patches and is very important to wildlife in this region. This habitat may be dominated by conifers, deciduous trees, or both, and tends to have structurally diverse understories. In nutrient-poor soil conditions evergreen shrubs dominate the understory, while nutrient-rich or moist sites contain more deciduous shrubs, ferns, and grasslike plants. Mosses are a major ground cover component, and older stands are rich with lichens.

Fire is the primary natural disturbance, with natural fire intervals ranging from less than one hundred to several hundred years. Fires in this habitat type are typically severe (e.g., often kill trees). Other significant sources of natural tree mortality include bark beetles, fungi, and landslides. Human management and disturbances include timber harvest and clearing for development. Widespread deforestation and subsequent reforestation in Douglas-fir monoculture has resulted in a reduction in canopy tree diversity and coarse woody debris in the Pacific Northwest, as well as excluding habitat succession to old growth stages.

Several wildlife species dependent on this habitat are at risk at the state and/or at the federal level. This includes one amphibian, the Northern Red-legged Frog. At-risk bird species dependent on this habitat include Band-tailed Pigeon, Northern Pygmy-owl, and Olive-sided Flycatcher. Mammals include two bat species (Long-legged Myotis and Silver-haired Bat) and a tree-dwelling rodent, the Red Tree Vole.

Westside oak and dry Douglas-fir forest and woodlands

This habitat is limited in area and declining in extent and condition in the Willamette Valley, and is therefore considered to be a Habitat of Concern. Conifers, deciduous trees or some combination of the two may dominate these typically dry woodlands. Canopy and understory structures are variable, ranging from single- to multi-storied, with large conifers sometimes emerging above deciduous trees in mixed stands. This habitat is too dry for Western hemlock and Western red cedar; lack of shade-tolerant tree regeneration, along with understory indicators such as Tall Oregongrape, help distinguish oak woodlands from Westside Lowlands Coniferous-Hardwood forests. Large woody debris and snags are less abundant than in other westside forested habitats. Sweet cherry (*Prunus avium*) and English hawthorn (*Crataegus monogyna*) have invaded and sometimes dominate this habitat's subcanopy in the Metro region.

The natural disturbance regime for this habitat is low to moderate severity fire, occurring every 50-100 years. Well adapted to this disturbance, oaks and madrones may resprout after fire. Because such fires do not kill all trees, varying tree density and multiple forest gaps created by fires are important contributors to structural diversity. Humans often use oak habitats for forestry, livestock grazing, and low-density residential development. Many oak stands in the Willamette Valley are degraded due to fire suppression and human disturbance-induced invasion by Scot's broom, non-native grasses and weedy species. In the absence of fire, this habitat converts to Douglas-fir forest; selective logging of Douglas-fir in oak stands can prevent loss of this important habitat. The historic distribution of oak woodlands was limited to low elevation dry areas with limited conifer competition.

Several wildlife species dependent on this habitat are considered at-risk at state and/or federal levels. These include Band-tailed Pigeon, Lewis' Woodpecker (extirpated as a breeding species), Acorn Woodpecker, and Western Bluebird. At-risk mammals include Western Gray Squirrel and Red Tree Vole.

Westside grasslands

Once widespread in the Willamette Valley, Westside Grasslands are now rare, limited, and currently declining due to fire suppression, conversion to agriculture and urban habitats, and invasion by non-native species. Native grasslands are considered to be a Habitat of Concern. In the Metro region, this habitat in its native form has virtually disappeared. Sometimes referred to as prairie or, in the Oregon Coast Range, grass balds, this habitat occurs near or adjacent to many other habitats. Often used for grazing and recreation, Westside Grasslands may be grassland or savanna, with less than 30 percent tree or shrub canopy cover. Bunchgrasses dominate native sites, with space between vascular plants covered with mosses, lichens and forbs. Rich diversity of native forbs is typical of sites in good condition. When present, tree and shrub species vary widely. Degraded sites tend to be dominated by exotic grasses. Grassland vegetation provides several essential wildlife functions and values. According to Partners in Flight (2000), 44 breeding bird species are highly associated with grassland/savanna areas in the Willamette Valley. Open meadows are also important to raptors, providing vital hunting grounds and in turn, keeping rodent populations in check.

Historically, dry soils and fire (lightning strikes and intentionally set by indigenous inhabitants to maintain food staples) eliminated or thinned invading trees, but fire suppression over the past century has led to Douglas-fir encroachment, converting many grasslands to shrublands and/or forests. Because grasses have rapid generation turnovers and do not block sun from taller plants, this habitat is particularly vulnerable to invasion by non-native species through human-associated disturbances such as vehicular use or grazing. Prescribed fires and other management activities can help control Scot's broom and Douglas-fir encroachment in these grasslands.

Several bird species dependent on this habitat are state and/or federally at risk, including Streaked Horned Lark (a subspecies of the Horned Lark), Vesper Sparrow and Western Meadowlark. The Western Meadowlark is Oregon's State Bird, and although once common, is now extirpated in the Metro region as a breeding species.

Agriculture, pasture and mixed environs

Occurring within a matrix of other habitat types, agricultural lands often dominate the landscape in flat or gently rolling terrain, on well-developed soils, and in areas with access to irrigation water. This habitat can be diverse, ranging from hayfields and grazed lands, to multiple crop types including low-stature annual grasses to row crops to mature orchards. Hedges, windbreaks, irrigation ditches, and fencerows provide especially important habitat for wildlife (Demers et al. 1995). USDA Conservation Reserve Program lands are included in this category and may provide valuable wildlife habitat. Agricultural lands are subject to exposed soils and harvesting at various times during the year and receive regular inputs of fertilizer and pesticides, thus influencing the quality of water-associated habitats.

The greatest conversion of native habitats to agricultural production occurred between 1950 and 1985, primarily as a function of U.S. agricultural policy (Gerard 1995). Since the 1985 Farm Bill and the economic downturn of the early to mid 1980's, the amount of land in agricultural habitat has stabilized and begun to decline (National Research Council 1989). The 1985 and subsequent Farm Bills contained conservation provisions encouraging farmers to convert agricultural land to native habitats (Gerard 1995; McKenzie and Riley 1995). Clean farming practices and single-product farms have become prevalent since the 1960's, resulting in larger farms and widespread removal of fencerows, field borders, roadsides, and shelterbelts (National Research Council 1989; Gerard 1995; McKenzie and Riley 1995). In Oregon, land-use planning laws prevent or slow urban encroachment and subdivisions into areas zoned as agriculture.

Because this habitat type is human-generated, there is no "natural" disturbance regime. Fire is nearly completely suppressed; in absence of fire or mowing, unimproved pastures become increasingly shrubby. Edges can be abrupt along habitat borders, with important implications for wildlife. Presence of non-cultivated or less intensively managed vegetation such as fencerows, roadsides, field borders and shelterbelts can enhance structural diversity. Integrated pest management plans and similar farming practices can help reduce the impacts of fertilizers and pesticides (Gerard 1995).

Twenty-nine percent of birds and 25 percent of mammals native to Oregon use croplands and pasturelands to meet their habitat needs (ODFW 1993). Agricultural fields left fallow for the winter often provide wintering habitat for migratory birds (ODFW 1993). Many of the species that use this habitat require the nearby associated aquatic habitats to meet their needs. Bird species at risk that depend on this habitat include Oregon Vesper Sparrow and Western Meadowlark. One mammal, the Camas Pocket Gopher, is at risk at the federal level.

Urban and mixed environs

These areas are widely distributed, but patchy. Urbanization in this scheme encompasses all habitats with impervious surfaces covering at least 10 percent of the land's surface (less than 10 percent is considered rural). Characterized by buildings and other structures, impervious surfaces and plantings of non-native species, urban environments provide habitat to some species requiring structures such as cavities, caves, cliffs and rocky outcrops, and ledges. This habitat is subdivided into low-density (10-29 percent impervious surfaces), medium density (30-59 percent impervious); and high density (60+ percent impervious) areas, described in detail in Johnson and O'Neil (2001). Many human-induced changes in urban areas are essentially irreversible; for example, building a house requires removing vegetation, scraping and leveling topsoil, building driveways and roads, and running sewers and utilities both above and underground. Canopy cover is reduced in these habitats, and structural features present in historical vegetation, such as snags and dead wood, are rare.

Frequent human disturbance is normal in urban habitats, and species that are disturbance-sensitive tend to be absent or reduced in numbers (Marzluff et al. 1998). The effects of urbanization on wildlife, including disturbance, habitat loss, conversion and fragmentation, and non-native species invasion, are discussed later in this chapter. Historical natural disturbance patterns are largely absent in urban habitats, although flooding, ice, wind, or fire still occur. Flooding and pollution is more frequent and more severe in areas with significant impervious surface cover and/or modified stream systems. Temperatures are elevated and background lighting is increased; wind velocities are altered by the urban landscape, often reduced except around the tallest structures downtown, where high-velocity winds are funneled around the skyscrapers. Urban development often occurs in areas with little or no slope and frequently includes wetland habitats. This habitat type is expected to increase at an accelerating pace locally and nationally (Parlange 1998).

Studies in the Pacific Northwest document declining wildlife diversity with increasing urbanization (Penland 1984). Nonnative species and generalists are most common in urban habitats. Few sensitive species are associated with this habitat, because sensitive species are often habitat specialists that are quickly out-competed by nonnatives and generalists. The only closely associated mammal of concern is Big Brown Bat, also known by the common name "house bat." This non-migratory species often lives in a variety of artificial structures, eating termites and beetles (Csuti et al. 1997).

Many man-made or artificial structures provide key habitat for wildlife in the urban area (ODFW 1993). For example, bridges provide important bat habitat. Fences, powerlines and poles provide perches from which hawks and falcons search for prey, an important means of rodent control in urban and agricultural settings. Nest boxes and bird feeders provide valuable resources, as the continuing recovery of Western Bluebirds within the Metro area demonstrates. Chapman Elementary School in Portland is renowned for the annual roosting of thousands of Vaux's swifts in the furnace chimney, and the school community is working to conserve these long-distance migrants (Robertson 1999). Since 1993 a pair of Peregrine Falcons has chosen the Fremont Bridge as a nesting place – similar to the high cliffs that would be attractive in the wild (Sallinger 2000). The bridge provides two important functions for the peregrine falcons: a high, inaccessible nesting spot and easy access to a constant food supply – nonnative pigeons and starlings. Several other nesting Peregrine pairs now also live in the city, and the young produced from these nests represent important contributions to this recovering species.

There are no species at risk dependent upon this habitat.

Impacts of Urbanization

The major impacts of urbanization on upland habitats fall into three main categories: habitat loss, habitat fragmentation, and human disturbance. These impacts change the ecological structure and function of naturally functioning systems in such a way that some wildlife populations decline, others thrive, and new species may arrive on the scene. Urban upland habitats are often fragmented, with residual patches of historic, native vegetation scattered amid urban, residential, and agricultural land uses (Ferguson 2001). The most successful species in the face of a changing landscape are generalists with the ability to adapt and use a variety of habitat types (ODFW 1993). Habitat specialists typically face the most difficulty when confronted with the impacts of urbanization.

Habitat loss and alteration

As discussed above, habitat loss is considered one of the leading causes of global species extinctions (Kerr and Currie 1995). In the Metro region, while we have retained some important natural areas within the urbanized landscape, the vegetation pattern has been dramatically changed since European settlement of the Willamette Valley (see Table 8 for estimated changes).

Habitat loss occurs due to destruction of the natural landscape, but also is a result of a change in the historical patterns of disturbance. Vegetative communities typically go through several stages of succession after a catastrophic event such as a fire or a flood. The historical landscape was composed of a mosaic of vegetation in several stages of succession, providing wildlife with important functions and values. For example, after a fire a typical vegetative community would be a meadow with native grasses. After several years, some shrubs may appear in certain areas, followed by larger trees, such as oak, creating a savanna-like habitat. Without the influence of another fire, conifers may gradually move in, growing taller than the oaks and overtaking the area (ODFW 1993). Each of these vegetative communities is important for a variety of wildlife, and the lack of natural evolutionary processes has reduced the variety of native habitats available. As described in the previous section, current vegetation differs dramatically from the vegetation and habitat historically found in the Metro region.

Habitat fragmentation

Habitat **fragmentation** along with general loss of habitat has been identified as a key factor in the decline of biodiversity throughout the world (Wilcox and Murphy 1985). As urbanization occurs, native habitat is destroyed and the remaining patches become fragmented, similar to islands in a sea of human altered landscape. Urbanization over the past few decades has typically occurred in a leapfrog fashion, and additional wildlife habitat and agricultural land has been converted to an urbanized landscape. Recently, there has been a push towards developing in a compact fashion, reducing the amount of land needed to provide necessary housing, commercial and industrial land. However, there are tradeoffs in encouraging a compact urban settlement pattern that contains sprawl and reduces rural development, as it could encourage habitat fragmentation. In the Metro region policy decisions have been made to simultaneously promote compact urban form that combats rural and habitat fragmentation outside the urban growth boundary and to knit together viable habitats inside the urban growth boundary.

Two theories are especially useful in understanding the unique situations of wildlife species in a fragmented habitat: island biogeography and **metapopulation** theory. Metapopulation theory helps to explain the population dynamics of wildlife species in a fragmented yet connected habitat, whereas island biogeography provides a useful framework for considering patch size, configuration, and connectivity for groups of species at the landscape scale. Both theories may be useful in urban habitats.

The theory of island biogeography has been applied to urban environments to further understand how habitat fragments function and as a basis for developing habitat protection plans (Davis and Glick 1978; Adams 1994; Duerkson et al. 1997). MacArthur and Wilson (1967) proposed the theory to explain species diversity on islands in the Pacific Ocean. It explains the number of species present on various islands based on a relationship between the immigration and extinction rates that are influenced by the size of the island and the distance from the mainland (Adams and Dove 1989). Many researchers have applied this theory to terrestrial habitat "islands", or patches of native habitat surrounded by other hostile land uses (Bolger et al. 1997a). Much of the research has focused on the species-area relationship, which indicates that species richness increases with habitat area (size).

Metapopulation theory can be used to describe subpopulations of wildlife inhabiting a series of connected patches on a landscape scale (Pulliam and Dunning 1997). The subpopulations are linked together by the movements of individuals between patches. A subpopulation on one patch could go temporarily extinct, but as long as the patch is connected to a populated patch it could be recolonized. This is called the **rescue effect**, and is crucial in the maintenance of small populations with limited habitat area (Pulliam and Dunning 1997).

In this section we discuss habitat fragmentation, using island biogeography and metapopulation theory to understand some of the impacts fragmentation has on wildlife. This section covers the issues of:

- Patch size
- Edge effect

- Distance effect
- Age effect
- Connectivity

Patch size

Davis and Glick (1978) first suggested applying island biogeography theory to urban ecosystems, describing each city as a collection of habitat islands. Small cities may be compared to islands close to the mainland, while a large city functions similarly to an island system far from the mainland. Increased urbanization causes more habitat fragmentation and reduces the connectivity necessary for maintaining species richness and preventing local extinctions. An established principle of island biogeography is that the extinction rate in an isolated habitat patch is negatively related to the size of the patch, or the *area effect.* Thus, extinction rates increase as patch size decreases. This phenomenon occurs even in relatively large habitat patches, due to the *edge effects* caused by habitat fragmentation (Soulé 1991a; Bolger et al. 1997a). That is, edge effects increase with increasing levels of fragmentation. Few empirical studies have been conducted to determine the appropriate patch size for various species, especially in an urban landscape (Hostetler and Holling 2000).

Large patches

Several studies have been conducted that indicate a larger habitat patch is better for the survival of native species. However, what constitutes a large patch is debatable and may vary geographically and by habitat type.

Most mammal research has been conducted outside the urban setting. However, Dr. Michael Murphy's graduate students at Portland State University are providing insights into small mammal needs in the urban area (Murphy 2005). As yet unpublished, their research indicates that the following small mammals may need large habitat patches: shorttail weasel, Oregon vole, Northern flying squirrel, shrew-mole, Trowbridge's shrew, vagrant shrew, Douglas squirrel, Western gray squirrel, and Townend chipmunk (see Appendix 1 for scientific names). Conversely, non-native mammals tended to decrease in abundance in larger patches. Hennings and Edge (2003) found

Wilcove (1985) studied the level of predation on Neotropical migratory songbirds in the northeastern U.S. and found an increased amount of predation in smaller forest patches. Bolger et al. (1997a), in a study of native rodent populations, found that species diversity increased with patch size. The habitat patches that did not contain native rodents were in general smaller fragments. Larger patches frequently retain more of the functions and values provided by native habitat. For example, many forest interior bird species are dependent on insects for food and a study in Ontario found that invertebrate biomass was 10 to 36 times higher in large forest patches than small forest patches (Burke and Nol 1998).

Much research supports a guideline that a single large patch is more beneficial than several small fragments for vertebrates and potentially other species (Soulé 1991a,b; Bolger et al. 1997a). The basic principal behind this is that extinctions of vertebrate species in similar habitat patches nearly always happen in a regular, predictable order (Patterson and Atmar 1986). Soulé et al.'s (1988) studies in canyons near San Diego, California support this theory. In the study the Roadrunner and Black-tailed Gnatcatcher always disappeared prior to other species, as they were most dependent on an undisturbed habitat. Other species would predictably be the last native survivors in an otherwise heavily impacted habitat. Smaller patches by their nature include more edge habitat, which provides more opportunity for habitat generalists and also allows predators increased access to the remaining interior areas.

Long-term trends in wildlife populations are directly related to the area of habitat available – the larger the patch size the longer a population can sustain itself (Duerkson et al. 1997). Some species require a certain amount of territory for foraging and breeding purposes. Other species are limited in population by the amount of resources available within a patch, thus the larger the patch the larger the population. Larger animals typically require a larger amount of land just to support their body mass. For example, a deer forages on a much larger range than a mouse. Predators require an even larger area of land that must support enough of their prey for a sustainable catch (Soulé 1991a).

Large predators play a crucial role in maintaining a functioning ecosystem, and they typically are unable to thrive on small habitat patches (Soulé 1991a; Berger et al. 2001). Large predators such as coyotes or cougars help to maintain biodiversity by suppressing smaller predators such as raccoons and maintaining a more sustainable population of herbivores, which may drastically influence riparian vegetation (Berger et al. 2001). Many smaller predators are extremely destructive to wildlife, especially ground and shrub nesting birds, when their population increases above the equilibrium (Soulé 1991a). Retaining the large predators allows for a functioning system in which populations of various species are kept at natural levels.

A study in the Seattle area that characterized the diet of coyotes in an urban environment found that house cats made up 13 percent of a coyote's diet in residential areas (Quinn 1997). Experts estimate that feral and domestic cats kill hundreds of million birds and perhaps a billion small mammals per year (Churcher and Lawton 1987; Mott 2004). However, this is not to imply that coyote abundance promotes natural biodiversity, but it provides an example to illustrate the importance of larger predators in an ecological system.

Small Patches

However, there are benefits to preserving smaller habitat patches in certain circumstances. Heske et al. (2001) concluded "...not all small patches are bad..." in a review of several studies on nest predation and songbirds. According to Soulé (1991a) small patches may be sufficient to preserve vegetation communities when the plants are not dependent on fire for regeneration, not subject to loss of genetic variability due to isolation, do not depend on animals for pollination or dispersal, and are able to compete in the absence of the natural disturbance caused by large animals and fire. Many species of rare butterflies are mostly sedentary as adults, and thus require maintenance of specific vegetation in small patches over a larger region (Smallidge and Leopold 1997). Butterflies also may require a series of successional habitats for different lifestages.

Small patches that are well connected to other patches will also provide important functions for wildlife species not dependent on interior habitat. Some species may be able to use small habitat patches that are individually too small by composing a home range made up of multiple habitat fragments (Dunning et al. 1992; Noss and Csuti 1997; Hostetler and Holling 2000). Other species may survive within the urban matrix if they have a series of relatively small patches that are connected by movement corridors (Bolger et al. 1997a). Proximity of small patches to stream corridors and wetlands undoubtedly elevates their significance for wildlife.

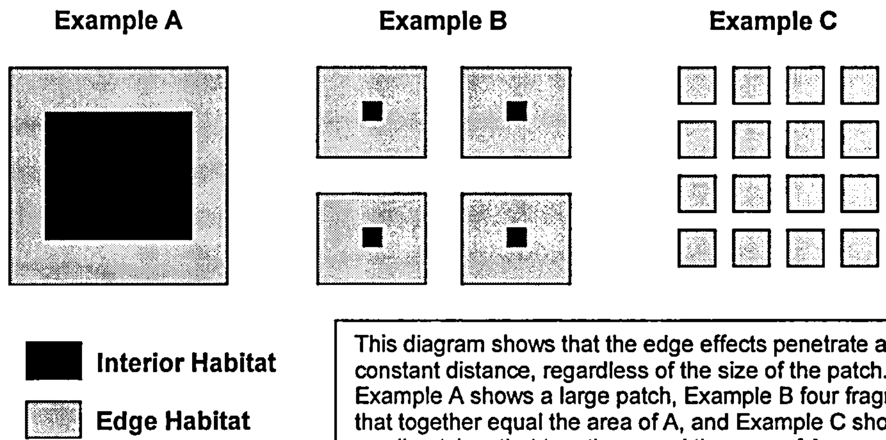
Quality of the habitat
The quality of the habitat in a patch is important, large patches that have degraded habitat will not support healthy wildlife populations even though edge effects are reduced (Martin 1993). Haire et al. (2000) found that the plant communities dominated by exotics had a negative effect on the abundance of Western Meadowlarks, demonstrating the importance of native vegetation within a habitat fragment for many species, particularly habitat specialists. In Arizona, Germaine et al. (1998) found a strong correlation between native vegetation and sensitive bird species in the urban area. Beissinger and Osborne (1982) compared bird communities in residential areas with mature trees and nearby undisturbed forests. They found that urbanization impacted the amount of vegetative cover, thus reducing the number of forest insect eating birds and increasing the number and diversity of birds able to glean food from the ground. The type of forest also impacts the quality of the habitat for certain songbirds. Studies have shown that nest predation is higher in coniferous forests than in deciduous forests due to the associated predators such as squirrels found in coniferous forests (Heske et al. 2001).

Edge effect
Xxxinsert lori's edge effects in this sectionEdge habitat occurs where one habitat type, such as a forest, meets a meadow, stream, road, or other natural or artificial habitat type (Forman and Godron 1986; Lidicker and Koenig 1996). The size of a patch, as well as the relationship with surrounding habitats, has a direct impact on the edge effect on wildlife populations. Species diversity is typically higher in edge habitats, but the number of habitat specialists, or species that require a particular type of habitat for survival, tends to decrease. Patch size and patch configuration both impact the amount of edge habitat – a large square will have less edge habitat and more interior habitat than a long, thinly shaped habitat (Soulé 1991a). Urbanization typically increases habitat fragmentation, providing more edge habitat and reducing the amount of original habitat (Lidicker and Koenig 1996).

The shape of a habitat patch can predict the effectiveness of the area in providing valuable habitat for wildlife. There are two general shapes of patches: circles or squares and rectangles or oblong shapes (Fleury and Brown 1997). Rectangular or oblong patches include more edge habitat and thus are less effective as wildlife habitat, especially for interior species. Circular or square patches often contain more species diversity, allow for increased foraging efficiency, and contain fewer barriers within the habitat patch than rectangular patches (Forman and Godron 1986).

Some species, often called habitat generalists, actually benefit from increased edge effect and fragmentation. Many predators such as foxes and coyotes are better able to hunt along edge habitats, where prey such as birds and small mammals are easier to find. Other species, for example the House Finch, Anna's Hummingbird, deer, and raccoons, have the ability to use resources provided in landscapes that have been altered by humans (Bolger et al. 1997b). Some species rely on interior habitat that is relatively undisturbed, such as the Swainson's Thrush and Winter Wren. Increased fragmentation frequently allows the edge species to thrive while interior dwellers decline (Soulé 1991a; Nilon et al. 1995; Hennings 2001; Hennings and Edge 2003). Most conservationists agree that too much edge habitat is detrimental for wildlife, and the focus when developing a habitat protection plan should be on retaining as much interior habitat as possible. Soulé (1991a) describes some of the major negative impacts of edge habitats as higher frequency and increased severity of fire; higher rates of hunting and poaching; and higher intensities of predation. Figure 12 below depicts the relationship between patch size and the amount of edge effect.

Figure 12: Relationship between patch size and edge effect.



This diagram shows that the edge effects penetrate a constant distance, regardless of the size of the patch. Example A shows a large patch, Example B four fragments that together equal the area of A, and Example C shows 16 small patches that together equal the area of A.

Source: Adapted from Soulé, 1991.

The edge effect can penetrate far into the interior habitat necessary for certain species. Some studies have shown that certain impacts such as invasion by exotic plants and predation can penetrate up to 500 meters into the forest (Wilcove 1985). Bolger et al. (1997b) found that the abundance of interior habitat bird species was reduced within 200 to 500 meters of an edge. A study in southern Ontario found that ovenbirds, an interior habitat species, select nest sites more than 250 meters from the forest edge, a distance that is not possible in a small habitat fragment (Burke and Nol 1998). Interior habitat specialists may respond to edge effects far from the actual edge habitat (Lidicker and Koenig 1996). Some of the impacts the edge effect may have on interior species include reduced survival rates, reduced reproduction rates and increased emigration from unsuitable habitat (Bolger et al. 1997b). Friesen et al. (1995) found that the edge effects of residential development impacted the diversity and abundance of songbirds in forested habitat patches regardless of the patch size. The response of wildlife movement to edge habitat varies by species, some species will not approach the edge while others will move freely through the edge habitat to another area (Lidicker and Koenig 1996).

Distance effect

Animal movement frequency decreases in direct relation to the distance between habitat patches, and is called the *distance effect.* Increased habitat fragmentation impacts the ability of wildlife to disperse between habitat patches (Soulé 1991a). Dispersal of animals between patches helps to preserve populations by protecting against catastrophes and preventing genetic decline due to inbreeding (Soulé 1991a; Lidicker and Koenig 1996). The distance effect can be observed in compact island archipelagos that have more species diversity than remote islands, because proximity facilitates the rescue of endangered populations and allows for the recolonization of islands where extinctions have occurred. However, the distance between habitat fragments need not be great before it begins to have an impact if a species is unable to move through the matrix of modified habitat (Bolger et al. 1997a).

Age effect

Another impact of fragmentation is called the **age effect.** This refers to the amount of time a fragment has been separated from the "mainland" or the surrounding landscape by urbanization. The length of time that a habitat patch has been fragmented typically correlates to lower native species diversity. Bolger et al. (1997a) found that in a time span of 20-80 years all native rodents had disappeared in over half of the habitat patches studied. Soulé et al. (1988) found that the size of patch along with the length of time a patch had been fragmented explained most of the variation in the number of bird species found within a habitat patch.

Connectivity

"When urbanization is occurring...habitat fragmentation is inevitable, and one of the only practical mitigation measures is the establishment of corridors of natural habitat or linkages, such as underpasses, that permit dispersal across barriers." (Soulé 1991a)

Habitat corridors may be defined as strips of habitat that allow the movement of organisms through the landscape matrix and between habitat patches (Lidicker and Koenig 1996; Beier and Noss 1998). The general consensus is that connections between habitat fragments are crucial to the survival of many species, and that well designed corridors can play a key role in maintaining ecosystem vitality (Adams and Dove 1989; Soulé 1991a,b; Beier and Noss 1998). Corridors provide the opportunity for many species to traverse through habitat that is not suitable for permanent residency to find better habitat, find a mate, dispersal of post-breeding young, or to escape over-predation or other dangers in their current habitat (Lidicker and Koenig 1996). Corridors tend to be most effective if they are not overly long, if there are few gaps, if the width is consistent, and if the corridor does not harbor an excessive number of predators (Lidicker and Koenig 1996). The functional role of corridors is related to the scale at which animals perceive their environment, and little research has been conducted on the kinds of corridors necessary for specific species (Lidicker and Koenig 1996; Clergeau and Burel 1997). Metapopulation theory and modeling provides much of the support for the use of corridors in wildlife conservation (Hess 1994).

Connectivity is important for wildlife for several reasons. Wildlife populations that are connected to each other are more likely to survive over the long term than an isolated population (Lidicker and Koenig 1996; Duerkson et al. 1997). A population that exists on a connected system of habitat fragments will be more likely to survive a catastrophic event on one patch, and the surviving population may be able to repopulate or revive an area that is in trouble (Hess 1994). Many species must migrate seasonally to meet basic needs for food, shelter and breeding, and connections between habitat patches allow this migration to occur (Lidicker and Koenig 1996; Duerkson et al. 1997). Connectivity between habitats allows populations to interbreed, which aids in the vigor and survival of the overall population by reducing genetic inbreeding

(Duerkson et al. 1997). Corridors play an important role in urban areas to provide opportunity for migration and movement, especially between upland and riparian habitats.

Several studies show the importance of corridors and connectivity for wildlife. Clergeau and Burel (1997) studied the Short-toed Tree Creeper, a small bird, in an agricultural area of France. Their study confirmed that the birds relied on the habitat connectivity provided by hedgerows to contain home ranges and to avoid long flights. Bolger et al. (1997a) identified the lack of connectivity between habitat fragments as an important possible cause of the extinction of native rodent species in over half of the sites studied near San Diego, California. In a study of the dispersal behavior of three migratory bird species in North Dakota, Haas (1995) found that movements by adult birds between habitat patches occurred more frequently between sites connected by a wooded corridor than between unconnected patches.

The benefits of habitat corridors have been heavily debated in the scientific literature (Simberloff and Cox 1987; Adams and Dove 1989; Soulé 1991a; Lidicker and Koenig 1996). Connectivity is important within a fragmented landscape. However, while corridors provide many benefits, there are some potential disadvantages, although they have not been quantified (Simberloff and Cox 1987; Adams and Dove 1989). Researchers speculate that corridors may allow exotic species, including plants, animals, and birds, easier access to invade native habitats and may serve as reservoirs of edge and introduced species (Simberloff and Cox 1987; Simberloff et al. 1992). Corridors may also allow for easier transmission of disease, faster predator movement, and could concentrate species in one area leaving a population more vulnerable to a catastrophic event (Adams and Dove 1989; Simberloff et al. 1992; Duerkson et al. 1997).

Hess (1994) developed a model that showed a landscape of connected patches generally suffered fewer metapopulation extinctions than a landscape of isolated patches. Beier and Noss (1998) conducted a review of scientific studies on the benefits and negative aspects of corridors. While the overall conclusion was that the literature is not yet sufficient to declare the positive value of corridors, several studies showed that corridors function as travel connections for wildlife in real life, and no studies provided empirical evidence of negative impacts from corridors. The literature appears to indicate that the benefits of a connected landscape typically outweigh the potential negative effects of corridors, especially in urban environments (Soulé et al. 1988; Beier and Noss 1998).

Fleury and Brown (1997) developed a framework for the design of wildlife corridors that considered critical corridor characteristics. Some of the general principles identified in the study were:

- corridors should be oriented perpendicular to habitat patches to direct wildlife through the corridor;
- barriers or breaks in the corridor should be minimized;
- corridors should be as short as possible to reduce the risk of mortality;
- corridor width should be based on the minimum width needed for the target species highest on the food chain; and
- corridors should be shaped as close to a rectangle as possible.

The size and shape of a corridor can have a direct impact on the effectiveness of the corridor for wildlife movement. The most effective corridor shape is a rectangle, directing animals straight through the corridor from one habitat patch to another (Fleury and Brown 1997). Soulé (1991a) concluded that any shape other than rectangular can increase the amount of time that must be spent in edge habitat, and that the most effective corridors have straight sides and a constant width.

Human disturbance

Humans introduce a wide variety of changes to the environment, and the specific effects of these changes remain largely unknown. Because human population has grown so quickly during the past century, changes have been rapid and are accelerating. There is no single solution to the complex environmental challenges posed by humans, but focusing on the most pervasive issues is an effective way to begin addressing the problems. The most obvious result of human disturbance is the loss, alteration and fragmentation of habitat, as discussed above. Here we focus on human disturbance in natural areas and some of the consequences to wildlife and habitat.

Nonnative species

Nonnative species – those that originate from outside the U.S. – pose a major threat to native species. Over 50,000 species have been introduced in the U.S., both intentionally and unintentionally. Of all the species listed as threatened or endangered under the federal Endangered Species Act (ESA), 42 percent are at risk primarily due to nonnative species (Wilcove et al. 1998). Excluding the enormous expenses involved with ESA listings and subsequent recovery efforts, nonnative species cost the U.S. more than $138 billion per year in environmental damage and losses (Pimentel et al. 2000). The rate of species introductions is increasing sharply, and successful nonnative species introductions are usually irreversible (Allan 1995). At least 42 nonnative vertebrate species occur in Oregon and Washington; about half of these have achieved widespread distribution and pose a threat to native biodiversity (Witmer and Lewis 2001). Early detection and rapid response to new invasions are key to controlling nonnative invasions (Toney et al. 1998).

Nonnative plants and animals are typically generalists that can thrive in a variety of habitats. They tend to respond positively to disturbance and often lack natural predators (Parendes and Jones 2000). Native species are not evolutionarily adapted to compete with nonnatives (Allan 1995). Nonnative species may alter habitat, introduce diseases and parasites, change community structure, and compete or hybridize with native species, but predation is a common cause of the replacement of native species with nonnatives (Allan 1995). Nonnative invasions regularly occur in upland, riparian, and aquatic habitats (Witmer and Lewis 2001). In the northwestern U.S., recent decades have seen a shift from primarily herbaceous toward greater proportions of shrub and tree invaders (Toney et al. 1998).

In natural circumstances, one or more types of barriers may prevent nonnative plant or animal invasions. These include biological barriers, such as low seed production; physical barriers affecting travel pathways, such as oceans, mountains, or closed canopy forest; or environmental barriers, such as unsuitable light, soil or moisture conditions (Parendes and Jones 2000). Human disturbance is one common pathway for nonnatives to overcome these barriers (Witmer and Lewis 2001).

Nonnative species have a strong impact on native plants and wildlife in the Metro area. In the Metro region, problematic nonnative plants include Himalayan Blackberries, English Ivy and Reed Canarygrass. Japanese knotweed is gaining a foothold and kudzu, an aggressive nonnative plant that has devastated areas of the south, recently appeared in southwest Portland (Toney et al. 1998; Christ 2000). European Starlings were the most abundant bird species detected in 54 sites in this area (Hennings 2001). Starlings monopolize nest cavities and may eradicate native bird species in some small habitat patches (Weitzel 1988). Other nonnative birds in our area include House sparrow, Rock Dove (pigeon), Monk Parakeet, and Ring-necked Pheasant. Nonnative Fox Squirrels and Eastern Gray Squirrels are contributing to the decline of native Western Gray Squirrel populations (Marshall et al. 1996). House Mouse, Norway Rat, Black Rat and Nutria are other common Metro area nonnative animals. Common Snapping Turtles and Red-eared Sliders are two nonnative turtles that have successfully established breeding populations in our area (Witmer and Lewis 2001). The number of nonnative insects competing with natives (which include critical native plant pollinators) is probably quite significant, but unknown because insects are relatively unstudied. Management activities that minimize favorable conditions for nonnative species would greatly benefit native wildlife in our region.

Increased predation and competition

Urbanization tends to increase predation and competition in native wildlife communities, due to changes in habitat (see *Habitat fragmentation* section above) and wildlife community structure. These effects are well documented for birds (Small and Hunter 1988; Marzluff et al. 1998). In Seattle, Washington researchers are monitoring birds and small mammals across an **urban gradient**. Their data indicates that small mammals tend to increase with urbanization. These increases are accompanied by a decrease in bird nest success, because small mammals such as mice routinely eat bird eggs. Domestic cats pose another threat to native wildlife, and are the primary reason for injured native wildlife brought to the Audubon Society of Portland's Wildlife Rehabilitation Center (Sallinger 2001, personal communication), and in England were shown to cause at least 30 percent of sparrow mortality (Churcher and Lawton 1987). Increased competition from native birds can also be a problem; Brown-headed Cowbirds lay their eggs in host species' nests, effectively decreasing reproductive success of the host. Cowbirds are edge-associated and are quite successful around humans (Lown 1980; Brown 1994; Larison et al. 1998).

Roads

Roads, while important to society, have widespread negative impacts on native plants, fish, and wildlife. Direct road effects include geomorphic (sedimentation and landslides), hydrologic (intercept rainfall and subsurface water moving down hillslopes; concentrate flow; and divert or reroute water), site productivity (remove and displace topsoil, alter soil properties, change microclimate, and accelerate erosion), habitat fragmentation and alteration, and biological invasions (Gucinski et al. 2001). Forman (2000) estimates that one-fifth of U.S. lands are directly ecologically affected by public roads.

Roads are a leading threat to biodiversity, for a variety of reasons (Wilcove et al. 1998; Trombulak and Frissell 2000). Trees and other vegetation are removed to build the road. Roads fragment habitat, increase wildlife mortality, and promote dispersal of nonnative plants because they alter habitats, stress native species, and provide seed resources and dispersal corridors (Tyser and Worley 1992; Lonsdale and Lane 1994; Parendes and Jones 2000; Trombulak and

Frissell 2000). Road networks contribute more sediments to streams than any other land management activity, from both surface erosion and landslides, degrading water quality and smothering gravel beds (Jones et al. 2000; Gucinski et al. 2001; see also Riparian and Aquatic Habitat chapter). Contaminants such as oil, gas and other toxins washing off roadways may pollute adjacent areas and degrade habitat. Roads add substantially to the total load of impervious surfaces in a watershed.

Wildlife most at risk due to roads include species that avoid edge environments, occur in low densities, are unwilling or unable to effectively cross roads (e.g., amphibians), or seek roads for heat (snakes) or food (owls) (Fleury and Brown 1997). Comparing high and low density road areas in New York, Steen and Gibbs (2004) found altered sex ratios in turtle populations, with many more males in high road density areas. Aresco (2005) found similar results in Florida. This suggests that more females are killed on roads during nesting migration, thus fewer eggs are laid each year. Tennessee, roads significantly depressed the abundance and richness of insects living in the soil (Haskell 2000). In addition, road noise may negatively influence wildlife through behavior modification. For example, birds sing during the breeding season to attract mates and defend their territories, but this effort is wasted if it cannot be heard. Local data suggests that long-distance migratory species such as Black-headed Grosbeak and Common Yellowthroat are especially susceptible to negative road impacts (Hennings 2001); reports elsewhere support this observation (Forman and Deblinger 1999; Ortega and Capen 1999). There is evidence of a time lag between road-building and species loss in wetlands (Findlay and Bourdages 2000), emphasizing the need for long-term studies.

Recreational use and human disturbance

The protection of wildlife and habitat also provides recreational opportunities for people. This is positive in that people desire to connect with nature, and exposure to wildlife and natural areas encourages people to care about preserving those natural values. In addition, many local communities benefit from dollars spent on hunting and wildlife watching (Wiedner and Kerlinger 1990; U.S. Fish & Wildlife Service 1997a). However, recreation in wildlife habitats is negative in that human intrusions lead to alterations in habitat – for example, vegetation trampling, trails and roads – and may alter wildlife behavior, physiology and distribution.

Some wildlife species are more sensitive to human intrusions than others (Major 1990; Gutzwiller et al. 1998), and some life history phases are more vulnerable to disturbance than others. For example, in the Metro region Steller's Jays and Swainson's Thrushes may be especially vulnerable to recreational disturbances during the breeding season (Hennings 2001). Montana studies suggest that breeding birds and young are very vulnerable, and may abandon nests or fail to feed young when disturbed (Montana Chapter, The Wildlife Society 1999). In Madrid, bird abundance and species richness declined when pedestrians walked near sampling points (Fernández-Juricic 2000). Bats are particularly sensitive to human disturbance, especially during breeding or hibernation (Montana Chapter, The Wildlife Society 1999). Carnivores are mixed in susceptibility – some thrive near humans (e.g. skunks, raccoons, coyotes), but others, such as wolves, black bears and fisher, may abandon den sites when disturbed (Montana Chapter, The Wildlife Society 1999), and it may be no coincidence that these former Metro-area inhabitants are now conspicuously absent. In Colorado, elk experienced reproductive failure when repeatedly approached by humans (Phillips and Alldredge 2000).

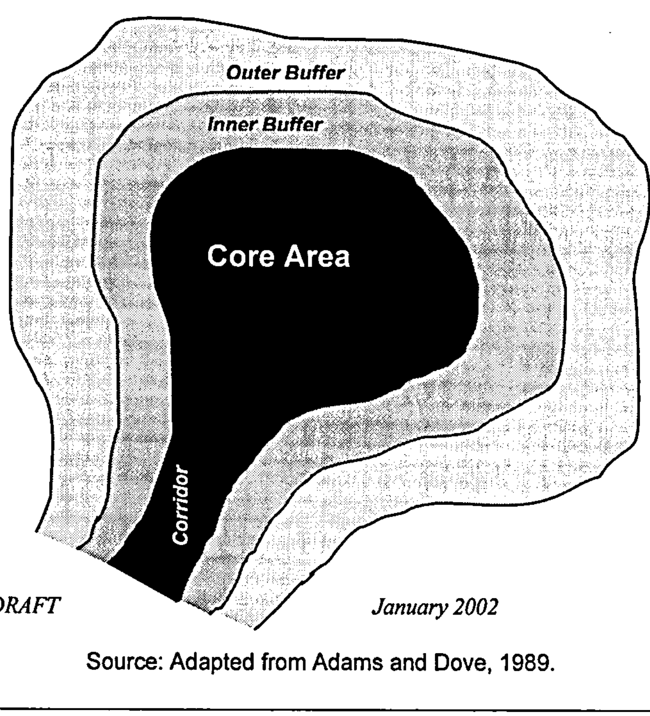
In addition to detrimental effects of roads and trails in natural areas, vegetation changes are another byproduct of recreational use. For example, in Washington State a recreational area was systematically exposed to vegetation trampling. In response, the amount of grasses and herbs increased, while the structurally important woody species decreased (Cole and Trull 1992). In a multi-state study including Washington, researchers found that one night of camping was sifficient to eliminate 30 to 50 percent of the vegetation from high-use portions of the campsite (Cole 1995). A Colorado study of military training on soil and vegetation properties found a 68 percent decrease in total above-ground plant mass, a 91 percent decrease in organic litter, decreased water infiltration and increased soil erosion when comparing high-use sites against a reference site (Whitecotton et al. 2000). As discussed above, roads (and similarly, trails) provide a means of nonnative plant invasion.

Buffers and Surrounding Land Use

The effectiveness of a habitat patch relates to the surrounding land use as well as its size, proximity, and connectivity to nearby patches. The landscape of an urbanized area is composed of habitat patches and connecting corridors embedded within a matrix of land altered by human activity (Linehan et al. 1995). Thus the matrix of the altered landscape covers more area than the habitat patches within it, and correspondingly plays a large role in the landscape dynamics. Friesen et al. (1995) studied the effects of residential development around forested habitat areas on Neotropical migrant songbirds in Ontario, Canada. The study found that the level of residential development drastically reduced the abundance and diversity of the songbirds, regardless of the size of the forest patch. The authors concluded that solely retaining intact forests is not enough to maintain healthy forest ecosystems that are able to support interior habitat specialists.

Habitat patches may be more valuable for wildlife and people if they are surrounded by a buffer zone within which low impact human activities may occur, reducing edge effects and leaving the

Figure 13. Example of a buffer system protecting a core area for wildlife habitat.



Core area: this area provides the highest level of protection for wildlife, with minimal disturbance allowed

Inner buffer: low impact human activities are allowed in an inner buffer, such as nature trails, wildlife observation areas, and play areas

Outer buffer: more disturbance is allowed in the outer buffer, such as low density or clustered residential development

Source: Adapted from Adams and Dove, 1989.

inner core habitat with as little disturbance as possible. While a buffer zone is by nature edge habitat, the "permeability" or softness of the edge has a direct impact on the ability of species to disperse and populate surrounding areas (Lidicker and Koenig 1996). Some species may be able to move through the matrix of land uses from one habitat fragment to another, while less mobile species may be trapped by the surrounding land uses. Berry et al. (1998) found that some bird species are more sensitive to urbanization of the landscape than others, indicating a need for additional buffers to protect habitat for these species.

One approach to counteracting the impact of edge effects is to protect habitat reserves by designing a system of buffers to protect wildlife from surrounding land uses, as well as to allow recreational use of a habitat reserve system. Figure 13 below depicts a core area and two types of buffers surrounding it. Little to no human disturbance would be allowed to intrude within the core area. The inner buffer could include nature trails and other opportunities for low impact human recreation, while the outer buffer could allow for low-density residential development or another low impact development type (Adams and Dove 1989; Adams 1994). Little research is available on the appropriate size of buffer widths and the types of activities that may occur within buffers that do not excessively impact interior habitat specialists.

Low-density residential uses are often seen as having the least impact on wildlife habitat, particularly for birds (Nilon et al. 1995). However, there are still several negative impacts such as an increase in small predators such as domestic cats and dogs, increased fragmentation due to roads and trails, and increased human use of habitat areas for recreation and relaxation. Theobald et al. (1997) found that clustered development patterns reduce the negative impacts of human disturbance on wildlife. The pattern of development was found to be more of an indicator of disturbance level than density. Blair (1996) found that the composition of bird communities changed from predominantly native species in undeveloped areas to nonnative birds in highly developed downtown areas. Studies have shown that habitat patches surrounded by agricultural uses have an especially high rate of nest predation (Heske et al. 2001).

Upland Habitat Patch Size and Connectivity Recommendations

Planning for wildlife habitat reserves in urban areas brings up many considerations, including the issue of providing habitat for species that are often sensitive to human activity while at the same time providing people the opportunity to use open spaces within the city for recreation and wildlife viewing (Johnson 1995). Some wildlife species have the ability to utilize many types of habitat and adapt well to the presence of people. Other species require a specific habitat type, and many species require the ability to migrate from one habitat type to another to fulfill basic needs such as foraging, breeding, and safe shelter. Habitat specialists will require the protection of larger reserves, but other wildlife species can be retained in the city if required habitat elements are provided within the context of urban development (Donnelly and Marzluff *in review*). Wildlife habitat can be provided in many ways: large natural areas, small portions of city parks that are left "wild", cemeteries, schoolyards, bridges and other man-made structures, and even backyards. Retaining native biodiversity will require a protection plan that utilizes an array of strategies to maintain and restore wildlife habitat.

Human impacts on wildlife can be minimized with the proper design of habitat reserves, based on the surrounding land uses. The movement needs of wildlife can be provided for using corridors, which may be described as linear (often narrow) strips of habitat embedded in other land uses that have value for wildlife by connecting fragmented patches of habitat (Adams and Dove 1989; Beier and Noss 1998). The effects of fragmentation can be combated to a certain extent by providing connections between remaining fragments. Soulé (1991a) states: "Wildlife corridors can be viewed as a kind of landscape health insurance policy – they maximize the chances that biological connectivity will persist, despite changing political and economic conditions." Corridor design, however, depends on the specific species or **species guild** that is being planned for as well as accounting for local conditions (Linehan et al. 1995). Human impacts can be further mitigated through management and design regulations for urban development as well as increasing the diversity and abundance of native vegetation in urban parks (Lancaster and Rees 1979).

Corridors often naturally follow utility rights of way, fencerows, trails, and riparian areas. The size of habitat patches are an issue in both rural and urban environments, as larger patch size typically provides more functions and values for wildlife than a smaller habitat area. However, small patches of unique habitat may provide the key in retaining sensitive species within an urban area. A functioning system of small patches can provide an overall benefit to wildlife if designed with connectivity in mind.

The most important conclusion from the scientific literature in planning to protect habitat for wildlife is that "the best way to maintain wildlife and ecosystem values is to minimize habitat fragmentation" (Soulé 1991a). There is no single method for retaining and restoring the natural ecosystems necessary for wildlife in the urbanizing landscape that has been proven to work. However, maintaining a system of habitat patches, large and small, that are as well connected as possible appears to be the most likely solution (Linehan et al. 1995).

While specific guidelines regarding patch size and shape, corridor width, and proximity have been developed in other regions, there are no universally applicable recommendations. For example, the Wildlife Division of Environment Canada (1998) has developed specific recommendations such as providing at least one 200 hectare forest patch that is a minimum of 500 meters in width to provide interior habitat within a subwatershed. In Arizona, Germaine et al. (1998) recommended retaining habitat patches greater than one hectare containing native vegetation throughout the urban matrix to allow provide for sensitive bird species. Table 11 below depicts a summary of planning guidelines derived from the scientific literature. In the future, as more local information becomes available, more precise recommendations may be developed for upland wildlife habitat.

Upland habitat areas play a crucial role in retaining native biodiversity as well as maintaining healthy ecosystems. As discussed above, urbanization of the landscape negatively impacts wildlife through habitat loss, habitat fragmentation, and human disturbance. In the Metro region we still have remnants of the diverse native habitat that blanketed our region prior to settlement in the 1850s. Abundant wildlife supported generations of Native Americans as well as European settlers arriving in the region. Today's residents continue to appreciate the accessibility of wildlife while enjoying the benefits of a city. The Metro region is projected to grow by around 500,000 people in the next twenty years. If retaining access to open spaces and the opportunity to view wildlife in the city is to remain a priority it becomes even more important to plan for a well conceived system of habitat preserves and corridors throughout the region.

Table 11. Planning guidelines for upland wildlife habitat

Guideline	Explanation	Supporting literature
Large patches are better than small patches, and they should be round or square to reduce the amount of edge effect	• Research shows that the edge effect ranges from 200-500 meters • Larger patches provide more interior habitat • Can support a larger number of individuals and a greater diversity of species • Can support a wildlife population for a longer time period • Provides greater opportunity for foraging and dispersal	Wilcove 1985 Forman and Godron 1986 Soulé 1991a Bolger et al. 1997a Duerkson et al. 1997 Fleury and Brown 1997 Germaine et al. 1998 Burke and Nol 1998 Environment Canada 1998
Small patches of unique habitat are worth saving	• Can retain unique vegetation communities • May provide "stepping stones" of habitat if in relatively close proximity, or in combination with habitat corridors • Can provide habitat for generalist and edge species • Especially important if near water resources	Soulé 1991a Dunning et al. 1992 Noss and Csuti 1997 Bolger et al. 1997a Environment Canada 1998 Hennings 2001
Connectivity to other patches is important, corridors should be as wide as possible, and it is cheaper to retain corridors than to create them after the fact	• Can play a key role in maintaining ecosystem vitality and the survival of may species • Connected populations are more likely to survive over the long term • Allows populations to interbreed, maintaining genetic variability • Provides movement corridors for seasonal migration, finding better habitat, finding a mate, dispersal of post-breeding young, and escape routes	Adams and Dove 1989 Soulé 1991a Linehan et al. 1995 Lidicker and Koenig 1996 Bolger et al. 1997a Clergeau and Burel 1997 Fleury and Brown 1997 Environment Canada 1998
Connectivity and/or proximity to water resources is valuable	• Habitat patches near water resources have increased diversity of wildlife • Most wildlife species use riparian areas for some aspect of their life history • Over 60 percent of mammals in the Northwest use riparian areas for breeding or feeding • Riparian corridors frequently serve as travel routes, especially in urban areas	Forman and Godron 1986 Environment Canada 1998 Hennings 2001 Kauffman et al. 2001
Buffers can help protect wildlife from human disturbance	• Surrounding land uses have an impact on the effectiveness of a habitat patch in providing functions and values to wildlife • People like to use natural areas and open space for recreation • A buffer zone allows for human use of a selected part of a habitat patch, while protecting wildlife from excessive disturbance	Adams and Dove 1989 Adams 1994 Nilon et al. 1994 Friesen et al. 1995 Linehan et al. 1995 Lidicker and Koenig 1996

Protecting upland habitat areas in this region will be a challenge while also ensuring enough land for urban development. However, the integration of these two seemingly contradictory goals is a central tenet of the Region 2040 Growth Concept, the Regional Framework Plan, and the Urban Growth Management Functional Plan. It is also much cheaper to protect existing habitat than to attempt to restore degraded habitat. The Metro Parks and Greenspaces Department and local park providers have been purchasing key natural areas throughout the region from willing sellers with the 1995 bond measure. Acquisition of habitat is one of the best methods to ensure a piece of land will remain in its natural state. However, there is not enough money available to purchase the amount of land necessary to provide a functioning system of habitat reserves and corridors that could maintain native biodiversity in the region. Education and incentives for landowners to manage private property to provide wildlife habitat would help to meet objectives of retaining native wildlife. A regulatory program that helps to guide urban development in a way that retains as much functional value for wildlife as possible will most likely be a necessary tool, combined with acquisition and incentive programs, to meet the objective of maintaining the region's biodiversity and implementing the Region 2040 Growth Concept. This approach may be most appropriate when planning for future urban areas that are brought within the urban growth boundary, when it would be possible to plan for wildlife preserves and corridors.

RESTORATION IN AN URBAN ENVIRONMENT

Introduction

Environmental degradation affects everyone. The ecological impacts associated with increasing human populations stress the environment, and it is critical to find ways to reduce these stresses if people, plants and wildlife are to be protected. Rapid population growth and dwindling salmon runs in the Metro region add a sense of urgency to such efforts. There is no quick or easy answer; most people do not want to contribute to fish and wildlife extinctions or widespread environmental degradation, yet few are certain what changes could be made to avert such problems.

Metro's Regional Urban Growth Goals and Objectives (RUGGOs) call for Metro to "protect, restore and ensure to the maximum extent practicable the integrity of streams, wetlands and floodplains, and their multiple biological, physical and social values" (Metro 1995). Accordingly, the purpose of this chapter is to outline an approach to habitat restoration that is based on science, relevant to urban ecosystems, and grounded in reality.

Urbanization negatively affects native fish and wildlife through impairment of the natural functions that create and maintain suitable habitat. Some degree of measurable resource degradation can be detected at virtually any level of urban development, but degradation can be mitigated by activities such as increasing or retaining forest canopy cover and reducing effective impervious surfaces (Shaw and Bible 1996; Booth et al. 1997; Booth 2000). Restoration can assist the recovery of functions necessary for watershed health; in turn, healthy watersheds can support people, fish and wildlife. Efforts to protect and restore habitat can, in many instances, also benefit humans by reducing flood damage and protecting water quality (Lucchetti and Fuerstenberg 1993a,b).

Successful restoration depends on addressing the causes of environmental degradation, rather than the symptoms. Goodwin et al. (1997) suggest asking several questions related to the causes of degradation: Is the disturbance local to the riparian area or does it originate outside in the adjacent upland or watershed? Is the disturbance ongoing, and if so, can it be eliminated? And finally, will recovery occur naturally if the disturbance is removed? The answers to these questions can help guide a restoration plan.

Four major impact categories – altered hydrology, water quality, loss of natural vegetation cover, and impervious surfaces – appear repeatedly in the literature addressing urban ecology. Combined with the presence of humans in the system, these impacts lead to: diminished stream channel and riparian corridor integrity; degraded water quality (chemistry); habitat loss, simplification and fragmentation; altered food webs; nonnative and invasive species invasions; changes to climate and microclimate conditions; and harassment, noise, vibration, light, and other human disturbances to wildlife.

These impacts cannot be realistically addressed through site-specific or small-scale restoration approaches; virtually all recent restoration literature suggests that watersheds are the *minimum* spatial unit for which restoration master planning should occur (e.g., Spence et al. 1996; Goodwin et al. 1997; Hollenbach and Ory 1999; IMST 1999; Watershed Professionals Network 1999; IMST 2001b). In urbanized regions such as ours, impacts in one watershed may influence adjacent or downstream watersheds. Thus all watersheds within the urban area, plus all adjacent watersheds, should be considered in a master restoration plan. The National Marine Fisheries Service (2000b) commented on the importance of considering restoration projects in a large-scale context:

> Projects planned and carried out based on at least a watershed-scale analysis and conservation plan and, where practicable, a sub-basin or basin-scale analysis and plan, are likely to be the most beneficial. NMFS strongly encourages those involved in watershed restoration to conduct assessments that identify the factors impairing watershed function, and to plan watershed restoration and conservation activities based on those assessments. Without the overview a watershed-level approach provides, habitat efforts are likely to focus on "fixes" that may prove short-lived (or even detrimental) because the underlying processes causing a particular problem may not be addressed.

Much of the information available on restoration deals with waterways because of their importance to humans, fish and wildlife, vulnerability to degradation, and influence on other parts of the landscape. In addition, many regional restoration efforts focus on instream and riparian restoration within limited areas to address ESA-listed salmonid recovery (Spence et al. 1996). These are good reasons to focus on stream systems, but this approach fails to adequately protect functions critical to other wildlife species and also fails to take into account the majority of the watershed: uplands.

Uplands provide unique and important wildlife habitat, such as oak-madrone and native grasslands (Larsen and Morgan 1998). Upland habitats also influence stream functions; for example, the amount of forest canopy cover strongly influences the health of Pacific Northwest streams (Shaw and Bible 1996; Booth et al. 2001). Uplands are vital components in any watershed, and the ecological principles and restoration concepts addressed in this chapter are meant to provide a restoration framework at the watershed scale or larger; therefore, uplands are implicitly included here and should be considered in watershed restoration planning. Well-planned watershed conservation and restoration efforts today may prevent future ESA listings, and will almost certainly benefit people and wildlife.

Definition of restoration and other terminology

Most definitions of ecological restoration involve the functional recovery of human-degraded ecosystems. For example, the Society for Ecological Restoration (SER) defines **ecological restoration** as the process of assisting the recovery and management of ecological integrity. Ecological integrity includes a critical range of variability in biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices (SER 2000) (Appendix 3). The Oregon Division of State Lands defines riparian restoration as "the rehabilitation of riparian areas to improve degraded functions" (Van Staveren et al. 1998). Title 3 defines restoration as the process of returning a disturbed or altered area or feature to a previously existing natural area; restoration activities reestablish the structure, function, and/or diversity to that which occurred prior to human impacts (Metro 1997b). The National Marine Fisheries Service (NMFS) considers a "habitat restoration activity" to be an activity whose primary purpose is to restore natural aquatic or riparian habitat processes or conditions; it is an activity that would not be undertaken but for its restoration purpose (NMFS 2000b).

Full ecological restoration is probably not possible in urban areas, because some changes are relatively permanent (such as roads and structures) and due to the cumulative nature of changes to urban watersheds (Beschta 1995; Goodwin et al. 1997). In reality, urban "restoration" may represent a range of improvements in function and condition over time, limited in an urban setting to what is actually achievable - in other words, an ecologically, economically and socially acceptable range of options that re-establishes natural functions. The end goal is sustainability, under a new urban equilibrium that supports diverse wildlife communities and healthy ecosystems.

The scientific literature reflects this reality through a variety of terms, all defining lesser versions of full restoration (e.g., restoring targeted functions rather than the full range of original functions). Title 3 defines **Mitigation** as measures used to reduce the adverse effects of a proposed project by considering, in the following order: a) avoiding the impact altogether by not taking a certain action or parts of an action; b) minimizing impacts by limiting the degree or magnitude of the action and its implementation; c) rectifying the impact by repairing, rehabilitating or restoring the affected environment; d) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action by monitoring and taking appropriate measures; and e) compensating for the impact by replacing or providing comparable substitute water quality resource areas (Metro 1997b). Mitigation will not necessarily result in a net ecological gain.

Enhancement is the alteration and/or active management of existing habitat to improve particular functions and values (Kauffman et al. 1997); enhancement activities may or may not return the site to pre-disturbance conditions, but create or recreate functions and processes that occur naturally. SER suggests the term **rehabilitation** for projects that are unlikely to achieve full ecosystem restoration, commenting that the term "restoration" is frequently applied inappropriately to site- or species-specific projects, or those designed to attain economic objectives (Clewell et al. 2000). SER is a leading scientific restoration organization and provides standardized terminology that is widely used and understood by restoration specialists. However, outside of scientific circles the term "restoration" is commonly used to refer to activities such as enhancement and rehabilitation. For the purposes of this document we will use the term "restoration" instead of rehabilitation or enhancement, while recognizing that full ecological restoration is unlikely in the urban environment.

Types of restoration

Passive restoration

Passive restoration allows natural processes to return through reducing or halting activities that cause degradation or prevent recovery (Kauffman et al. 1997). In riparian corridors, this often means removing the damaging influences and letting the river or stream do the work (Hollenbach and Ory 1999). Passive restoration techniques include retaining riparian buffers, altering land use designs in a watershed to reduce soil erosion and increase stormwater infiltration, keeping toxic chemicals out of the water, managing the adverse impacts of construction, and reintroducing or allowing the presence of beaver (Horner et al. 2001). Many Best Management Practices (discussed below) are forms of passive restoration.

Active restoration

Active restoration refers to changing the ecosystem to reestablish desired biological and physical functions. Some forms of active restoration – such as planting native vegetation and removing exotic vegetation and fish-blocking culverts – have a relatively low risk of failure, even in an urban setting. Other active restoration efforts – such as making instream improvements – are less likely to succeed in an urban setting because of **cumulative impacts**, and should be used with caution. Some active restoration options are discussed in the BMPs and Site Specific Restoration section (see also Table 13 and Appendix 4).

Elements of successful restoration

A limited set of urban literature and substantial non-urban literature can provide clues as to how to approach urban restoration. Several concepts appear repeatedly in the literature and appear important to successful restoration efforts. These fall under the categories of master planning, using a scientific approach, monitoring and adaptive management, and considering urban-specific impacts.

SER provides a set of general, conceptual guidelines for conceiving, organizing, conducting, and assessing ecological restoration projects (Clewell et al. 2000). These guidelines apply to any ecosystem, terrestrial or aquatic, and are available online at SER's website. SER advises that plans for restoration projects should contain, at a minimum, the following items:

- A baseline ecological description of the kind of ecosystem designated for restoration, which accounts for the regional expression of that ecosystem in terms of the **biota** and poignant features of the abiotic environment.
- An evaluation of how the proposed restoration will integrate with other components of the regional landscape, especially those aspects of the landscape that may affect the long term sustainability of the restored ecosystem.
- Explicit plans and schedules for all on-site preparation and installation activities, including plans for contingencies.
- Well developed and explicitly stated performance standards, by which the project can be evaluated objectively.
- Monitoring protocols by which the performance standards can be measured.
- Provision for the procurement of suitable planting stocks and for supervision to guarantee their proper installation.
- Procedures to expedite promptly any needed post-installation.

Master planning for restoration

Ecosystems are incredibly complex with numerous interactions between components, and any attempts to restore urban ecosystems must start with master planning. Planners should consider the largest spatial and time scales possible for a framework, then use a hierarchical scheme (e.g., basin; subbasin; watershed; subwatershed; stream reach) for master planning, implementation and monitoring (U.S.D.A. Forest Service and U.S.D.I. Bureau of Land Management 1999). The minimum unit considered for the plan should be the watershed, and ecological rather than political boundaries are recommended in order to provide consistent treatment of functionally related areas, and because every part of the watershed can contribute to improved or reduced ecological functions. Watershed assessments should be conducted for all involved watersheds prior to restoration prioritization. Forming a vision that incorporates ecological, socioeconomic, and cultural values prior to embarking on watershed assessment and shaping a plan of action will help keep restoration efforts on track and help identify acceptable restoration strategies (see Fausold and Lilieholm 1999; Fight et al. 2000). Reference sites (relatively undisturbed watersheds that allow comparison to predisturbance conditions) will be necessary to identify functions that have been lost or altered in urban watersheds, and to provide ecological benchmarks of success or failure (Beschta 1995; Harris 1999; FIRSWG 1998).

Long-term funding sources, realistic goal-setting and creating successful partnerships must be addressed at the outset (Grayson et al. 1999). Long-term funding sources for monitoring and evaluation will help ensure implementation of the master plan. Goal-setting must be ecologically and financially feasible and success is unlikely without engaging stakeholders. The creation of successful partnerships is critical, including an interdisciplinary scientific team, agencies, local governments, communities, watershed councils, and other stakeholders. These partnerships will build consensus and increase information resources, expertise, and potential person-hours available for working on the project (FIRSWG 1998). Having one responsible party will help keep the master plan on course and will increase accountability for results.

Scientific approach

One of the difficulties in urban restoration is that land use planners and land managers are typically not scientists and lack the knowledge and vocabulary to take a scientific approach to ecosystem management. Furthermore, planners are obliged to consider conflicting resource needs between humans and wildlife. While societal needs clearly must be considered, the scientific literature indicates that a rigorous scientific approach, including hypothesis formation and testing, is the best way to ascertain what is possible, what might be effective and whether the desired results have been achieved (Bradbury et al. 1995; Henry and Amoros 1995). Henry and Amoros (1995) commented that: "Ecological restoration is a recent discipline that should be conducted scientifically and rigorously to move from a trial-and-error process to a predictive science to increase its success and the self-sustainability of restored ecosystems."

SER offers a set of ecological principles and guidelines for managing land use (Dale et al. 2000) in which they propose five actions to develop the science that is needed by land managers:

1. Apply ecological principles to land use and land management.
2. Explore ecological interactions in both pristine and heavily used areas.
3. Develop spatially explicit models that integrate social, economic, political, and ecological land-use issues.
4. Improve the use and interpretation of onsite and remotely sensed data to better understand and predict environmental changes and to monitor the environment.

5. Communicate relevant ecological science to users (including landowners and the general public).

A scientific approach lends credibility to restoration efforts and also provides systematic, repeatable methodologies that can be applied over large areas for consistency and comparability. The emphasis should be on restoring natural processes, and linkages among soils, geology, hydrology, biota, and other ecosystem components must be recognized (Roni et al. 2002). An interdisciplinary approach addressing physical, biological, and social issues is important because each is a critical factor in ecosystem degradation (Booth et al. 2001).

Consider the metapopulation

A restoration approach should be developed that addresses habitat requirements of populations and metapopulations, not just individual fish and wildlife needs (Lidicker and Koenig 1996; Watershed Professionals Network 1999; Dale et al. 2000; Roni et al. 2002; see also Figure 14). This approach requires addressing connectivity (as discussed in the Habitat Fragmentation section) as well as a hierarchical view of populations and space, with corresponding factors important to protection and restoration of habitat.

Address urban-specific issues

In order to address the cumulative impacts wrought by urbanization, we must know the most common and critical causes of environmental degradation, the reason why restoration efforts most commonly fail, and develop an overall strategy for a more successful approach (Booth et al. 2001). The critical factors in addressing watershed hydrology are impervious surfaces (see City of Olympia 1996), stormwater management (see Urban Watershed Institute 2001), and vegetative cover, with the goal of restoring a more natural flow regime in streams (Poff et al. 1997; Booth et al. 2001; Roni et al. 2002). In terrestrial riparian and upland habitats, controlling exotic species and restoring habitat connectivity and quality is vital. In all watersheds, education and community outreach is not just appropriate but crucial. Considering socioeconomic factors, however, is separate from and in addition to a scientific approach to restoration.

Monitoring

Habitat conditions must be linked to wildlife. Ecological conditions are best assessed by biological response to those conditions, because the complexity and health of natural systems is reflected in the structure and diversity of plant and wildlife communities (Lammert and Allan 1999; Roni et al. 2002). Monitoring may comprise a major portion of restoration budgets, because at least 10 years of monitoring are necessary to detect a biological response to activities and account for natural fluctuations in fish and wildlife numbers (Kondolf 2000; Roni et al. 2002).

A monitoring program to measure progress in protecting and restoring urban fish and wildlife habitat should include a set of biological indicators that are particularly responsive to environmental conditions, including urbanization (Bauer and Ralph 2001). In addition, instream measures such as Total Maximum Daily Loads (TMDLs; a set of standards developed by the Oregon Department of Environmental Quality to protect beneficial uses such as drinking water, salmonid spawning, recreation and agriculture) may be necessary (Watershed Professionals Network 1999). Streamflow and discharge measures provide important hydrological monitoring indicators, and these have been empirically developed and tested for the Pacific Northwest (see Booth et al. 2001). Spence et al. (1996) discuss programs for monitoring implementation (compliance) and assessment (effectiveness) and offer a general monitoring framework, as well as recommendations for biological and other types of indicators. McCarron et al. (1997) discuss bioassessment approaches to evaluate cumulative effects. Appendix 6 provides some potential indicators of the success of restoration activities seen repeatedly in the scientific literature.

Adaptive management

Adaptive management is a type of natural resource management that implies making decisions as part of an on-going process, as new information is received and incorporated into plans and activities. Adaptive management provides the opportunity for course correction through evaluation and action, thus it provides a bi-directional flow of information (FIRSWG 1998; National Marine Fisheries Service 1996a; CH2MHILL 2000; Kondolf 2000). Monitoring the results of activities makes adaptive management possible by allowing assessment of whether resource goals, objectives, and targets are being achieved.

General strategy for urban restoration

The success of restoration depends on ecosystem response to anthropogenic (human-caused) disturbances (resistance) and the system's capacity to recover after disturbances are halted (resilience) (Kauffman et al. 1997). Specifically, resistance is the capacity of an ecosystem to maintain natural function and structure after a natural disturbance or an introduction of an anthropogenic perturbation; resilience is the capacity of species or ecosystems to recover after a natural disturbance or following the cessation of an anthropogenic perturbation.

Ecosystem resilience may change with significant alterations to the disturbance regime (Jones et al. 2000). For example, increased flooding and debris flows are a known side effect of road systems, but the patchy nature of these disturbances leave numerous headwater and side-channel refuges for aquatic wildlife. These refuges are part of the resilience of the system. However, if significant portions of the stream network are damaged or removed (e.g., this region's loss of approximately 25 percent of original streams), the system's resilience to disturbance is reduced.

Reduced floodplain connectivity provides another example of loss of ecosystem resilience. A group of scientists convened in 1998 by the Oregon Department of Fish and Wildlife voted the two most critical long-term salmonid conservation measures along the Willamette River to be restoring floodplain function and hydrologic integrity, and improving water quality (Martin 1998). Restoration of the floodplain function and hydrologic integrity would likely result in improved resistance to disturbance (e.g., reduced flooding, fewer sediments and toxins entering the waterway), as well as improved resilience (e.g., biotic recovery after floods, recovery from recreational trampling, etc.). In highly disturbed areas such as urban regions, elements and processes that promote ecosystem resilience and, therefore, recovery should be protected, preserved, and fostered (Ebersole et al. 1997). These include floodplain, hydrologic, and riparian connectivity.

Functional restoration should be based on science, but approached with good business sense by weighing ecological benefits against project costs. How can we achieve the most significant results per restoration dollar? How can watersheds and projects be prioritized to achieve this practical approach? There are a number of references available to assist this process. For example, Nehlsen (1997) described an Oregon-based ecosystem approach to prioritizing watersheds for restoration and salmonid recovery (the Bradbury framework; Bradbury et al. 1995) and provided a sample application that was applied with apparent success at three different spatial scales. Richter (1997) recommended urban-oriented criteria for the restoration and creation of wetland habitats of Pacific Northwest amphibians, as well as a long-term monitoring strategy (Richter and Ostergaard 1999). Schueler (1995) offered an extensive set of recommendations regarding site planning for urban stream protection. May et al. (1997b) published a series of habitat quality indices for urbanization effects in Puget Sound Lowlands streams. In addition, below we offer a general strategy for prioritization of urban restoration sites and projects, based on first preserving the most ecologically intact areas, then prioritizing remaining habitats for functional restoration.

Preserve the best

By the time large-scale efforts to protect, conserve and restore urban watersheds are considered, substantial ecological damage has typically already occurred. Pristine habitats are scarce or absent, and habitats in excellent or good condition are limited. It is much easier to protect a high-quality area than to restore functions to an ecologically degraded area (Bradbury et al. 1995), and in the long run protection may be less expensive than restoration. Thus, the first ecological priority for protecting fish and wildlife habitat in any urbanized region should be to recognize and preserve high-quality, low-development watershed areas. Protection of these areas within Metro's jurisdictional boundary should be included in a restoration master plan; however, any program would need to include an Economic, Social, Environmental and Energy (ESEE) analysis to weigh the consequences of protection plans. Protection may be accomplished through a number of means, including direct land purchase, conservation easements, and land use regulations. A recent urban-rural gradient study suggested that two locations along the gradient – the most remote portions of the landscape, and at the outer envelope of urban expansion – may hold disporportionate influence over water quality in the future (Wear et al. 1998).

Identification of sensitive, critical, or refuge habitats (at-risk habitats and species) to conserve remaining biodiversity provides one way to identify which areas to protect. This can be accomplished through identification and protection of endangered habitats, and through identifying habitats critical to state- or federally-listed species, including specific areas such as known nest sites. Metro's species list includes state- and federally-listed vertebrate species.

The Oregon Biodiversity Project, launched in 1994 to develop a statewide strategy to conserve Oregon's biological diversity, identified four general habitat types – native prairie grasslands, oak savannas and woodlands, wetlands, and bottomland hardwood forest – as conservation priorities in the Willamette Valley (Defenders of Wildlife 2000). These habitats should be identified in the Metro region and protected. Roni et al. (2002) reviewed methods for identifying and prioritizing conservation areas, and Table 12 provides an example of a prioritization scheme for protecting sensitive, critical or refuge habitats in Larimer County, Colorado (note that economic interests are built into the scheme). Other habitat ranking systems are also available in the literature (see Rossi and Kuitnen 1996; Csuti et al. 1997).

Table 12. Example of a prioritization scheme for protecting sensitive, critical or refuge habitats. Local conditions mapped for environmental protection as part of the Partnership Land Use System (PLUS) developed by Larimer County, Colorado.

Environmental Value	Definition	Data Source
Conservation sites	Areas containing one or more imperiled species (plants or animals)	Field surveys by Colorado Natural Heritage Program
Habitat for economically important species	Winter range and migration corridors for mule deer, elk, and pronghorn antelope	Field surveys by Colorado Division of Wildlife
Areas of high species richness	Areas where predicted vertebrate species richness exceeds 95 percent of all areas included in the analysis	Vegetation map derived from Thematic Mapper satellite image Habitat modeled from vegetation associations of all vertebrate species in county
Rare plant communities	Plant communities covering less than 3 percent (individually) of the land area of the county	Vegetation map derived from Thematic Mapper satellite image

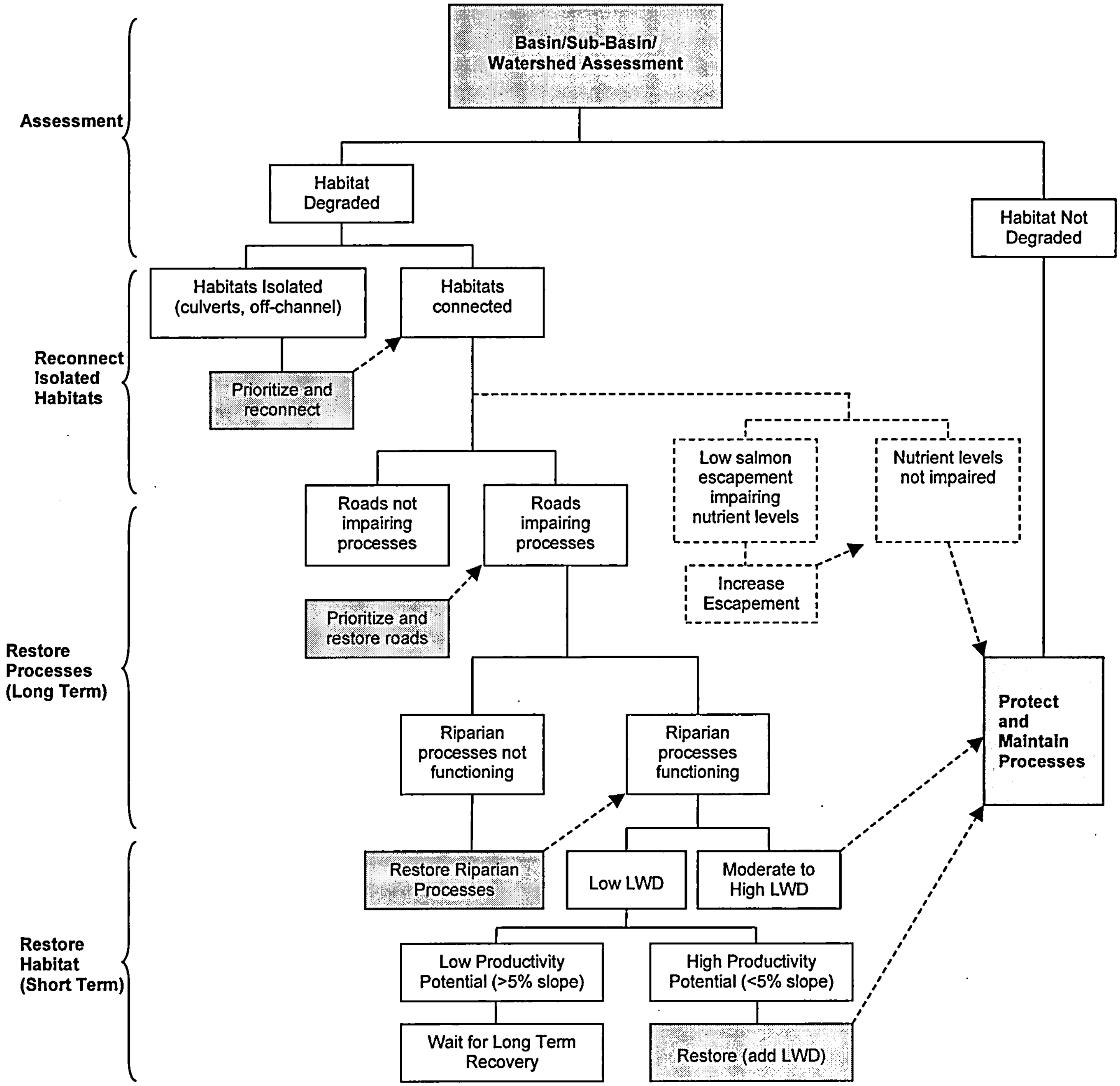
Source: Society for Ecological Restoration's website, 2001.
Note: While the criteria may change geographically, this provides an example of a habitat conservation prioritization scheme.

Home-range sizes vary considerably among different species. Certain species, such as some Neotropical migratory birds, seem to require larger habitat patches to successfully live or reproduce (see *Impacts of Urbanization, Habitat Fragmentation*). In addition, local evidence indicates that Neotropical migrants respond negatively to roads near their habitat patch (Hennings 2001); although unstudied, this is likely to be true for some mammals and other species. Thus preserving as many large habitat patches as possible, particularly those not divided by roads, is another means of preserving the best remaining habitats in the region. The value of these patches is further enhanced if other natural areas are nearby, because animal movement between patches may help prevent local extinctions.

Restore the rest

The scientific literature indicates that the best restoration candidates are moderately degraded areas, because severely degraded areas are much more difficult to restore (Kauffman et al. 1997; Booth et al. 2001). Therefore, the first priority is to aggressively restore streams and other habitats where recovery of ecosystem functions and processes is possible. Next, improve the most degraded sites by analyzing and addressing the acute cause(s) of degradation. Finally, where complete recovery is not feasible but well-selected efforts may yield direct improvement, restore selected elements of moderately degraded urban watersheds. All of these actions should take place under the umbrella of a watershed master plan. Figure 14, on the following page, shows a salmon-oriented hierarchical prioritization scheme.

Figure 14. An example of a salmon-based hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds.



Source: Roni et al. 2001

Develop wisely

Planning for development is an important part of an environmental protection or enhancement plan. Setting an urban growth boundary (UGB) is one example. Another is Metro's 2040 Growth Concept, which defines the form of regional growth and development for the Portland metropolitan region. The Growth Concept was adopted in the Region 2040 planning and public involvement process in December 1995. The 2040 Growth Concept is implemented through the Regional Framework Plan (RFP), adopted in 1998. The RFP includes specific land use guidelines, such as a stream and floodplain protection plan. Metro also has a Greenspaces Master Plan, ensuring the acquisition and protection of natural areas and open spaces within and near the UGB.

It is much more difficult to repair environmental damage than to prevent it. Based on a large volume of scientific literature, much of it specific to the Pacific Northwest, is it clear that responsible development should:

- Plan well to reduce impervious surfaces such as transportation network
- Retain and add forest canopy cover
- Plan storm sewer and runoff systems with past, current, and future hydrology in mind

Figures 15 and 16 illustrate Pacific Northwest examples of how planning can influence environmental conditions. In Figure 15, land planners assess the opportunity to mitigate the influences of urbanization on hydrology through projected land-use changes and construction of proposed detention ponds and bypass pipelines. Note that while the future alternative does not return the hydrology to predevelopment conditions, it projects a marked improvement over current conditions. Figure 16 estimates the interaction of forest canopy cover and imperviousness in a rural setting. The graph suggests that about 65 percent canopy cover is needed to protect stream channel stability under typical rural development conditions.

Control nonnative species

As discussed in previous chapters, nonnative species ("exotics") pose a major threat to native plants and animals in the United States, particularly in urban areas due to the concentration of people. SER (1993) recommends the following regarding nonnative species:

1. The control of exotic species should be an integral component of all restoration projects and programs.
2. Monitoring of exotics and periodic reassessment of their control should be integrated into all restoration plans and programs.
3. Highest priority should be given to the control of those species that pose the greatest threats, namely:
    - Exotics that replace native key (keystone) species.
    - Exotics that substantially reduce native species diversity, particularly with respect to the species richness and abundance of conservative species.
    - Exotics that significantly alter ecosystem or community structure or functions.
    - Exotics that persist indefinitely as sizable sexually reproducing or clonally spreading populations.
    - Exotics that are very mobile and/or expanding locally.
4. Restoration plans and management programs should include contingencies for removing exotics as they first appear and for implementing new control methods as they become available.
5. Control programs should cause the least possible disturbance to native species and communities and, for this reason, may be phased over time.

6. The restoration and management program must, of necessity, be strategic. Protection of native habitats, levels of infestation, appropriate resource allocation, and knowledge of control methods should be integrated into the monitoring and management program.
7. Exotic species should not be introduced to the site in the restoration plan.
8. Native species should also be evaluated for their potential threat to native communities. Weedy native species should be avoided in restoration plans as well as native planting stocks representing non-native ecotypes.

Upland habitat restoration

Most watershed assessment methodologies deal primarily with aquatic and riparian habitat conditions, with little attention paid to upland conditions. This may be appropriate in non-urban watersheds, but upland components play a critical role in urban watershed health (Hollenbach and Ory 1999; Booth et al. 2001). For example, vegetation slows and stores water runoff and pollutants, while impervious surfaces do exactly the opposite. Adding native canopy cover provides one means of mitigating the negative effects of impervious surfaces (Shaw and Bible 1996; Booth et al. 2001). Other potential mitigating effects are offered through various sources (e.g., porous pavement; lawn management techniques [Watershed Protection Techniques 1994]; reducing the effects of imperviousness, Center for Watershed Protection 1998, 2001).

Small streams versus large rivers

Restoration of small streams and large rivers requires different methodologies, due in part to the extensive floodplain interactions associated with large rivers and damming (Sparks et al. 1990; Sparks 1995; Poff et al. 1997), but the two are linked. Local governments, including Metro, have potentially greater influence over small streams that originate or are largely contained within the urban area than over larger rivers, and small streams account for over three quarters of the total stream length in the United States (Lowrance et al. 1997). Restoration of large river systems depends on renewal of physical and biological interactions between the main channel, backwaters, and floodplains, and often involves managed flooding and floodplain reconnection (Sparks et al. 1990; Gore and Shields 1995; Stanford et al. 1996; Molles et al. 1998).

The Willamette River has been confined to a single channel with little sinuosity, high flow velocities, and low levels of habitat diversity to control floods and water resources, and has experienced a fourfold decrease in surface water volume from historic levels (Gore and Shields 1995). These modifications are due, in part, to restrictions of the river's bank, dams and flood control. Snagging and streamside forest removal has further isolated the river from much of its floodplain (Sedell and Froggatt 1984). Restoration of this river will pose a daunting task, much more so than dealing with small streams; however, small streams must be addressed in order to restore large rivers into which they feed. This re-emphasizes the importance of first addressing the whole system rather than individual components (Regier et al. 1989).

Figure 15. Modeled flow-duration curve for Des Moines Creek, Washington, displaying dramatic improvement in future flow durations relative to current. Analysis assumes projected land-use changes and construction of proposed detention ponds and bypass pipelines. (Source: Booth 2000)

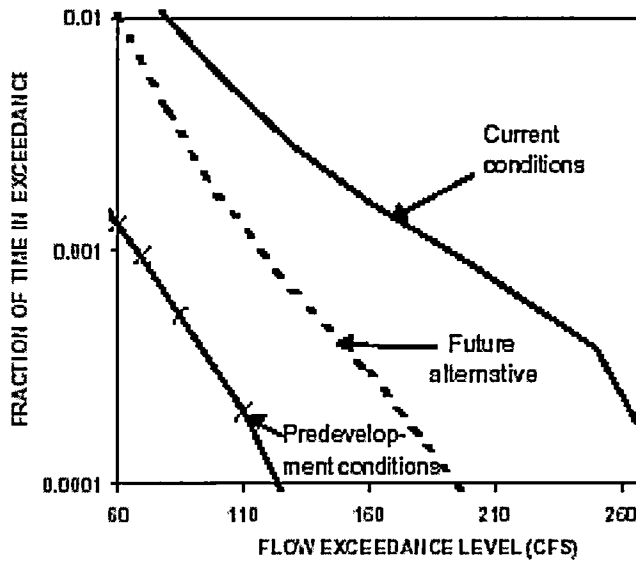
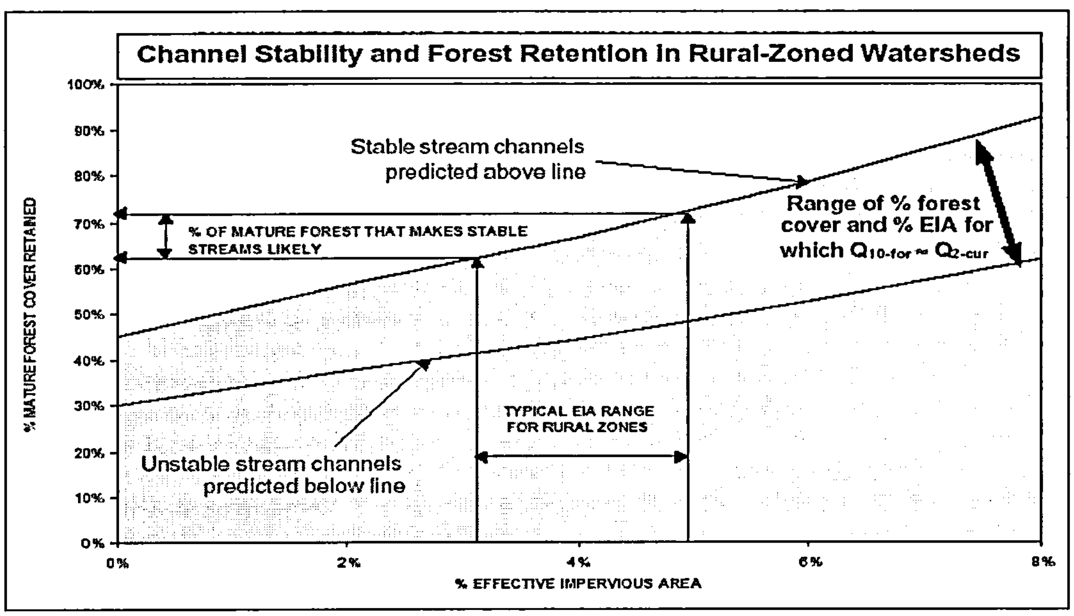


Figure 16. Booth's (2001) model predicting the amount of mature forest needed under rural conditions in order to maintain stable streams. Conditions of forest cover and impervious surface in an HSPF-modeled watershed with moderate slopes and till soils relative to the channel-stability criterion $Q_{2\text{-cur}} = Q_{10\text{-for}}$ [see Booth et al. 2001 for variable descriptions]. The range of forest-retention values reflects uncertainty in the hydrologic parameters; the range of effective impervious areas reflects variation in rural land cover conditions. Note the relatively high range of forest canopy cover predicted to be necessary to maintain stable streams in the typical EIA range for rural zones. Source: Booth et al. (2001)



BMPs and specific restoration activities

Best Management Practices

Some restoration tools are known as Best Management Practices (BMPs), and these tend to be most effective when implemented throughout a watershed. Several examples of BMPs are available online (e.g., Strassler and Strellec 1999; Clark County Washington 2000; O'Brien 2001; Urban Water Resources Research Council 2001). Many relate to impervious surface management and reducing the impacts of stormwater. Metro's Greenstreets efforts and Metro's Water Resources Policy Advisory Committee recommendations are available now as best management practices for local governments within the region.

BMPs may be site-specific or very general. For example, construction BMPs may require silt fences to reduce sediment inputs to the stream during construction. On the other hand, a BMP may apply over a large spatial scale. For example, riparian/wetland buffers are a common BMP. Horner and May (1999) found that, "The retention of a wide, nearly continuous riparian buffer in native vegetation has greater and more flexible potential than other option to uphold biological integrity when development increases. Upland forest retention also offers valuable benefits, especially in managing any development occurring in previously undeveloped or lightly developed watersheds" (see Figure 5). Buffer issues and design are discussed in detail in the ***Riparian Area Width*** section.

Site-specific restoration activities

Site-specific efforts are essential components of habitat restoration, but cumulative impacts in urban watersheds may cause these projects to fail, and may even cause further damage (Frissell and Nawa 1992; Booth et al. 1997; Hollenbach and Ory 1999; Watershed Professionals Network 1999; Roni et al. 2002). Another common cause of restoration project failure is disregarding geomorphic factors at the watershed scale (Kondolf 2000). In addition, many issues related to long-term persistence of salmonids and other species involve much larger spatial scales and hence require statewide or multistate planning (Spence et al. 1996; IMST 1999; National Marine Fisheries Service 2000a; IMST 2001b).

Few site-specific restoration activities should take place without a watershed assessment and careful master planning, which should including addressing existing and future development through hydrology, impervious surfaces and natural vegetation cover. However, below we will discuss a few methodologies commonly used in urban areas, and their apparent success or failure. In addition Appendix 6 outlines some potential restoration activities, keyed by function, and provides some suggestions for indicators of ecological change based on a literature review.

The Center for Watershed Protection (CWP), in cooperation with the U.S. EPA, has recently published the first of 11 manuals, dubbed the "Urban Subwatershed Restoration Manual Series." The eleven manuals are:

1. An Integrated Framework to Restore Small Urban Watersheds
2. Methods to Develop Restoration Plans for Small Urban Watersheds
3. Storm Water Retrofit Practices
4. Stream Repair and Restoration Practices

5. Riparian Management Practices
6. Discharge Prevention Practices
7. Previous Area Management Practices
8. Pollution Source Control Practices
9. Municipal Practices and Programs
10.The Unified Stream Assessment: A User's Manual
11. The Unified Subwatershed and Site Reconnaisance: A User's Manual

The manuals are available through CWP's website at www.cwp.org.

In the Pacific Northwest, riparian and upland forests are a key contributor to watershed health (Booth et al. 1997; May et al. 1997; Horner and May 1999; Booth 2000; Horner et al. 2001). The value of revegetating stream banks and riparian areas cannot be overemphasized. Pacific Northwest studies show positive relationships between the percentage of intact riparian forest in a watershed and instream biotic integrity (May et al. 1997; Horner et al. 2001; see also Figures 5 and 16). Retaining and adding upland vegetation is also very important for mitigating the hydrologic impacts associated with urbanization (Booth et al. 1997; Horner and May 1999; Booth 2000; Horner et al. 2001). Local watershed councils, the Natural Resources Conservation Service, and Oregon Department of Fish and Wildlife are good resources for revegetation and site-specific restoration techniques.

Frissell and Nawa (1992) evaluated rates and causes of damage or failure for 161 fish habitat structures in 15 streams in southwest Oregon and Washington after floods with a 2-10 year recurrence interval. The structures were comprised primarily of instream log or boulder clusters. Damage and failure was prevalent, particularly in low-gradient streams with signs of recent watershed disturbance, high or elevated sediment loads, high peak flows, and/or unstable channels; the authors suggested that commonly prescribed structural modifications are often inappropriate and counterproductive in such streams (e.g., those found in this urban region). Only two types of structures – cabled natural woody debris and individual boulder placements – experienced impairment or failure in less than half the cases. All log weir designs had high rates of impairment or failure, and one type, the downstream-V weir, failed or was impaired in every instance. Boulder structures had lower failure rates than log weirs in low-gradient streams, but most boulder structures the authors studied were in relatively stable southwest Washington streams. Shields et al. (1995a, 1995b) found stone weirs to be a successful rehabilitation technique in an incised lowland Mississippi stream.

Booth et al. (1996) provide design approaches for urban channel rehabilitation, with emphasis on large wood and the various hazards associated with such projects in an urban setting. The authors state that while large wood is critical to the health of most Pacific Northwest streams, instream placement of such structures in urban environments is hampered by lack of geomorphic and channel type considerations and greatly increased peak flows (see also Moses and Morris 2001). Possible loss of flood conveyance, the potential for the wood to clog existing channel constrictions, and the possibility of flow diversion causing bank erosion further complicate placement of this critical stream component. This is not meant to imply that large wood placement cannot be a valuable restoration tool in urban settings. However, the complexity and variability of these stream systems mandates a great deal of forethought, careful study of the effectiveness of projects conducted in similar settings, long-term post-project evaluation, and communication of the results to others.

Keim et al. compiled an annotated bibliography of selected guides for stream habitat improvement in the Pacific Northwest (Keim et al. 2004). The Oregon Watershed Enhancement Board (OWEB) provides guidelines on conducting restoration projects in a watershed (OWEB 1999). Many other references are available on specific restoration techniques and their effectiveness (e.g., Oregon Department of Forestry and Oregon Department of Fish and Wildlife 1995; Dooley and Paulson 1998; Riley 1998; Morris and Moses 1999; Roni 2001). Table 13, on the following page, shows the typical response time, duration, variability of success and certainty of success of various common restoration techniques.

Table 13. Typical response time, duration, variability in success and certainty of success of common active restoration techniques.

Restoration Type	*Specific Action*	Years to achieve response	Longevity of action (years)	Variability of success among projects	Certainty of success
Reconnect isolated habitats	Culverts	1 to 5	10 to 50+	Low	High
	Off-channel	1 to 5	10 to 50+	Low	High
	Estuarine	5 to 20	10 to 50+	Moderate	Moderate to high
Roads	Removal	5 to 20	Decades to centuries	Low	High
	Alteration	5 to 20	Decades to centuries	Moderate	Moderate to high
Riparian	Fencing	5 to 20	10 to 50+	Low	Moderate to high
	Riparian replanting	5 to 20	10 to 50+	Low	Moderate to high
	Rest-rotation or grazing strategy	5 to 20	10 to 50+	Moderate	Moderate
	Conifer conversion	10 to 100	centuries	High	Low to moderate
Instream restoration	Artificial log structures	1 to 5	5 to 20	High	Moderate[a]
	Natural LWD placement	1 to 5	5 to 20	High	Moderate[a]
	Artificial log jams	1 to 5	10 to 50+	Moderate	Moderate[a]
	Boulder placement	1 to 5	5 to 10	Moderate	Moderate[a]
	Gabions	1 to 5	10	Moderate	Moderate[a]
Nutrient enhancement	Carcass placement	1 to 5	Unknown	Low	Moderate to high
	Stream fertilization	1 to 5	Unknown	Moderate	Moderate to high
Excavate or create new habitats	Off-channel	1 to 5	10 to 50+	High	Moderate
	Estuarine	5 to 10	10 to 50+	High	Low
	Instream	See various instream restoration techniques above			

Source: Roni et al. 2002
[a] Low to high depends upon species and project design.

Fish passage

If fish cannot pass through a culvert or other blockage, the entire upstream reach is rendered uninhabitable. The Oregon Department of Fish and Wildlife is the lead state agency for all types of fish passage concerns in Oregon, and has produced guidelines regarding fish passage (Robison et al. 1999). Key measurements of interest in fish-blocking culverts include culvert and adjacent slopes, outlet drop, and outlet pool dimensions, as well as the shape of the culvert and local hydrologic information (Robison et al. 1999). The ODFW guidelines specify maximum velocities, entrance drops, and minimum water depth criteria for culverts. Examples of fish passage-oriented restoration include culvert replacement, connecting upstream reaches of piped streams to lower sections, and "daylighting" of piped streams (IMST 2001a). Further guidance on specific culvert design and implementation strategies are offered in an annotated bibliography by Moore et al. (1999). The Inventory section of this report indicates piped stream sections in the Metro area.

Fish passage issues will necessarily be addressed in Metro's Goal 5 program phase. Metro's Regional Culvert Survey (1999-2000) augmented existing culvert inventories by the Oregon Department of Fish and Wildlife and several local governments by examining culverts located within a geographic area corresponding roughly to the Metro Urban Growth Boundary that had not been included in the previous surveys. Metro's survey identified almost 1,500 unexamined culverts. Fieldwork determined that approximately 150 of these inhibit fish passage. Site-specific structures such as culverts can be more easily addressed than watershed TIA, and their carefully planned removal or appropriate modification represents significant opportunities for stream enhancement. However, both are critical issues that need to be addressed in urban ecosystems, and master planning plays an important role in such efforts; for example, it is sensible to remove downstream barriers before upstream barriers, and to remove barriers blocking larger areas than those blocking smaller areas.

Restoration costs and funding

Funding is clearly a limiting factor in many restoration efforts, particularly when dealing with large-scale efforts such as those necessary to restore urban regions. Funding for large-scale projects is unlikely without collaboration with appropriate partners. Sometimes partial funding may be provided by revenues from restoration activities; for example, the City of Seattle developed a Habitat Conservation Plan (HCP) for the Cedar River Watershed, a relatively undeveloped watershed near the urban region (City of Seattle 2004). Seattle estimates the total HCP costs at $113,078 (in 1998 dollars) and comments that some funding may be generated from the sale of water, timber, and surplus land outside the watershed, in addition to grants and contributions. The Oregon Watershed Enhancement Board, U.S. Fish and Wildlife Service, and numerous other agencies and organizations are potential funding partners for local efforts. Wy'East Resource Conservation and Development (2002), the U.S. EPA (1999), and other online resources provide guidance for restoration funding opportunities.

Measuring success of restoration activities

Ecological conditions are best assessed by biological response to those conditions (Roni et al. 2002), thus wildlife (i.e., aquatic invertebrates, breeding birds, etc.) and plant surveys are appropriate measures of a given site's ecological value. In addition, surveys conducted in a scientifically sound, repeatable way will provide valuable baseline data with which to gauge ecological changes in the future and will add credibility to restoration efforts. However, there are a number of other appropriate non-biological indicators of ecological change, such as water chemistry and sedimentation. May et al. (1997b) offer suggestions on hydrologic parameters of interest for monitoring changes in Pacific Northwest streams over time. Appendix 6 provides some suggestions for indicators of ecological change.

Recommendations of the Oregon Progress Board

The Oregon Progress Board proposes a set of key indicators to guide the state's basic environmental monitoring program, but cautions that these indicators are not sufficient to fully convey environmental conditions (Oregon Progress Board 2000). When possible and appropriate, these indicators should be used in assessment and monitoring efforts in order to standardize methodologies statewide to allow comparisons. The indicators include:

- *Water Quantity:* a) the degree to which stream flows meet ecological needs based on the proportion of instream water rights that can be met; b) the proportion of streams and rivers with good to excellent water quality according to the Oregon Water Quality Index

- ***Freshwater Wetlands:*** change in area of freshwater wetlands as compared to historical distribution (acres/percent)
- ***Riparian Ecosystems:*** a) the amount of intact or functional riparian vegetation found along streams and rivers; b) trends in the health of stream communities using an index comparing invertebrate populations to those expected in healthy aquatic habitats.
- ***Freshwater fish communities:*** the percentage of wild, native fish populations, including salmon, that are classified as healthy.
- ***Agricultural ecosystems:*** a) trends in soil quality and erosion rates; b) area of land in agricultural production.
- ***Urban areas:*** a) percentage of assessed groundwater that meets the current drinking water standards; b) frequency that the Air Quality Index exceeds the existing standards; and c) the amount of carbon dioxide emitted.
- ***Biological diversity:*** a) change in area of native vegetation types; b) percentage of at-risk species that are protected in dedicated conservation areas; and c) number of nuisance invasive species.

Proper functioning condition (PFC)

Proper Functioning Condition (PFC) is a qualitative method for assessing habitat conditions developed by the Bureau of Land Management and others; the term PFC describes both a specific assessment process and a defined, on-the-ground condition of a given habitat (Prichard et. al 1998; FIRSWG 1998). PFCs delineate how well the physical processes are functioning in a stream, wetland or other habitat. For example, Prichard (1998) provides a user guide to assessing PFCs in **lotic** (a flowing body of fresh water such as a stream or river) areas and defines riparian-wetland areas to be functioning properly when sufficient vegetation, landform, or large woody debris is present to provide certain functions, including:

- Dissipate stream energy associated with high waterflows, thereby reducing erosion and improving water quality;
- Filter sediment, capture bedload, and aid floodplain development;
- Improve floodwater retention and groundwater recharge;
- Develop root masses that stabilize streambanks against cutting action;
- Develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses; and
- Support greater biodiversity.

The PFC technique is not a substitute for inventory of monitoring protocols designed to yield detailed information on the habitat or populations of plants or animals dependent on an ecosystem. For example, proper functioning condition in a stream does not necessarily indicate the presence of shrub habitat critical to riparian-dependent bird species (FIRSWG 1998). However, PFC can be a useful tool for watershed analysis when combined with other watershed and habitat condition information. National Marine Fisheries Service has developed a PFC system based on a "Matrix of Pathways and Indicators" (NMFS 1996b) and is currently developing an urban-specific set of pathways and indicators (Liverman personal communication 2002).

Grayson et al. (1999) offer advice on the assessment of wetland habitat restoration projects in urban wetlands, commenting that restoration goals have often been unrealistic because they failed to consider that urban wetlands are subjected to ongoing anthropogenic disturbances, which fundamentally alter wetland functions.

Case studies

Skagit Watershed Council

The Skagit Watershed Council (Beamer et al. 2000) developed a two-tiered strategy for identifying stream restoration and protection actions: the Strategy Application and Case by Case Screening. The two tiers result in a final, single prioritization list. In the Strategy Application tier, habitat types are classified and locations identified where six landscape disturbance diagnostics (hydrology, sediment supply, riparian conditions, floodplain conditions, isolated habitat, and water quality) are identified as impaired, partially impaired or functioning. A list of desired restoration and protection actions is created based on habitat type classifications, landscape disturbance diagnostics, and best available information. In the Case by Case Screening tier, proposed projects are screened for consistency with the Strategy on an individual basis using best available information, and a list of projects determined to be consistent with the Strategy is formed. The end product is a prioritization scheme of desired restoration and protection actions for expected costs and benefits. Beamer et al. (2000) used a cost-effectiveness prioritization scheme.

Puget Sound Lowlands

Booth et al. (2001) developed what they consider to be a robust approach to urban stream restoration based on the extensive knowledge gained in the Puget Sound Lowland region over the past few decades. The approach blends knowledge from the physical, biological, and social sciences by documenting the consequences of urban development on urban streams, understanding the causes of the resulting ecological degradation, and using that understanding to evaluate restoration strategies and techniques. They offer specific recommendations for restoration efforts in urbanized watersheds, including:

- *Evaluate stream conditions:* Make direct, systematic, and comprehensive evaluation of stream conditions in areas of low to moderate development.
- *Mitigating urban hydrologic conditions is crucial:* The hydrologic consequences of urban development cannot be reversed without extensive redevelopment of urban areas, which is infeasible in the near future. Likewise, the recovery of physical and biological conditions of streams is infeasible without hydrologic restoration over a large fraction of the watershed land area. This conflict can be resolved only if there are particular, ecologically relevant characteristics of stream flow patterns that can be managed in urban areas. Effective hydrologic mitigation will require approaches that 1) can delay the timing of stormflow discharges in relatively small storms and 2) can store significant volumes of rain for at least days or weeks. In the long run the goal should be to mimic the hydrologic responses across the hydrograph [a chart that measures the amount of water flowing past a point as a function of time] and not just truncate the high or low flow components. The rate of rise and decline of the hydrograph is just as important as the existence of peaks and lows. This almost certainly requires greater reliance on hillslope ("onsite") storage to better emulate the hydrologic regime of undisturbed watersheds, either through dispersed infiltration, onsite detention, or forestland preservation.
- *Riparian vegetation is important, but is not enough to maintain biological integrity:* The effectiveness of localized patches of riparian corridor in maintaining biological integrity varies as a function of basin-wide urbanization. Where overall basin development is low to moderate, natural riparian corridors have significant potential to maintain or improve biological condition. Protecting high-quality wetland and riparian areas that persist in less-developed basins may also serve as a source of colonists (be they plants, invertebrates, fish, etc.) to other local streams that are subject to informed restoration efforts. At the same time, even small patches of

urban land conversion in riparian areas can severely degrade local stream biology. As both a conservation and restoration strategy, protection and re-vegetation of riparian areas is critical for preventing severe stream degradation, but these measures alone are not adequate to maintain biological integrity in streams draining highly urban basins.

- *Education of property owners is crucial:* Approaches must be developed to address the unanticipated, and unappreciated, consequences on channel conditions of human actions in the name of backyard improvements. Regional and national efforts now fall particularly short in this regard.
- *Instream projects are unlikely to be effective:* There is little evidence that instream projects can reverse even the local expressions of watershed degradation in urban channels. Addition of LWD to the urban streams we examined produced more physical channel characteristics typical of undisturbed streams, such as pools and sediment storage sites formed by LWD. Any increase in sediment storage and grade control in these moderate-slope alluvial channels was less assured. The steepest project reaches examined did not store more sediment, although LWD provided more grade control in the steepest reaches. Stabilizing or retaining sediment to reduce downstream sedimentation and associated flooding was not accomplished by adding LWD to the channel. No positive effect on biological condition from the restoration activities was detected over the time scales sampled; the physical characteristics in the reach that did change displayed no clear relationship to biological condition.
- *Channel stabilization is rarely effective in the urban area:* Aggressive efforts at channel stabilization during the period of active watershed urbanization will probably achieve only limited rehabilitation gains at high and perhaps unnecessary cost, even though bank armoring projects are constructed in the name of stream-habitat "improvement." Most lowland channels achieve a stable physical form some years or decades following urbanization, with or without human intervention. Yet the restabilization of urban channels, either by natural processes or by direct intervention, is generally incompatible with true "rehabilitation," because the resulting channel is rarely biologically hospitable and often is socially unwelcome as well.

Specific steps to watershed assessment

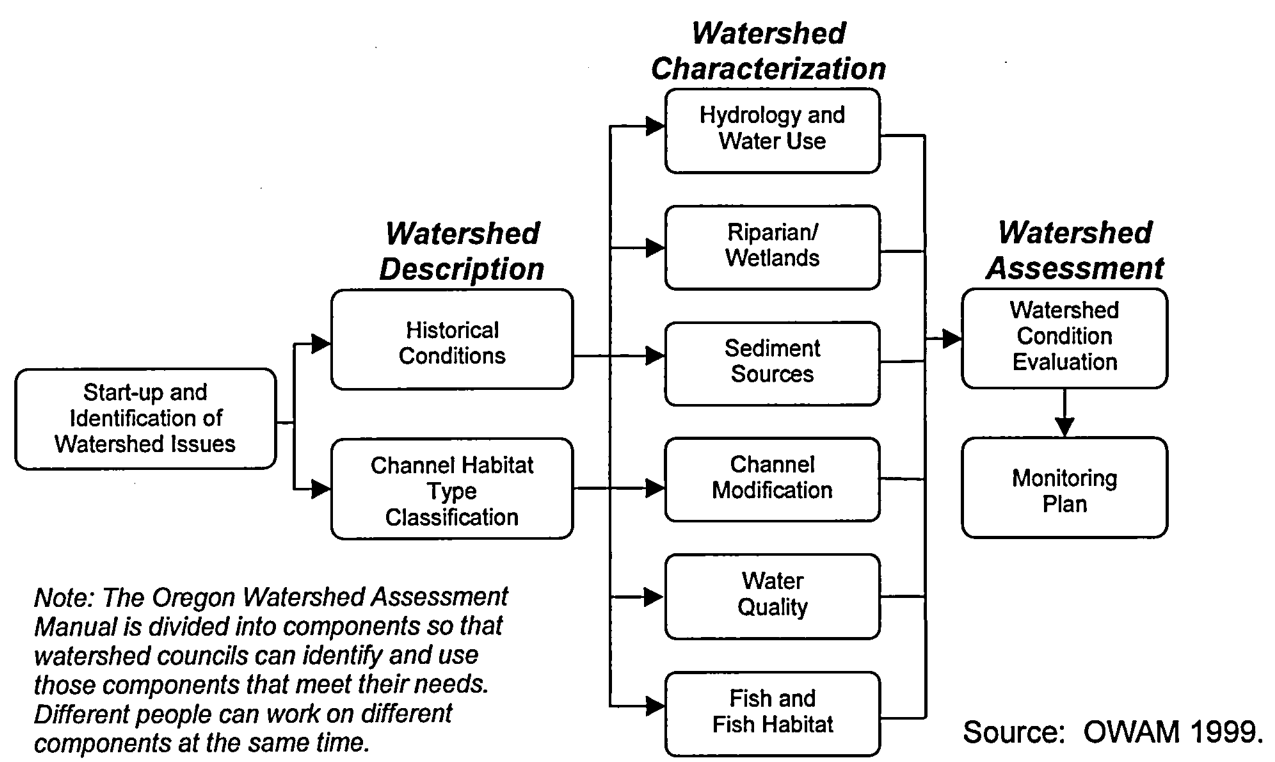
Without clearly defined goals that can be measured by quantifiable data, restoration attempts are likely to fail due to loss of momentum, project "scope creep," and lack of adaptive management. The precise and correct restoration mission, goals, and objectives, and appropriate performance indicators of restoration success or failure, must be defined early in the restoration process (Henry and Amoros 1995). All of the watershed assessment techniques referenced here deal with goal-setting, which is different for each project and hence will not be discussed here. However, assessment of success is less clearly delineated. The following section and Appendix 6 deal with measuring success in restoring ecological functions. This section provides an overview of the watershed assessment process.

Watershed assessment is a process for evaluating how well a watershed is functioning; it includes steps for identifying issues, examining the history of the watershed, describing its features, and evaluating various resources within the watershed. The overall goal is to figure out where, within a given watershed, natural functions relating to fish and wildlife habitat and watershed health should be restored. Specifically, the goals of a watershed assessment are to identify features and processes important to fish habitat and water quality, determine how natural processes are influencing those resources, understand how human activities are affecting fish habitat and water quality, and evaluate the cumulative effects of land management practices over time. This helps us determine which features and processes in a watershed are working well and which are not. Roni et al. (2002) proposed a method to place site-specific restoration within a watershed context. The underlying assessment and restoration objectives are more important than the specific assessment methodology chosen (Booth et al. 2001).

Several step-by-step methodologies exist to guide watershed assessment, but the general frameworks are similar (e.g., Bradbury et al. 1995; Regional Interagency Executive Committee 1995; Spence et al. 1996; U.S.D.A. Forest Service 1997; FIRSWG 1998; Prichard 1998; van Staveren et al. 1998; Watershed Professionals Network 1999; Sholz and Booth 2001). In general, the underlying assessment and subsequent restoration objectives are more important than the specific assessment methodology chosen (Booth et al. 2001), although some methodologies perform best at relatively specific spatial scales (discussed below). Figure 17 outlines one methodology, the Oregon Watershed Assessment Manual (OWAM), that dovetails with statewide efforts to standardize data collection and untangle the complex process of watershed assessment (Watershed Professionals Network 1999). This method, like others, includes components on getting started (e.g., setting up teams, subdividing watersheds, etc.), watershed description (overall characteristics in current and historical contexts), watershed characterization (individual watershed functions or components, such as hydrology and sediment sources), and watershed assessment (evaluation of conditions and formation of a monitoring plan).

Spatial scale is an important consideration in selecting an assessment method. For example, the Interior Columbia Basin Ecosystem Management Project provides assessment protocols for four geographic levels: broad scale (basin-level), mid-scale (subbasin; 4th field HUCs), fine-scale (watershed 5th field HUCs), and site-scale (project/site analysis, including NEPA analysis) (U.S.D.A. Forest Service and U.S.D.I. Bureau of Land Management 1999). The Oregon Watershed Assessment Manual (Watershed Professionals Network 1999) deals with **ecoregions,**

Figure 17. Components of the Oregon Watershed Assessment Manual.



or landscapes sharing fundamental characteristics. Ecoregions may be described at different spatial levels; the OWAM assessment procedure uses Level III and IV ecoregions; our region (Level III) is the entire Willamette Valley.

Conducting an assessment of a very large basin, as in the case of the Bradbury Process (Bradbury et al. 1995), may help establish regional priorities, but this coarse-scale approach will not be of much value for specific project prioritization and development (Watershed Professional Network 1999). This is due to the difficulty in compiling and interpreting large amounts of data in meaningful way. On the other hand, comprehensive assessment in a very small basin is too site-specific to be useful in an urbanized region because it fails to address cumulative impacts. However, if the proper method is selected (based on spatial scale), individual assessments may be compiled for larger assessments. For example, using the HUC codes described in the **Inventory Chapter**, 5th field assessments (e.g., the Johnson Creek watershed) can be combined to form a composite assessment of a larger basin or ecoregion.

The OWAM assessment process begins by looking at the entire watershed, because streams and their channels are the result not only of surrounding landform, geology, and climate, but of all upslope and instream influences as well. OWAM relies on existing data, local knowledge of land managers, and field surveys in order to reveal which natural and human-altered processes influence watershed health. The assessment bridges the gap to site-specific conditions by stratifying the stream network into Channel Habitat Types (CHTs), determined by the slope of the channel bottom and valley width. This helps identify segments of the stream network with high potential for biological production and which are sensitive to disturbance, in order to identify:

- Areas with highest potential for improvement
- High-priority areas for restoration
- Types of improvement actions that will be most effective

After analysis and planning identify the restoration actions needed and the actions are implemented, monitoring is used to track progress. The assessment template defines ecological indicators that can be monitored to track the restoration process. Other monitoring methods are available in the literature; for example, Scholz and Booth (2000) offer a monitoring strategy for urban streams in the moist Pacific Northwest that includes riparian canopy, bank erosion and bank hardening, and instream large woody debris.

Regional and local conservation, assessment and restoration efforts

There are numerous local or regional examples of watershed conservation, assessment and restoration efforts. Each may provide valuable insights into how to go about large-scale conservation planning and some, such as Clean Water Services' (formerly Unified Sewerage Agency) Watersheds 2000, may provide data relevant to conservation in the Metro region. Several such projects are described below. The Oregon Watershed Enhancement Board provides a list of current watershed restoration groups in Oregon (OWEB 2002).

There is significant overlap between many of the restoration projects listed here and many more ongoing projects that we have not mentioned. No one particular project addresses the range of problems and opportunities unique to the entire Metro region. All such projects should be brought into a larger regional restoration plan, if possible. This will help prioritize projects on a basin-wide scale and prevent duplicative or harmful projects, thereby making the best use of limited watershed restoration funds.

The Urban Watershed Institute

The Urban Watershed Institute (UWI) was launched in 1999 in response to increasingly complex urban environmental challenges (UWI 2001). While this is not an on-the-ground assessment or restoration effort, it may provide a valuable resource to those embarking on such efforts. UWI offers accredited classes (e.g., urban watershed assessment, wetlands and urban stream ecology, stream and watershed restoration methods, etc.), workshops and conferences to clarify environmental regulations and present strategies for achieving stream protection and regulatory compliance through multi-disciplinary approaches and new techniques and technologies. UWI's mission is to provide multidisciplinary training and encourage innovative partnerships to improve the ecological condition of urban watersheds.

The Gap Analysis Program

This is a nationwide program managed by U.S.G.S. Biological Resources Division (Shaughnessy and O'Neil 2001). The program focuses on working with each state to develop digital data layers used with GIS to identify the "gaps," or natural land cover types and native vertebrate species not adequately represented in existing network of conservation lands. This is a coarse-filter approach, working from the statewide scope to larger geographic regions.

King County, Washington

King County is ahead of the Metro region in regional watershed planning and implementation, reflecting governmental response to habitat degradation caused by the Seattle region's large population and growth rates over the past decades. King County has also collaborated considerably with University of Washington scientists to fill their research needs. Although there are differences, the Seattle and Portland regions are ecologically relatively similar and have been developed over roughly the same time period. Thus we can capitalize on our northern neighbors' successes and review their failures to aid planning and restoration efforts in the Metro region.

King County and others have initiated the Puget Sound Ecosystem Restoration Initiative, a proposed program to restore habitat for salmon and other species throughout the Puget Sound Basin (King County Department of Natural Resources 2001). The initiative's goals are to identify, prioritize, and construct the most effective habitat projects in the 17 watersheds comprising the basin, implemented by the Army Corps of Engineers and other local and state agencies, tribes, and key private interests. Two key elements are comprised in the initiative: identifying the best habitat projects in the Puget Sound basin to construct, and constructing them quickly and effectively. Designed to complement other local, state, and federal programs for salmon recovery, the plan will recognize prior habitat studies and plans, focus new studies and technical assistance where they are most needed, and establish priorities across the entire basin. If implemented, this science-based plan may provide an excellent model for similar efforts in the Portland Metro region.

In 2004, the King County Council approved limits on developing rural land (Langston 2004). The changes include requiring rural residents to keep half to two-thirds of their property covered in forest or natural vegetation, depending on the property size, to protect habitat, prevent flooding and erosion and protect water quality.

The Pacific Northwest Ecosystem Research Consortium (PNERC)

PNERC is an interdisciplinary research group comprised of scientists from Oregon's state universities, the U.S. EPA, private research consultants, and others (PNERC 2001). The consortium's goals are to understand the ecological consequences of societal decisions in the Pacific Northwest, develop transferable tools to support management of ecosystems at multiple spatial scales, and strengthen linkages between ecosystem research activities and ecosystem management applications in the Pacific Northwest. Specific objectives are to characterize ecosystem condition and change, identify and understand critical processes, and evaluate outcomes (including modeling alternative future scenarios and potential consequences of these alternatives to humans and the environment). PNERC offers several data products, including maps modeling Willamette Valley land use from the 1850's, existing habitats in the Willamette Valley, and Habitat Suitability Index models for wildlife species in which wildlife trends may be modeled under various future alternatives. All major conservation strategies in the Pacific Northwest should establish contact with PNERC to better plan and coordinate science-based conservation efforts.

The Northwest Power Planning Council

The Northwest Power Act, passed in 1980, created the Northwest Power Planning Council to give the governors of Oregon, Washington, Montana and Idaho valuable tools to address energy, fish and wildlife concerns in the region (Northwest Power Planning Council 1998). These tools include substantial input into investment of power ratepayer money in energy, fish and wildlife initiatives, an open forum for public debate, and the capability to provide high-quality, independent analyses of complex resource issues. The Council's responsibility is to mitigate the impact of hydropower dams on all fish and wildlife in the Columbia River Basin through a program of enhancement and protection, and provides guidance and recommendations on hundreds of millions of dollars per year of projects funded through Bonneville Power Administration revenues. The Council has undertaken a number of important restoration-related activities in recent years, including input on subbasin inventory, assessment and planning; development of a fish and wildlife program for the Columbia Basin; and publication of several major scientific reports.

The Columbia River Inter-Tribal Fish Commission

The Commission developed a tribal approach to salmon recovery through protecting and restoring watersheds in the Columbia Basin (Hollenbach and Ory 1999). This effort emphasizes the importance of the entire watershed, including uplands, to well-functioning rivers and streams based on science, ecology, and traditional Native American understanding and respect for the natural world. It includes healthy human communities as part of healthy landscapes. The Inter-Tribal Fish Commission endorsed the Governor's Watershed Enhancement Board Watershed Assessment Manual as a good watershed assessment resource (although Oregon-specific, and many tribal lands involved are located in Washington). The Inter-Tribal report includes contact information for organizations related to watershed assessment, conservation land acquisition, water acquisition and instream flow conservation, placing instream structures, beaver reintroduction, monitoring and evaluation, and a large section on fundraising opportunities.

The Oregon Plan for Salmon and Watersheds

The Oregon Plan was initiated in 1997 and has provided legislative support and funding for: watershed restoration, local level restoration actions to improve watershed health, water quality, and conserve or restore habitats that support native salmon and trout. In addition, it provides guidance to shape rural and urban communities in an ecologically sound manner. This is the most comprehensive conservation effort ever undertaken by any state (Nicholas 2001). The Willamette Restoration Initiative (see below) is part of The Oregon Plan. The Plan's principles (abbreviated here) are simple but poignant: seek truth, learn, and adapt; be humble about our place on the earth; obey the law and live up to commitments; respect people and nature (the two are inseparable); act voluntarily; exercise patience; build partnerships, make friends, and strengthen community; strive to let rivers be rivers, and untame, a little, our watersheds; share information, decision-making and responsibility for action; consider our children's needs; and (our favorite) never give up hope.

The Oregon Watershed Enhancement Board (OWEB)

OWEB is an independent state agency created by a legislative act (House Bill 3225; an earlier version was GWEB, the Governor's Watershed Enhancement Board) (Nicholas 2001). It is funded by state lottery dollars obtained through Ballot Measure 66, passed by voters in 1998. This agency created the Oregon Watershed Assessment Manual, discussed previously, and ties into The Oregon Plan for Salmon and Watersheds. OWEB provided about $32 million in funds during the 1999-2001 biennium to conduct watershed enhancement projects statewide. OWEB does not yet have a system for verifying watershed investment results. NMFS generally supports OWEB's efforts.

The Oregon Biodiversity Project

The Oregon Biodiversity Project is part of The Biodiversity Partnership, an alliance of organizations and individuals involved in cooperative efforts to conserve Oregon's biological diversity (Defenders of Wildlife 2000). Defenders of Wildlife took the lead on the project, with major participation from The Nature Conservancy and the Oregon Natural Heritage Program. The key idea is to pioneer a collaborative approach to conservation planning, with a large-scale view of identifying conservation priorities for Oregon's native species and the habitats and ecosystems that support them. The Biodiversity Project aims to improve land stewardship with emphasis on private landowner incentives; expand the existing network of conservation lands; improve biodiversity information to enhance decision-making and adaptive strategies; increase public awareness; and demonstrate and test collaborative approaches to biodiversity conservation that could provide a model for other states or regions. Resources produced by this project would be valuable to any Oregon watershed aiming to link wildlife and habitats in a restoration plan.

The Willamette Restoration Strategy

This strategy was developed through the Willamette Restoration Initiative (WRI) to supplement the Oregon Plan for Salmon and Watersheds, as directed by Governor John Kitzhaber and in consultation with the state Legislature (Jerrick 2001). The Strategy focuses on improving fish and wildlife habitat, enhancing water quality, and managing floodplains in the Willamette Basin, within the context of human habitation and projected population growth. Developed through a diverse advisory group including government, natural resource, and business interests, the Strategy offers four key recommendations and 27 critical actions it believes are necessary to restore the health of the Willamette Basin. The 27 critical actions and Metro's current activities that contribute to these actions are in Appendix 7. The four key recommendations are:

1. Use the Habitat Conservation and Restoration Opportunities map developed by WRI as a tool to guide restoration decisions in the basin.
2. Use environmental indicators from the Oregon State of the Environment Report 2000 (Oregon Progress Board 2000) to guide development of basin-specific restoration targets, and provide a new system for accurately tracking restoration progress.
3. Begin the process of establishing a sound restoration investment plan for the basin by clearly identifying existing assets and forecasting future needs and funding sources.
4. Provide for an organization to continue the refinement of the Willamette Restoration Strategy and track its implementation.

As Appendix 7 indicates, there are many ways in which Metro currently contributes to these efforts. However, Metro could contribute more substantially in the future by directly tying conservation efforts to WRI's restoration targets, thereby strengthening a regional approach to managing watershed health within the Willamette Basin and providing a more unified approach to the multitude of ecological problems facing our region.

The Lower Columbia River Estuary Plan

The Lower Columbia River Estuary Plan's mission is to preserve and enhance the water quality of the estuary to support its biological and human communities (Jerrick 1999). Developed by the Governors of Oregon and Washington, the U.S. EPA and other parties, this project relates to the Metro region because the water, and all of the sediments and pollutants contained therein, derive from or pass through this region to reach the estuary – an excellent example of cumulative effects. The Estuary Plan offers strategies for aquatic ecosystem monitoring, information management, and a program for analysis and inventory. The Estuary Plan's board is currently working with NMFS to tie their efforts more closely to ESA-related salmonid conservation efforts.

City of Portland

The City of Portland, which has jurisdiction over the largest city in the state, has undertaken many efforts to protect the environment. For example, the City's Bureau of Environmental Services has developed: a Clean River plan for the Willamette; a long-term strategy for eliminating combined sewer outflows and incentives for reducing effective impervious areas; and strong public outreach including the Community Watershed Stewardship Program (which funds restoration, education and citizen involvement activities) (City of Portland 2001). The City is also developing a comprehensive, science-based program for watershed restoration and fish recovery program with tie-ins to other local and regional programs. This program has the potential for guiding a regional urban framework for managing watershed health and restoration. A brief description of the City of Portland's response to the ESA is included in Appendix 8.

Watersheds 2000

Clean Water Services' (formerly Unified Sewerage Agency) Watersheds 2000, involving a number of local project partners, is an inventory of the location and condition of streams in Washington County, Oregon, one of the three counties encompassing the Metro region. The project will also identify on-the-ground projects likely to improve the health of these streams and will help Clean Water Services and its partners make informed resource management decisions (Clean Water Services 2001). This effort has collected a large body of quantitative and qualitative stream and riparian corridor data that will be available to Metro and the public beginning approximately June 2001. These data could greatly reduce costs involved in initiating an urban watershed restoration master plan, particularly if the same data collection methodologies could be applied to other jurisdictions within the Metro region.

The Tualatin River Watershed Council

The Tualatin River Watershed Council provides an example of an effective watershed council, with a citizen biological monitoring program, educational activities, native riparian enhancement projects, and cooperative efforts with other local organizations such as Clean Water Services, Friends of Trees, and Stop Oregon Litter and Vandalism (SOLV) (Tualatin River Watershed Council 2001). They have obtained funding from a variety of sources for these activities and have a fully funded watershed coordinator position overseeing all watershed projects, related activities, and communications with other groups. Such efforts can provide valuable information for larger scale planning efforts.

The Johnson Creek Watershed

The Johnson Creek Watershed has received more attention than most watersheds in the Metro region because urbanization greatly increased flood risks in that area. The Portland Multnomah Progress Board, in cooperation with the Johnson Creek Watershed Council and many other governmental and non-governmental organizations, assessed current watershed conditions and prepared a strategy toward salmonid recovery in the Johnson Creek (Multnomah County) watershed (Meross 2000). This and other watershed assessments and restoration plans should be integrated into any regional plans addressing watershed health.

Oregon Department of Fish and Wildlife

The Oregon Department of Fish and Wildlife is directly involved with wildlife conservation in the metro region. For example, ODFW's Wildlife Diversity Program emphasizes protection and management of the 88 percent of the state's native fish and wildlife species that are not hunted, angled or trapped (the so-called "nongame" species; ODFW 1993). The plan is a blueprint for addressing the needs of Oregon's native fishes, amphibians, reptiles, bird and mammals, and contains information on all species and habitats in the state. ODFW also provides technical input to various Metro programs, including Goal 5 (as does the U.S. Fish and Wildlife Service). ODFW's website provides information on naturescaping, threatened and endangered species, timing for instream projects to protect salmonids, exotic species, and various technical reports on fish, wildlife and habitat (see ODFW's website at www.dfw.state.or.us). ODFW also manages the Sauvie Island Wildlife Area, an area remarkably important to migratory songbirds and waterfowl.

The Urban Ecosystem Research Consortium (UERC) of Portland-Vancouver

The UERC is a consortium of people from various universities and colleges, state and federal agencies, local governments, non-profit organizations and independent professionals interested in supporting urban ecological research and creating an information-sharing network of people that collect and use ecological data in the Portland/Vancouver area. The UERC's mission is to advance the state of the science of urban ecosystems and improve our understanding of them, with a focus on the Portland/Vancouver metropolitan region, by fostering communication and collaboration among researchers, managers and citizens at academic institutions, public agencies, local governments, non-profit organizations, and other interested groups. The UERC hosts annual symposia for people involved in natural resources issues in this metropolitan area. In January 2005, the UERC held its third annual symposium with over 300 attendees. Symposia proceedings and other UERC information are available online at http://www.esr.pdx.edu/uerc/.

USFWS and Metro Greenspaces Program

Since 1991, the U.S. Fish and Wildlife Service (USFWS) has funded the Greenspaces Program to support habitat restoration, natural resource conservation, and environmental education efforts in the Portland, Oregon and Vancouver, Washington metropolitan area. USFWS works in partnership with Metro to award cost-share funding under the following programs:

- Conservation and Restoration Program: This program is designed to benefit fish and wildlife by supporting natural resource conservation, restoration and enhancement projects as well as efforts that will build upon current information and knowledge about local fish and wildlife and their habitats.
- Environmental Education Grant Program: This program supports environmental education programs and projects that teach about ecological principles and local watersheds, foster community involvement in habitat conservation issues, and promote citizen stewardship of urban natural areas.

Summary

The cumulative nature of human impacts in a watershed make return of the full, original range of ecological functions unlikely. The real question is whether we can improve, or even maintain, the range of ecological functions currently existing in the Metro region. Addressing impervious surfaces, natural vegetation cover, and hydrology are keys to success in formulating watershed plans. The danger that we face is that while a number of ambitious, large-scale restoration plans have been made there is no guarantee of follow-through, and in fact many of these efforts have faltered. This loss of project momentum is a common scenario, and results in a tremendous waste of funds that could have been used to make direct watershed improvements. A science-based restoration master plan encompassing the entire Metro region is one way to answer this question. In this way, each jurisdiction could be assured that other jurisdictions are contributing to reducing the cumulative effects of urbanization, with shared efforts and results. Actions are needed now, before all watersheds in the region are degraded beyond the point of repair.

Preventing further degradation and improving current conditions will require a collective effort of everyone in the region. These efforts are vital to protect some of the fundamental values expressed by Oregonians – a healthy environment, access to nature, and a legacy of these values for future generations. The process of restoring health to our environment will cost money, time, and effort, but we believe it can, and in fact *must* be done in order to sustain future generations of people, fish and wildlife.

CONCLUSION

This technical report provides us with a foundation to answer the questions we set out to address, as described below.

What are the key ecological attributes that characterize a healthy watershed?

- Uplands dominated by native forest cover
- Continuous stream corridors with healthy, fully functioning riparian zones
- Floodplains connected with river channels
- Relatively unaltered hydrologic regimes
- Intact hyporheic zones
- Natural (or ecologically sustainable) input rates of sediment, organic matter, and nutrients that support healthy, productive and diverse fish and wildlife populations
- Lateral, longitudinal and vertical connections between system components
- Natural (or ecologically sustainable) rates of landscape disturbances

What are the functions and values of fish and wildlife habitat and how can they be retained?

- For riparian corridors, we can characterize the main fish and wildlife habitat functions in six main categories: microclimate and shade; streamflow moderation and water storage; bank stabilization and pollution control; large wood and channel dynamics; organic material sources; and riparian wildlife habitat and connectivity.
- Native vegetation plays a critical role in a watershed, particularly the longitudinal and lateral connectivity of the riparian corridor.
- Downed wood and snags (or large woody debris), frequently found in natural ecosystems but often lacking in disturbed environments, are crucial in providing high quality habitat in both aquatic and terrestrial ecosystems.
- Retention of key functions in riparian corridors will require a varying buffer width based on site-specific conditions.
- Upland habitat is important for many wildlife species. Important guidelines in developing a conservation plan for upland habitat are: large patches are better than small patches; small patches of unique habitat are worth saving; connectivity to other patches is important; and connectivity and/or proximity to water resources is valuable.
- Habitat fragmentation is a critical issue; thus buffers and surrounding land use play an important role in maintaining the functions of remaining habitat.

What are the species of fish and wildlife that characterize the biodiversity of our region?

- There are 292 native vertebrate species in the Metro region. Ninety-three percent use riparian areas, with 45 percent dependent on those areas to meet life history requirements. Eighty-nine percent of all terrestrial species in the Metro region are associated with upland habitats, with at least 28 percent depending on these habitats.
- In the Metro region several species of salmonids are listed as threatened under the federal Endangered Species Act. There are also numerous species that are identified as at risk both by the state and federal agencies. However, in this region we still have much habitat worth protecting and restoring for the purpose of retaining existing species and preventing future listings.

What are the impacts of urbanization on healthy watershed function and fish and wildlife habitat?

- Urban environments have similar ecological problems worldwide; including habitat loss, habitat damage and alteration (instream and terrestrial), modified hydrology, introduced species, and human disturbance.
- In the Metro region we have already lost about 400 miles of streams and many of the remaining stream miles suffer from degraded water quality, fragmentation, and simplification of riparian corridors for fish and wildlife.
- Human disturbance has played a major role in modifying fish and wildlife habitat; including the introduction of nonnative species, pollution, and habitat alteration and simplification.

What is restoration and how is it best approached in an urban context?

- Ecological restoration is the process of assisting the recovery and management of ecological integrity. Ecological integrity includes a critical range of variability in biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices (SER 2000).
- Urban "restoration" may represent a range of improvements in function and condition over time, limited in an urban setting to what is actually achievable - in other words, an ecologically, economically and socially acceptable range of options that re-establishes natural functions. The end goal is sustainability, under a new urban equilibrium that is different from that in the original ecosystem, but which supports diverse wildlife communities and healthy ecosystems.
- Addressing hydrology, impervious surfaces, and natural vegetation are keys to success.

Metro will utilize the information in this technical report to help in the development of a regional Goal 5 program to protect fish and wildlife habitat. Specifically, the technical report will help to inform the following steps in the Goal 5 process:

- developing criteria to determine significant riparian and upland wildlife habitat and to address the location, quality, and quantity requirements of the Goal 5 rule;
- conducting an ESEE analysis to weigh the consequences of protection of significant fish and wildlife habitat and allowing development of the resources, and to identify the tradeoffs for decision makers; and
- formulating a program to protect fish and wildlife habitat that is scientifically based.

Integrating the needs of people with the needs of fish and wildlife in an urban environment is not an easy task. There has been debate on the value of providing habitat reserves in urban and developing areas, considering the difficulty many species have cohabiting with humans and the economic value of developable land in urban areas (Linehan et al. 1995). However, a large body of evidence indicates that people living in urban areas appreciate access to fish and wildlife habitat (Adams and Dove 1989; Adams 1994; U.S.D.A. Forest Service and N.O.A.A. 2000). According to the National Survey on Recreation and the Environment, over 86 percent of Americans think it is important to protect wildlife habitat, and 93 percent believe that the natural environment has intrinsic value (U.S.D.A. Forest Service and N.O.A.A. 2000).

Metro's policies have consistently placed a high level of importance on the protection of the natural environment as a means of maintaining the high quality of life citizens of this region expect. This technical report provides an important framework to guide us in doing just that.

GLOSSARY

Abiotic – something that is not living (e.g., rock).

Age effect – refers to the amount of time a fragment has been separated from the "mainland" or the surrounding landscape by urbanization.

Algal bloom – a condition that occurs when excessive nutrient levels and other physical and chemical conditions facilitate rapid growth of algae. Algal blooms may cause changes in water color. The decay of the algal bloom may reduce dissolved oxygen levels in the water.

Allochthonous – refers to something formed somewhere other than its present location. Examples include leaf litter, insects, etc. falling into a stream. Antonym of autochthonous.

Anadromous fish – fish that are born in freshwater, spend a significant portion of their life in the ocean, and return to natal streams as adults to spawn.

Aquatic – having to do with water.

Armoring (channel armoring) – the formation of a resistant layer of relatively large particles resulting from removal of finer particles by erosion.

At risk species, or species at risk – a catch-all term for species that are officially listed in some manner through state and/or federal Endangered Species Act programs (see Species List for technical definitions).

Autochthonous – Refers to something formed in its present location. Example includes instream algae. Antonym of allochthonous.

Baseflow – Streamflow that results from precipitation that infiltrates into the soil and eventually moves through the soil to the stream channel. This is also referred to as ground water flow, or dry-weather flow.

Benthic zone – associated with stream bottoms

Bioaccumulation – storage of a chemical within a living organism at concentrations higher than found in the surrounding environment.

Biological oxygen demand – indicator of organic pollutants in an effluent measured as the amount of oxygen required to support them. The greater the BOD the greater the pollution and less oxygen available for higher aquatic organisms.

Biodiversity – full range of variety and variability within and among living organisms and the ecological complexes in which they occur. The concept of biodiversity encompasses ecosystem processes, species diversity and genetic variation.

Biota – plants and animals living in a habitat.

Biotic – something that is living, or pertaining to living things.

Carnivore – an animal that feeds on other animals.

Carrying capacity – the maximum sustainable size of a population in a given ecosystem.

Channelization – the process of changing and straightening the natural path of a waterway.

Coarse scale data – applicable on a large spatial scale.

Connectivity – for streams, the physical connection between tributaries and the river, between surface water and groundwater, and between wetlands and these water sources. For terrestrial habitat, concept is similar but in this context refers generally to sufficient connectivity to allow wildlife passage between habitat patches.

Cumulative impacts – the sum of effects from all factors that influence the condition of a watershed that together have a greater impact than if each acts alone

Denitrification – reduction of nitrate or nitrite to molecular nitrogen or nitrogen oxides by microbial activity (dissimilatory nitrate reduction) or by chemical reactions involving nitrite (chemical denitrification). Results in the effective removal of substances which, in high amounts, are toxic to animals.

Detritivore – any organism that eats decaying organic matter.

Diatoms – single-celled creatures with hard, silica-based shells. Frequent aquatic residents that form part of the aquatic food web.

Discharge – the volume of water moving down a channel per unit of time. Alternatively, the volume of water released from a dam or powerhouse at a given time, usually expressed in cubic feet per second.

Disturbance – any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment. In aquatic systems, refers to any significant fluctuation in the supply or routing of water, sediment, or woody debris that causes a measurable change in channel morphology and leads to a change in a biological community.

Diversity – see also biological diversity. In ecology, this term usually refers to how many different kinds of plants and animals are found in an area.

Ecoregion – land areas with fairly similar geology, flora and fauna, and landscape characteristics that reflect a certain ecosystem type.

Ecosystem – the totality of components of all kinds that make up a particular environment; the complex of biotic community and its abiotic, physical environment

Edge – the area of transition between two different vegetation communities, such as forest and meadow. Also refers to human-made systems, such as the transition between a natural area and a residential development.

Effective impervious area (EIA) – the area where there is no opportunity for surface runoff from an impervious surface to infiltrate into the soil before it reaches a conveyance system (pipe, ditch, stream, etc.). An example of an EIA is a shopping center parking lot where the water runs off the pavement and directly goes into a catch basin where it then flows into a pipe and eventually to a stream. In contrast, some homes with impervious roofs collect the roof runoff into roof gutters and send the water down downspouts, where it can be directed either into a pipe or dumped on a splash block. Roof water dumped on a splash block then has the opportunity to spread out into the yard and infiltrate into the soil. Such roofs are not considered to be 100 percent effective impervious area.

Endangered Species Act – 1973 Act of U.S. Congress, amended several times subsequently, that elevates the goal of conservation of listed species above virtually all other considerations. The act provides for identifying (listing) endangered and threatened species or distinct segments of species, monitoring candidate species, designating critical habitat, preparing recovery plans, consulting by federal agencies to ensure that their actions do not jeopardize the continued existence of listed species or adversely modify critical habitats, restricting importation and trade in endangered species or products made from them, restricting the taking of endangered fish and wildlife. The act also provides for cooperation between the federal government and the states.

Enhancement – is the alteration and/or active management of existing habitat to improve particular functions and values; enhancement activities may or may not return the site to pre-disturbance conditions, but creates or recreates functions and processes that occur naturally

Entrenchment – the vertical containment of a river and the degree to which it is incised in the valley floor. A stream may also be entrenched by the use of dikes or other structures.

Ephemeral streams – streams that flow only during or immediately after periods of precipitation, generally less than 30 days per year.

Erosion – the movement of soil particles resulting from the actions of water or wind. Erosion produces sediment that moves in suspension from its site of origin by air, water, or gravity.

Eutrophication – rapid increase in the nutrient status of a water body, natural or occurring as a by-product of human activity. Excessive production leads to anaerobic conditions below the surface waters. Especially refers to high concentrations of nitrates and phosphates in water, which may lead to algal bloom.

Evaporation – conversion of liquid water into water vapor. See also evapotranspiration and transpiration.

Evapotranspiration – a collective term that includes water discharged to the atmosphere as a result of evaporation from the soil and surface-water bodies and as a result of plant transpiration. *See* also evaporation and transpiration.

Extinct – complete loss of a species, i.e., no surviving individuals exist.

Extirpated – a species that has gone locally extinct.

Fecal coliform – present in large numbers in the feces and intestinal tracts of humans and other warm-blooded animals, and can enter water bodies from human and animal waste. Some fecal coliform bacteria may cause illness, and if a large number of fecal coliform bacteria (over 200 colonies/100 milliliters (ml) of water sample) are found in water, it is possible that pathogenic (disease- or illness-causing) organisms are also present in the water.

Flashiness – generally refers to high variability of stream flow. The ratio of the flow that is exceeded 90 percent of the time to the flow exceeded 10 percent of the time (90:10 ratio) is indicative of the flashiness or variability of stream flow. Excessive stream flashiness may be caused by human impacts such as impervious surfaces and loss of vegetative cover, resulting in hydrologic alterations that change the biotic communities able to live in and near the stream.

Floodplain – the area immediately adjacent to the stream or river channel that becomes inundated with overbank flows during large storm events.

Flood-pulse concept – identifies the predictable advance and retraction of water on the floodplain of a pristine system as the principal agent in enhancing biological productivity and maintaining diversity in the system.

Flow (streamflow) – water flowing in the stream channel. It is often used interchangeably with discharge.

Food web – the complex system of transfer of energy among living things; in other words, what eats what.

Fragmentation – the breaking up of once contiguous habitats or populations that may result in decreasing patch or population size and increasing isolation.

Geomorphic – of or resembling the earth, its shape, or surface configuration. See also geomorphology.

Geomorphology – the study of present-day landforms, including their classification, description, nature, origin, development, and relationships to underlying structures. Also the history of geologic changes as recorded by these surface features. The term is sometimes restricted to features produced only by erosion and deposition.

Gradient – the slope of a stream channel. Also pertains to the ecological concept of change across space or time; for example, an urban gradient refers to differences observed from undeveloped to heavily developed areas.

Groundwater – generally all subsurface water as distinct from surface water; specifically, that part of the subsurface water in the saturated zone (a zone in which all voids are filled with water) where the water is under pressure greater than atmospheric.

Habitat – an area with the combination of the necessary resources (e.g., food, cover, water) and environmental conditions (temperature, precipitation, presence or absence of predators and competitors) that promotes occupancy by individuals of a given species (or population), and allows those individuals to survive and reproduce.

Headwaters – the smallest streams that combine to form a larger stream; the uppermost reaches of a river or stream.

Herbivore – animals that eat primarily vegetation.

Hydrograph – a graph showing the water level (stage), discharge, or other property of a river volume with respect to time.

Hydrologic cycle – the continuous cycling of water from atmosphere to earth and oceans and back again.

Hyporheic zone – the saturated sediment underneath a stream or river channel and below the riparian area where groundwater and channel water mix. Properties of both groundwater and channel water are blended in the hyporheic zone, significantly changing the water's chemical composition and stimulating biological activity.

Imperviousness – the ability to repel water, or not let water infiltrate. Pertaining to impermeable surfaces, or materials preventing fluids from passing through.

Index of Biological Integrity (IBI) – an integrative expression of site condition across multiple metrics. An index of biological integrity is often composed of at least seven metrics. The plural form is either indices or indexes.

Infiltration capacity – the maximum rate at which water can enter the soil at a particular point under a given set of conditions.

Insectivore – a species whose primary food is insects.

Intermittent streams – streams that flow only during certain times of the year, but usually more than 30 days per year.

Invertebrates – see macroinvertebrates.

Keystone species – species whose effect on community structure is out of proportion to its abundance.

Large woody debris (LWD) – any large piece of woody material that intrudes into a stream channel or is present in terrestrial habitats. Also known as Large Wood, Large Organic Debris.

Limnetic zone – deep open water dominated by phytoplankton and freshwater fish, extending to the limits of light penetration. Profundal zone below limnetic zone, devoid of plant life and dominated by detritivores. Benthic zone includes bottom soil and sediments.

Littoral zone – at edge of lakes is the most productive with diverse aquatic beds and emergent wetlands (part of Herbaceous Wetland habitat).

Low-gradient zone – portions of a stream that flow along a gradual or relatively flat slope.

Macroinvertebrates – animals without backbones that can be seen with the naked eye. Includes insects, crayfish, snails, mussels, clams, etc.

Meander – following a winding and turning course. A meandering stream is an alluvial stream characterized by a series of pronounced alternating bends.

Metapopulation – a collection of localized populations that are geographically distinct, yet are genetically interconnected through movement of individuals among populations. See also Rescue effect.

Microclimate – the climate of a small, specific area rather than an entire area. More specifically, the photosynthetically active radiation, air or water temperature, and vapor pressure deficit present at a specific site. Chen et al. (1999) describe microclimate as the suite of climatic conditions measured in localized areas near the earth's surface.

Mid-section zone – the portion of a stream between the headwaters and low-gradient zone, which tends to have a band of riparian vegetation that is influenced by channel dynamics (e.g., meandering, flooding).

Mitigation – measures used to reduce the adverse effects of a proposed project by considering, in the following order: a) avoiding the impact altogether by not taking a certain action or parts of an action; b) minimizing impacts by limiting the degree or magnitude of the action and its implementation; c) rectifying the impact by repairing, rehabilitating or restoring the affected environment; d) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action by monitoring and taking appropriate measures; and e) compensating for the impact by replacing or providing comparable substitute water quality resource areas.

Nutrient cycling – all the processes by which nutrients are transferred from one organism to another. For instance, the carbon cycle includes uptake of carbon dioxide by plants, ingestion by animals, and respiration and decay of the animal.

Organochlorine pesticide – A class of organic pesticides containing a high percentage of chlorine. Includes dichlorodiphenylethanes (such as DDT), chlorinated cyclodienes (such as chlordane), and chlorinated benzenes (such as lindane). Most organochlorine insecticides were banned or severely restricted in usage because of their carcinogenicity, tendency to bioaccumulate, and toxicity to wildlife.

Organochlorine compound – synthetic organic compounds containing chlorine. As generally used, term refers to compounds containing mostly or exclusively carbon, hydrogen, and chlorine. Examples include organochlorine insecticides, polychlorinated biphenyls (PCBs) and some solvents containing chlorine.

Overflow channel - An abandoned channel in a floodplain that may carry water during periods of high stream or river flows.

Overland flow – precipitation runoff that occurs when the precipitation rate exceeds the infiltration rate of the ground's surface; water flowing over the surface of the earth.

Oxbow – a meander severed from the main channel; an abandoned stream meander.

Oxbow lake – a body of water created after clay, other material, or channel dynamics plugs the oxbow from the main channel.

Passive restoration – allows natural processes to return through reducing or halting activities that cause degradation or prevent recovery.

Perennial stream – a watercourse that flows throughout the year or most of the year (90 percent), in a well-defined channel. Also known as a live stream. Flows continuously during both wet and dry times; baseflow is dependably generated from the movement of groundwater into the channel.

pH – the negative log of the hydrogen ion concentration ($-\log10$ [H+]); a measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. The scale is 0-14. Aquatic organisms tend to be restricted in the pH range in which they can survive.

Phytoplankton – free-floating microscopic aquatic organisms capable of photosynthesis.

Pool – an area of relatively deep slow water in a stream that offers shelter to fish.

Precipitation – any form of water, such as rain, snow, sleet, or hail, that falls to the earth's surface.

Profundal zone – is the deepest part of the ocean or lake where light does not penetrate. This layer usually has fewer nutrients, more silt, and

fewer organisms than the surface.

Reference condition – conditions that represent the optimal or best attainable conditions for habitats or ecosystems.

Rehabilitation – improvements to a natural resource that return it to a good condition but not the condition prior to disturbance.

Rescue effect – see also Metapopulation. A subpopulation on one habitat patch could go temporarily extinct, but as long as the patch is connected to a populated patch it could be recolonized. This effect is crucial in the maintenance of small populations with limited habitat area.

Respiration – the physical and chemical processes by which an organism supplies its cells and tissues with the oxygen needed for metabolism and relieves them of the carbon dioxide formed in energy-producing reactions; any of various energy-yielding oxidative reactions in living matter.

Riffle – area of a stream or river characterized by a rocky streambed and turbulent, fast-moving, shallow water.

Riparian area – the land and vegetation adjacent to waterbodies such as streams, rivers, wetlands and lakes that are influenced by perennial or intermittent water and hydric soils (soils formed under periodic saturation or flooding). Riparian areas are dynamic biological and physical systems that act as the interface between terrestrial (land) and aquatic (water) ecosystems.

Riparian corridor – includes the stream or river; riparian vegetation; off-channel habitat such as wetlands and side channels, and the floodplain; the hyporheic zone; and the zone of influence.

Riparian vegetation – the plant communities occurring within the riparian area that are adapted to wet conditions and are distinct from upland communities.

River Continuum Concept – the best known longitudinal model for rivers, the River Continuum Concept (RCC) attempts to generalize and explain observed longitudinal changes in stream ecosystems. It proposes that rivers exhibit continuous longitudinal changes and identifies the relationships between the progressive changes in stream structure, such as channel size and stream flow, and the distribution of species. According to the RCC, characteristics of particular reaches are associated not only with discrete factors such as water temperature, but with their positions along the length of the river. The model is especially useful at the basin and stream scale, because it accounts for observed longitudinal shifts in biotic communities.

Salinity – the concentration of salt in water, usually measured in parts per thousand (ppt).

Salmonids – fish that belong the Salmonidae family. This includes salmon and steelhead.

Saturated overland flow – runoff that occurs when the water table rises to the ground surface, usually during a large rainstorm, causing groundwater to break out of the saturated soil and to travel as overland flow.

Sediment – particles and/or clumps of particles of sand, clay, silt, and plant or animal matter carried in water.

Sediment load – mass of sediment passing through a stream cross section in a specified period of time, expressed in millions of tons (mt). Amount of sediment carried by running water. The sediment that is being moved by a stream.

Sedimentation – occurs when eroded soil is deposited by runoff into rivers, harbors and lakes, degrading water quality.

Smoltification – the physiological changes anadromous salmonids undergo in freshwater while migrating toward saltwater that allow them to live in the ocean.

Sinuosity – the amount of curvature in the channel and is computed by dividing the channel centerline length by the length of the valley centerline.

Species at risk – see At risk species.

Species guild – a group of organisms with similar functional characteristics, such as trophic or migratory levels.

Species of concern – species which the U.S. Fish and Wildlife Service is reviewing for consideration as candidates for listing under the Endangered Species Act.

Species richness – the number of species in a given area or habitat.

Stormflow (stormwater) – precipitation that reaches the channel by moving downslope as overland flow or as shallow subsurface flow.

Substrate – the material forming the underlying layer of streams, may be bedrock, gravel, boulders, sand, clay, etc.; materials such as rocks or logs found in streams that can provide habitat for aquatic organisms

Subsurface flow – precipitation runoff that occurs when the precipitation rate exceeds the infiltration rate of the ground's surface; water flowing under the shallow surface of the earth when there is a relatively impermeable layer underneath permeable topsoil.

Surface water – an open body of water, such as a stream or a lake.

Talus – a sloping heap of loose rock fragments lying at the foot of a cliff or steep slope.

Terrace – a berm or discontinuous segments of a berm, in a valley at some height above the floodplain, representing a former abandoned flood plain of the stream.

Terrestrial – living or growing on land.

Total impervious area (TIA) – the total amount of actual impervious surface on a site or within a drainage area, basin, or subbasin.

Total sediment load – includes bed sediment load, suspended sediment load, and wash load (that part of the suspended load that is finer than the bed material; limited by supply rather than hydraulics).

Transpiration – diffusion of water vapor from plant leaves to the atmosphere; transpired water originates from water taken in by roots.

Trophic – pertaining to feeding and nutrition. Formally, an organism's position in the food chain, determined by the number of energy-transfer steps to that level.

Turbidity – measure of extent to which light passing through water is reduced due to suspended materials. Cloudiness of water, measured by how deeply light can penetrate into the water from the surface. The cloudy appearance of water caused by the presence of suspended material.

Upland – land above water level and beyond ground that is saturated by water for any length of time; they are formed by the larger geologic processes over time. Uplands contain plants that grow in drier soils and may provide habitat for different kinds of animals than a riparian zone.

Urban gradient – an environmental gradient is a spatially varying aspect of the environment which is expected to be related to species composition; the urban gradient is a specific type of environmental gradient representing a gradient of urbanization conditions.

Velocity – speed.

Wastewater – water that carries wastes from homes, businesses, and industries.

Watershed – all the land and tributaries draining to a body of water; a drainage basin which contributes water, organic materials, nutrients, and sediments to a river, stream or lake.

Watershed assessment – is a process for evaluating how well a watershed is functioning; it includes steps for identifying issues, examining the history of the watershed, describing its features, and evaluating various resources within the watershed.

Wetlands – wetlands may occur adjacent to stream channels and within the floodplain of the riparian corridor. They are defined as ecosystems that depend on frequent and recurrent shallow inundation or saturation at, or near, the soil surface. Swamps, marshes, bogs and similar areas are generally considered wetlands. Plant communities of wetland habitats are dominated by species adapted to survive and grow under extended periods of anaerobic (absence of oxygen) soil conditions.

Zone of influence – refers to the transition area between the riparian area and the upland forest where vegetation is not directly influenced by hydrologic conditions, but where vegetation still influences the stream by providing shade, microclimate, fine or large woody materials, nutrients, organic and inorganic debris, terrestrial insects, and habitat for riparian associated wildlife.

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† = derived directly from empirical evidence (primary literature)
‡ = urban study, includes urban study sites or conveys urban-specific information

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APPENDIX 1

Metro Region Species List:

Purpose and Limitations

The purpose of Metro's Species List is threefold:

1. To identify fish and wildlife species occurring in the Metro region.
2. To identify the relative importance of various types of habitat to fish and wildlife species.
3. To provide a biologically meaningful way in which to describe the biodiversity of the Metro region.

THE LIST IS NOT A STATEMENT OF POLICY. In keeping with Metro's Streamside Vision Statement, the focus of the list is on native fish and wildlife species whose historic ranges include the metropolitan area and whose habitats are or can be provided for in urban habitats. Urban habitats may never be conducive to significant populations of some species, such as black bear and cougar. Further analysis and Metro Council deliberation will help determine (to the extent possible) the type, amount, and location of fish and wildlife habitats that should be protected and/or restored. For example, landowner incentives will be developed for conservation purposes.

This list contains:

1. All known native vertebrate species that currently exist within the Metro region (the final version will include a map of area involved) for at least a portion of the year and could be found in the region through diligent search by a knowledgeable person. Vagrant species (those that do not typically occur every year) are not included on this list.
2. Extirpated (locally extinct) native vertebrate species known to have inhabited the region in the past.
3. Nonnative vertebrate species with established breeding populations in the region.

The species list is based on the opinion of more than two dozen local wildlife experts. The Oregon Natural Heritage Program (ORNHP), Endangered Species Act (ESA), and Oregon Department of Fish and Wildlife (ODFW) status categories were obtained from ORNHP's February, 2001 *Rare, Threatened and Endangered Plants and Animals of Oregon* publication. Habitat associations were obtained from Johnson and O'Neil's new book, *Wildlife Habitats and Relationships in Oregon and Washington.* The taxonomic standards for common and scientific names for birds is based on the American Ornithological Union Check-list. We are also developing a separate aquatic and terrestrial invertebrate list, but this will not be as comprehensive in scope as the vertebrate species list.

For questions or comments regarding this list, please contact Lori Hennings at Metro (503/797-1726).

Metro Region Species List:
Key to Notations

* Indicates species that are non-native (also known as alien or introduced) to Metro region.

( ) Parentheses indicate a species that was historically present but was extirpated from the Metro region within approximately the last century.

1 **Code** (type of animal)
A = Amphibians
B = Birds
F = Fish
M = Mammals
R = Reptiles

2 **Migratory Status** (indicates trend for the majority of a given species in the Metro region):
A = Anadromous (fish; lives in the ocean, spawns in fresh water)
C = Catadromous (fish; lives in fresh water, spawns in the ocean)
M = Migrates through area without stopping for long time periods
N = Neotropical migratory species (birds; majority of individuals breeding in the Metro region migrate south of U.S./Mexico border for winter)
R = Permanent resident (lives in the area year-round)
S = Short-distance migrant (from elevational to regional migration, e.g., across several states)
W = Winters in the Metro region

3 **Federal Status** is based on current Endangered Species Act listings. **E** = Endangered, **T** = Threatened. Endangered taxa are those which are in danger of becoming extinct within the foreseeable future throughout all or a significant portion of their range. Threatened taxa are those likely to become endangered within the foreseeable future.
LE = Listed Endangered. Taxa listed by the U.S. Fish and Wildlife Service (USFWS) or the National Marine Fisheries Service (NMFS) as Endangered under the Endangered Species Act (ESA), or by the Departments of Agriculture (ODA) and Fish and Wildlife (ODFW) of the state of Oregon under the Endangered Species Act of 1987 (OESA).
LT = Listed Threatened. Taxa listed by the USFWS, NMFS, ODA, or ODFW as Threatened.
PE = Proposed Endangered. Taxa proposed by the USFWS or NMFS to be listed as Endangered under the ESA or by ODFW or ODA under the OESA.
PT = Proposed Threatened. Taxa proposed by the USFWS or NMFS to be listed as Threatened under the ESA or by ODFW or ODA under the OESA.

C = Candidate taxa for which NMFS or USFWS have sufficient information to support a proposal to list under the ESA, or which is a candidate for listing by the ODA under the OESA.
SoC = Species of Concern. Former C2 candidates which need additional information in order to propose as Threatened or Endangered under the ESA. These are species which USFWS is reviewing for consideration as Candidates for listing under the ESA.

4 **ODFW Status** (state status) is based on current Oregon Department of Fish and Wildlife "Oregon Sensitive Species List," 2001. See Federal Status (above) for definitions of LT and LE.
SC (Critical) = Species for which listing as threatened or endangered is pending; or those for which listing as threatened or endangered may be appropriate if immediate conservation actions are not taken. Also considered critical are some peripheral species which are at risk throughout their range, and some disjunct populations.
SV (Vulnerable) = Species for which listing as threatened or endangered is not believed to be imminent and can be avoided through continued or expanded use of adequate protective measures and monitoring. In some cases the population is sustainable, and protective measures are being implemented; in others, the population may be declining and improved protective measures are needed to maintain sustainable populations over time.
SP (Peripheral or Naturally Rare) = Peripheral species refer to those whose Oregon populations are on the edge of their range. Naturally rare species are those which had low population numbers historically in Oregon because of naturally limiting factors. Maintaining the status quo for the habitats and populations of these species is a minimum requirement. Disjunct populations of several species which occur in Oregon should not be confused with peripheral.
SU (Undetermined Status): Animals in this category are species for which status is unclear. They may be susceptible to population decline of sufficient magnitude that they could qualify for endangered, threatened, critical or vulnerable status, but scientific study will be required before a judgement can be made.

5 **ORNHP Rank (ABI – Natural Heritage Network Ranks)**: ORNHP participates in an international system for ranking rare, threatened and endangered species throughout the world. The system was developed by The Nature Conservancy and is maintained by The Association for Biodiversity Information (ABI) in cooperation with Heritage Programs or Conservation Data Centers (CDCs) in all 50 states, in 4 Canadian provinces, and in 13 Latin American countries. The ranking is a 1-5 scale, primarily based on the number of known occurrences, but also including threats, sensitivity, area occupied, and other biological factors. On Metro's Species List the first ranking (**rank**/rank) is the Global Rank and begins with a "G". If the taxon has a trinomial (a subspecies, variety or recognized race), this is followed by a "T" rank indicator. A "Q" at the end of this ranking indicates the taxon has taxonomic questions. The second ranking (rank/**rank**) is the State Rank and begins with the letter "S". The ranks are summarized below.

1 = Critically imperiled because of extreme rarity or because it is somehow especially vulnerable to extinction or extirpation, typically with 5 or fewer occurrences.
2 = Imperiled because of rarity or because other factors demonstrably make it very vulnerable to extinction (extirpation), typically with 6-20 occurrences.
3 = Rare, uncommon or threatened, but not immediately imperiled, typically with 21-100 occurrences.
4 = Not rare and apparently secure, but with cause for long-term concern, usually more than 100 occurrences.
5 = Demonstrably widespread, abundant, and secure.
H = Historical Occurrence, formerly part of the native biota with the implied expectation that it may be rediscovered.
X = Presumed extirpated or extinct.
U = Unknown rank.
? = Not yet ranked, or assigned rank is uncertain.

6 **ORNHP List** is based on Oregon Natural Heritage Program data.
List 1 contains taxa that are threatened with extinction or presumed to be extinct throughout their entire range.
List 2 contains taxa that are threatened with extirpation or presumed to be extirpated from the state of Oregon. These are often peripheral or disjunct species which are of concern when considering species diversity within Oregon's borders. They can be very significant when protecting the genetic diversity of a taxon. ORNHP regards extreme rarity as a significant threat and has included species which are very rare in Oregon on this list.
List 3 contains species for which more information is needed before status can be determined, but which may be threatened or endangered in Oregon or throughout their range.
List 4 contains taxa which are of conservation concern but are not currently threatened or endangered. This includes taxa which are very rare but are currently secure, as well as taxa which are declining in numbers or habitat but are still too common to be proposed as threatened or endangered. While these taxa currently may not need the same active management attention as threatened or endangered taxa, they do require continued monitoring.

7 **Riparian Association** indicates use of any of the 4 water-based habitats. Single "X" in any habitat type (upland or water-associated) indicates general association; "XX" indicates close association, as per Johnson and O'Neil 2001.

8 **Habitat Types** based on Johnson and O'Neil (2001). These habitats are described more fully within the text of the upland and riparian chapters.
WLCH = Westside Lowlands Conifer-Hardwood Forest
WODF = Westside Oak and Dry Douglas-fir Forest and Woodlands
WEGR = Westside Grasslands
AGPA = Agriculture, Pasture and Mixed Environs

URBN = Urban and Mixed Environs
WATR = Open Water - Lakes, Rivers, Streams
HWET = Herbaceous Wetlands
RWET = Westside Riparian-Wetlands

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Appendix 1. Species list and habitat associations for species normally occurring within the Metro region. Study area is the Metro jurisdictional boundary plus 1 mile buffer, plus UGB study areas.

			Migratory	Federal	ODFW	ORNHP	ORNHP	Riparian	Habitat Type[8]							
Code[1]	Common Name	Genus/Species	Status[2]	Status[3]	Status[4]	Rank[5]	List[6]	Assn.[7]	WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
F	River Lamprey	*Lampetra ayresi*	A	SoC	None	G4/S4	4	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Western Brook Lamprey	*Lampetra richardsoni*	A	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Pacific Lamprey	*Lampetra tridentata*	A	SoC	SV	G5/S3	2	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	White Sturgeon	*Acipenser transmontanus*	A	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	American Shad*	*Alosa sapidissima*	A	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Chiselmouth	*Acrocheilus alutaceus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Goldfish*	*Carassius auratus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Common Carp*	*Cyprinus carpio*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Peamouth Chub	*Mylocheilus caurinus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
(F)	(Oregon Chub - extirpated from Metro area)	*Oregonichthys crameri*	R	LE	SC	G2/S2	1	(XX)	(XX)	(XX)	N/A	N/A	N/A	N/A	N/A	N/A
F	Northern Pikeminnow (Squawfish)	*Ptychocheilus oregonensis*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Longnose Dace	*Rhynichthys cataractae*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Leopard Dace	*Rhynichthys falcatus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Speckled Dace	*Rhynichthys osculus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Redside Shiner	*Richardsonius balteatus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Largescale Sucker	*Catostomus macrocheilus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Brown Bullhead*	*Ameiurus nebulosus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	XX	N/A	N/A	N/A	N/A	N/A	N/A
F	Eulachon (Columbia River Smelt)	*Thaleichthys pacificus*	A	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Coastal Cutthroat Trout, SW WA/Col. R. ESU	*Oncorhynchus clarki clarki*	A	PT	SC	G4T2Q/S2	2	XX	XX	X	N/A	N/A	N/A	N/A	N/A	N/A
F	Coastal Cutthroat Trout, Upper Will. R. ESU	*Oncorhynchus clarki clarki*	A	SoC	None	G4T?Q/S3?	4	XX	XX	X	N/A	N/A	N/A	N/A	N/A	N/A
F	Chum Salmon, Columbia River ESU	*Oncorhynchus keta*	A	LT	SC	G5T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Coho Salmon, Oregon Coast ESU	*Oncorhynchus kisutch*	A	LT	SC	G4T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Coho Salmon, Lower Columbia R./Southwest Washington ESU	*Oncorhynchus kisutch*	A	C	LE	G4T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Rainbow Trout (resident populations)	*Oncorhynchus mykiss*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Steelhead (anadromous Rainbow Trout), Oregon Coast ESU	*Oncorhynchus mykiss*	A	C	SV	G5T2T3Q/S2S3	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Steelhead, Lower Columbia River ESU	*Oncorhynchus mykiss*	A	LT	SC	G5T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Steelhead, Upper Willamette River ESU, winter run	*Oncorhynchus mykiss*	A	LT	SC	G5T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Steelhead, Middle Columbia River ESU	*Oncorhynchus mykiss*	A	LT	SC/SV	G5T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Steelhead, Snake River Basin ESU	*Oncorhynchus mykiss*	A	LT	SV	G5T2T3Q/S2S3	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Steelhead, Upper Columbia River ESU	*Oncorhynchus mykiss*	A	LE	None	G5T2Q/SU	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Sockeye Salmon, Snake River ESU	*Oncorhynchus nerka*	A	LE	None	G5T1Q/SX	1 - ex	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Chinook Salmon, Lower Columbia R. ESU	*Oncorhynchus tshawytscha*	A	LT	SC	G5T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Chinook Salmon, Upper Wilt. R spring run	*Oncorhynchus tshawytscha*	A	LT	None	G5T2Q/S2	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Chinook Salmon, Snake River Fall-run ESU	*Oncorhynchus tshawytscha*	A	LT	LT	G5T1Q/S1	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Chinook Salmon, Snake River Spr/Sum.run	*Oncorhynchus tshawytscha*	A	LT	LT	G5T1Q/S1	1	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Chinook Salmon, Upper Col. R. Spring-run	*Oncorhynchus tshawytscha*	A	LE	None	G5T1Q/SU	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Mountain Whitefish	*Prosopium williamsoni*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Sand Roller	*Percopsis transmontanus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Mosquitofish*	*Gambusia affinis*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	XX	N/A	N/A	N/A	N/A	N/A	N/A

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			Migratory	Federal	ODFW	ORNHP	ORNHP	Riparian	Habitat Type[8]							
Code[1]	Common Name	Genus/Species	Status[2]	Status[3]	Status[4]	Rank[5]	List[6]	Assn.[7]	WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
F	Three-spined Stickleback	*Gasterosteus aculeatus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Prickly Sculpin	*Cottus asper*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Reticulate Sculpin	*Cottus perplexus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Green Sunfish*	*Lepomis cyanellus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Pumpkinseed Sunfish*	*Lepomis gibbosus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Warmouth*	*Lepomis gulosus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Bluegill*	*Lepomis macrochirus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Smallmouth Bass*	*Micropterus dolomieu*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Largemouth Bass*	*Micropterus salmoides*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	X	N/A	N/A	N/A	N/A	N/A	N/A
F*	White Crappie*	*Pomoxis annularis*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Black Crappie*	*Pomoxis nigromaculatus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F*	Yellow Perch*	*Perca flavescens*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	X	N/A	N/A	N/A	N/A	N/A	N/A
F*	Walleye*	*Stizostedion vitreum vitreum*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
F	Starry Flounder	*Platichthys stellatus*	R	None	None	None	None	XX	XX	?	N/A	N/A	N/A	N/A	N/A	N/A
A	Northwestern Salamander	*Ambystoma gracile*	R	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
A	Long-toed Salamander	*Ambystoma macrodactylum*	R	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
A	Pacific Giant Salamander	*Dicamptodon tenebrosus*	R	None	None	None	None	XX			XX	X	X	X		X
A	Cope's Giant Salamander	*Dicamptodon copei*	R	None	SU	G3/S2	2	XX	X		XX	X				
A	Columbia Torrent Salamander	*Rhyacotriton kezeri*	R	None	SC	G3/S3	2	XX			XX	X				
A	Cascade Torrent Salamander	*Rhyacotriton cascadae*	R	None	SV	G3/S3	2	XX			XX	X				
A	Rough-skinned Newt	*Taricha granulosa*	R	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
A	Dunn's Salamander	*Plethodon dunni*	R	None	None	None	None	X			X	X	X			X
A	Western Red-backed Salamander	*Plethodon vehiculum*	R	None	None	None	None	X			X	X	X			X
A	Ensatina	*Ensatina eschscholtzii*	R	None	None	None	None	X			X	XX	X	X	X	X
A	Clouded Salamander	*Aneides ferreus*	R	None	SU	G3/S3	3					X	X		X	X
A	Oregon Slender Salamander	*Batrachoseps wrighti*	R	SoC	SU	G4/S3	1	X			X	X				
A	Western Toad	*Bufo boreas*	R	None	SV	G4/S4	4	XX	XX	XX	XX	X	X	X	X	X
A	Tailed Frog	*Ascaphus truei*	R	SoC	SV	G4/S3	2	XX			XX	X				
A	Pacific Chorus Frog (tree frog)	*Hyla regilla*	R	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
A	Northern Red-legged Frog	*Rana aurora aurora*	R	SoC	SV/SU	G4T4/S3	2	XX	XX	XX	XX	XX	X	X	X	X
(A)	(Oregon Spotted Frog - extirpated)	*Rana pretiosa*	R	C	SC	G2G3/S2	1	(XX)	(XX)	(XX)	(XX)	(X)	(X)	(X)	(X)	
A*	Bullfrog*	*Rana catesbeiana*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	XX	XX	X	X	X	X	X
R*	Common Snapping Turtle*	*Chelydra serpentina*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	XX	X				X	X
R	Painted Turtle	*Chrysemys picta*	R	None	SC	G5/S2	2	XX	XX	XX	X		X		X	X
R	Northwestern Pond Turtle	*Clemmys marmorata marmorata*	R	SoC	SC	G3T3/S2	1	XX	XX	XX	XX	X	XX	X	X	X
R*	Red-eared Slider*	*Trachemys scripta elegans*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	XX	X				X	X
R	Northern Alligator Lizard	*Elgaria coerulea*	R	None	None	None	None	X			X	X	X	X		X
R	Southern Alligator Lizard	*Elgaria multicarinata*	R	None	None	None	None	X			X	X	X	X	X	X
R	Western Fence Lizard	*Sceloporus occidentalis*	R	None	None	None	None					X	X	X	X	X

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Code[1]	Common Name	Genus/Species	Status[2]	Status[3]	Status[4]	Rank[5]	List[6]	Assn.[7]	WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
R	Western Skink	*Eumeces skiltonianus*	R	None	None	None	None					X	X	X	X	X
R	Rubber Boa	*Charina bottae*	R	None	None	None	None	X			X	X		X	X	X
R	Racer	*Coluber constrictor*	R	None	None	None	None						X	X	X	X
R	Sharptail Snake	*Contia tenuis*	R	None	SV	G5/S3	4	X			X	X	X	X	X	X
R	Ringneck Snake	*Diadophis punctatus*	R	None	None	None	None	X			X	X	X	X	X	X
R	Gopher Snake	*Pituophis catenifer*	R	None	None	None	None						X	X	X	X
R	Western Terrestrial Garter Snake	*Thamnophis elegans*	R	None	None	None	None	X		X	X		X	X	X	X
R	Northwestern Garter Snake	*Thamnophis ordinoides*	R	None	None	None	None	X			X	X	X	X	X	X
R	Common Garter Snake	*Thamnophis sirtalis*	R	None	None	None	None	XX		XX	XX	X	X	X	X	X
B	Red-throated Loon	*Gavia stellata*	W / M	None	None	None	None	XX			XX					
B	Pacific Loon	*Gavia pacifica*	W / M	None	None	None	None	XX			XX					
B	Common Loon	*Gavia immer*	W / M	None	None	None	None	XX	X	XX						
B	Pied-billed Grebe	*Podilymbus podiceps*	S / N	None	None	None	None	XX	X	XX	X					
B	Horned Grebe	*Podiceps auritus*	W / M	None	SP	G5/S2B, S5N	2	XX	XX	XX						
B	Eared Grebe	*Podiceps nigricollis*	W	None	None	None	None	XX	XX	XX						
B	Western Grebe	*Aechmophorus occidentalis*	W	None	None	None	None	XX	XX	XX						
B	Clark's Grebe	*Aechmophorus clarkii*	W / M	None	None	None	None	XX	XX	XX						
B	Doubled-crested Cormorant	*Phalacrocorax auritus*	R / S	None	None	None	None	XX	XX	X	X					X
B	American Bittern	*Botaurus lentiginosus*	S / N	None	None	None	None	XX		XX					X	
B	Great Blue Heron	*Ardea herodias*	R	None	None	None	None	XX	XX	XX	XX	X	X	X	XX	X
B	Great Egret	*Ardea alba*	W / M	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
B	Green Heron	*Butorides virescens*	N / S	None	None	None	None	XX	X	XX	XX					
B	Black-crowned Night Heron	*Nycticorax nycticorax*	S	None	None	None	None	XX	XX	XX	X					
(B)	(California Condor - extirpated)	*(Gymnogyps californianus)*	R	LE	None	G1SX	1-ex	(X)			(X)			(X)		
B	Turkey Vulture	*Cathartes aura*	N	None	None	None	None	X		X	X	X	X	X	X	X
B	Greater White-fronted Goose	*Anser albifrons*	W / M	None	None	None	None	XX	XX	XX					XX	
B	Snow Goose	*Chen caerulescens*	W / M	None	None	None	None	XX	XX	XX					XX	
B	Ross's Goose	*Chen rossii*	W / M	None	None	None	None	XX	XX	XX					XX	
B	Canada Goose	*Branta canadensis*	VARIABLE	None	None	None	None	XX	XX	XX	X				XX	
B	Dusky Canada Goose	*Branta canadensis occidentalis*	W / M	None	None	G5T2T3/ S2N	4	XX	XX	XX	X				XX	
B	Aleutian Canada Goose (wintering)	*Branta canadensis leucopareia*	W / M	LT	LE	G5T3/S2N	1	XX	XX	XX	X				XX	
B	Trumpeter Swan	*Cygnus buccinator*	W / M	None	None	None	None	XX	XX	XX					XX	
B	Tundra Swan	*Cygnus columbianus*	W / M	None	None	None	None	XX	XX	XX					XX	
B	Wood Duck	*Aix sponsa*	S	None	None	None	None	XX	XX	X	XX	X			X	
B	Gadwall	*Anas strepera*	W / M	None	None	None	None	XX	XX	XX				X	X	
B	Mallard	*Anas platyrhynchos*	R	None	None	None	None	XX	X	XX	XX				X	X
B	Eurasian Wigeon	*Anas penelope*	W / M	None	None	None	None	XX	XX	X					X	

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Code[1]	Common Name	Genus/Species	Status[2]	Status[3]	Status[4]	Rank[5]	List[6]	Assn.[7]	WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
B	American Wigeon	*Anas americana*	W / M	None	None	None	None	XX	X	XX	X				XX	
B	Blue-winged Teal	*Anas discors*	W / M	None	None	None	None	XX	X	XX				X	XX	
B	Cinnamon Teal	*Anas cyanoptera*	N	None	None	None	None	XX	X	XX				X	XX	
B	Northern Shoveler	*Anas clypeata*	W / M	None	None	None	None	XX	XX	XX				X	X	
B	Northern Pintail	*Anas acuta*	W / M	None	None	None	None	XX	XX	XX					X	
B	Green-winged Teal	*Anas crecca*	S	None	None	None	None	XX	X	XX	X			X	X	
B	Canvasback	*Aythya valisineria*	W / M	None	None	None	None	XX	XX	XX						
B	Redhead	*Aythya americana*	W / M	None	None	None	None	XX	XX	XX						
B	Ring-necked Duck	*Aythya collaris*	W / M	None	None	None	None	XX	X	X	XX					
B	Greater Scaup	*Aythya marila*	W / M	None	None	None	None	XX	XX							
B	Lesser Scaup	*Aythya affinis*	W / M	None	None	None	None	XX	XX	XX						
B	Surf Scoter	*Melanitta perspicillata*	W / M	None	None	None	None	X	X							
B	Harlequin Duck	*Histrionicus histrionicus*	W / M	SoC	SU	G4/S2B, S3N	2	XX	XX		XX					
B	Bufflehead	*Bucephala albeola*	W / M	None	SU	G5/S2B,S5N	4	XX	XX	XX	X					
B	Common Goldeneye	*Bucephala clangula*	M	None	None	None	None	XX	XX	X						
B	Barrow's Goldeneye	*Bucephala islandica*	W / M	None	SU	G5/S3B,S3N	4	XX	XX	X						
B	Hooded Merganser	*Lophodytes cucullatus*	W / M	None	None	None	None	XX	XX	X	XX	XX				
B	Common Merganser	*Mergus merganser*	W / M	None	None	None	None	XX	XX		XX	XX				
B	Red-breasted Merganser	*Mergus serrator*	W / M	None	None	None	None	X	X							
B	Ruddy Duck	*Oxyura jamaicensis*	W / M	None	None	None	None	XX	XX	XX						
B	Osprey	*Pandion haliaetus*	N	None	None	None	None	XX	XX		X	X	X		X	X
B	White-tailed Kite (appears to be undergoing range expansion)	*Elanus leucurus*	W / M	None	None	G5/S1B, S3N	2	X			X	X		X	XX	
B	Bald Eagle[a]	*Haliaeetus leucocephalus*	S	LT[a]	LT	G4/S3B, S4N	2	XX	XX	X	X	X	X	X	X	X
B	Northern Harrier	*Circus cyaneus*	N	None	None	None	None	X		X	X			X	X	X
B	Sharp-shinned Hawk	*Accipiter striatus*	N	None	None	None	None	X		X		X	X	X	X	X
B	Cooper's Hawk	*Accipiter cooperii*	S	None	None	None	None	X		X	X	X	X	X	X	X
B	Northern Goshawk	*Accipiter gentilis*	W / M	SoC	SC	G5/S3	2	X		X	X	X	X			
B	Red-shouldered Hawk (appears to be undergoing range expansion)	*Buteo lineatus*	?	None	None	None	None	X			X	X			X	
B	Red-tailed Hawk	*Buteo jamaicensis*	S / N	None	None	None	None	X		X	X	X	X	X	XX	X
B	Rough-legged Hawk	*Buteo lagopus*	W / M	None	None	None	None	X		X	X	X	X	X	X	X
B	American Kestrel	*Falco sparverius*	S	None	None	None	None	X		X	X	X	X	X	X	X
B	Merlin	*Falco columbarius*	W / M	None	None	G5/S1B	2	X	X	X	X	X	X	X	X	X
B	American Peregrine Falcon	*Falco peregrinus anatum*	N	None	LE	G4T3/S1B	2	X	X	X	X	X	X	X	X	X
B*	Ring-necked Pheasant*	*Phasianus colchicus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	X		X	X	X	X	XX	XX	X
B	Ruffed Grouse	*Bonasa umbellus*	R	None	None	None	None	XX			XX	XX	X		X	
B	Blue Grouse	*Dendragapus obscurus*	R	None	None	None	None	X			X	XX	X			

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B*	Wild Turkey*	*Meleagris gallopavo*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	X			X	X	X	X	X	X
(B)	(Mountain Quail - extirpated)	*Oreortyx pictus*	R / S	SoC	SU	G5/S4?	4	(X)			(X)	(X)	(X)		(X)	(X)
B	California Quail	*Callipepla californica*	R	None	None	None	None	X		X	X	X	X	X	X	X
B	Virginia Rail	*Rallus limicola*	R / S	None	None	None	None	XX		XX					X	
B	Sora	*Porzana carolina*	S / N	None	None	None	None	XX		XX					X	
B	American Coot	*Fulica americana*	R / S	None	None	None	None	XX	XX	XX					X	X
B	Lesser Sandhill Crane	*Grus canadensis*	W / M	None	None	None	None	XX		XX					XX	
B	Black-bellied Plover	*Pluvialis squatarola*	M	None	None	None	None	X	X						XX	
B	American Golden-plover	*Pluvialis dominica*	W / M	None	None	None	None	X	X						XX	
B	Semipalmated Plover	*Charadrius semipalmatus*	M	None	None	None	None	XX	XX						X	
B	Killdeer	*Charadrius vociferus*	S / N	None	None	None	None	X		X	X	X	X	X	XX	X
B	Greater Yellowlegs	*Tringa melanoleuca*	W / M	None	None	None	None	XX	XX	XX	X			X	X	
B	Lesser Yellowlegs	*Tringa flavipes*	W / M	None	None	None	None	XX	XX	XX	X			X	X	
B	Solitary Sandpiper	*Tringa solitaria*	W / M	None	None	None	None	XX	XX	XX	XX			X	X	
B	Spotted Sandpiper	*Actitis macularia*	N	None	None	None	None	XX	X	X	XX				X	
B	Semipalmated Sandpiper	*Calidris pusilla*	W / M	None	None	None	None	XX	XX							
B	Western Sandpiper	*Calidris mauri*	W / M	None	None	None	None	XX	XX	XX					X	
B	Least Sandpiper	*Calidris minutilla*	W / M	None	None	None	None	XX	X	XX					X	
B	Baird's Sandpiper	*Calidris bairdii*	W / M	None	None	None	None	XX	X	XX					X	
B	Pectoral Sandpiper	*Calidris melanotos*	W / M	None	None	None	None	XX	X	XX					X	
B	Dunlin	*Calidris alpina*	W / M	None	None	None	None	XX	XX	XX					XX	
B	Short-billed Dowitcher	*Limnodromus griseus*	W / M	None	None	None	None	X		X					X	
B	Long-billed Dowitcher	*Limnodromus scolopaceus*	W / M	None	None	None	None	XX	X	XX					XX	
B	Common Snipe	*Gallinago gallinago*	S / N	None	None	None	None	XX		XX				X	XX	
B	Wilson's Phalarope	*Phalaropus tricolor*	W / M	None	None	None	None	XX	X	X						
B	Red-necked Phalarope	*Phalaropus lobatus*	W / M	None	None	None	None	X	X							
B	Bonaparte's Gull	*Larus philadelphia*	M / W	None	None	None	None	XX	X						X	X
B	Mew Gull	*Larus canus*	W / M	None	None	None	None	XX	XX						X	X
B	Ring-billed Gull	*Larus delawarensis*	W / M	None	None	None	None	XX	XX	X					X	X
B	California Gull	*Larus californicus*	S	None	None	None	None	XX	XX	X					X	X
B	Herring Gull	*Larus agentatus*	W / M	None	None	None	None	XX	XX	X					X	X
B	Thayer's Gull	*Larus thayeri*	W / M	None	None	None	None	XX	XX	X					X	X
B	Western Gull	*Larus occidentalis*	R / S	None	None	None	None	X	X							XX
B	Glaucous Gull	*Larus hyperboreus*	W / M	None	None	None	None	XX	XX	X						X
B	Glaucous-winged Gull	*Larus glaucescens*	W / M	None	None	None	None	XX	X							XX
B	Caspian Tern	*Sterna caspia*	N	None	None	None	None	XX	XX	XX						
B	Forster's Tern	*Sterna forsteri*	M	None	None	None	None	XX	XX	XX						

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			Migratory	Federal	ODFW	ORNHP	ORNHP	Riparian	Habitat Type[8]							
Code[1]	Common Name	Genus/Species	Status[2]	Status[3]	Status[4]	Rank[5]	List[6]	Assn.[7]	WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
B	Common Tern	*Sterna hirundo*	W / M	None	None	None	None	X	X							
B*	Rock Dove*	*Columba livia*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien							X	XX	XX
B	Band-tailed Pigeon	*Columba fasciata*	S	SoC	None	G5/S4	4	XX			XX	XX	XX		X	X
B	Mourning Dove	*Zenaida macroura*	S	None	None	None	None	XX			XX	X	X	X	XX	X
B	Barn Owl	*Tyto alba*	R / S	None	None	None	None	X		X	X		X	X	XX	X
B	Western Screech-Owl	*Otus kennicottii*	R	None	None	None	None	X		X	X	X	X		X	X
B	Great Horned Owl	*Bubo virginianus*	R	None	None	None	None	X		X	X	X	X	X	X	X
B	Northern Pygmy-Owl	*Glaucidium gnoma*	R	None	SC	G5/S4?	4	X		X	X	XX	X		X	X
(B)	(Northern Spotted Owl - extirpated from Metro region)	*(Strix occidentalis caurina)*	(S)	LT	LT	G3T3S3	1					(XX)	(X)			
B	Barred Owl	*Strix varia*	R	None	None	None	None	X			X	XX	X			X
B	Long-eared Owl	*Asio otus*	W / M	None	None	None	None	X		X		X	X	X	X	
B	Short-eared Owl	*Asio flammeus*	W / M	None	None	None	None	XX		XX				X	XX	
B	Northern Saw-whet Owl	*Aegolius acadicus*	R / S	None	None	None	None	X			X	XX	XX		X	X
B	Common Nighthawk (nearly extirpated)	*Chordeiles minor*	N	None	SC	G5/S5	4	X	X	X	X	X	X	X	X	X
B	Vaux's Swift	*Chaetura vauxi*	N	None	None	None	None	XX	XX	X	X	X	X	X		X
B	Anna's Hummingbird	*Calypte anna*	R	None	None	None	None	X			X	XX	X			X
B	Rufous Hummingbird	*Selasphorus rufus*	N	None	None	None	None	X		X	X	X	X	X	X	X
B	Belted Kingfisher	*Ceryle alcyon*	S	None	None	None	None	XX	XX		XX					
B	Lewis's Woodpecker (extirpated as breeding species)	*Melanerpes lewis*	W / M	SoC	SC	G5/S3B, S3N	4	X			X		XX	X	X	X
B	Acorn Woodpecker	*Melanerpes formicivorus*	R	SoC	None	G5/S3?	4						XX	X		X
B	Red-breasted Sapsucker	*Sphyrapicus ruber*	S	None	None	None	None	X			X	X	X	X	X	X
B	Downy Woodpecker	*Picoides pubescens*	R	None	None	None	None	XX			XX	X	X		X	X
B	Hairy Woodpecker	*Picoides villosus*	R	None	None	None	None	X			X	X	X	X	X	X
B	Northern Flicker	*Colaptes auratus*	R	None	None	None	None	X			X	X	X	X	X	X
B	Pileated Woodpecker	*Dryocopus pileatus*	R	None	SV	G5/S4?	4	X			X	X	X		X	X
B*	Monk Parakeet*	*Myiopsitta monachus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX			XX		X		X	XX
(B)	(Yellow-billed Cuckoo; extirpated)	*Coccyzus americanus*	N	SoC	SC	G5/S1B	2	(XX)			(XX)					
B	Olive-sided Flycatcher	*Contopus cooperi (= borealis)*	N	SoC	SV	G5/S4	4	X			X	XX				
B	Western Wood-Pewee	*Contopus sordidulus*	N	None	None	None	None	X			X	X	X		X	X
B	Willow Flycatcher (western OR race)	*Empidonax traillii brewsteri*	N	None	SV	G5TU/S1B	4	XX			XX	X	X		X	X
B	Hammond's Flycatcher	*Empidonax hammondii*	N	None	None	None	None					X	X			
B	Dusky Flycatcher	*Empidonax oberholseri*	M	None	None	None	None	X			X	X	X			
B	Pacific-slope Flycatcher	*Empidonax dificilus*	N	None	None	None	None	X			X	XX	X			
B	Say's Phoebe	*Sayornis saya*	N	None	None	None	None							X	X	X
B	Western Kingbird	*Tyrannus verticalis*	N	None	None	None	None						X	X	X	X
B	Northern Shrike	*Lanius excubitor*	W / M	None	None	None	None	X		X				X	XX	

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Code[1]	Common Name	Genus/Species	Status[2]	Status[3]	Status[4]	Rank[5]	List[6]	Assn.[7]	WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
B	Cassin's Vireo	*Vireo cassinii*	N	None	None	None	None					X	XX			X
B	Hutton's Vireo	*Vireo huttoni*	R / S	None	None	None	None	X			X	X	XX		X	X
B	Warbling Vireo	*Vireo gilvus*	N	None	None	None	None	XX			XX	XX	X		X	X
B	Red-eyed Vireo	*Vireo olivaceus*	N	None	None	None	None	XX			XX	X				
B	Steller's Jay	*Cyanocitta stelleri*	R	None	None	None	None	X			X	X	X		X	X
B	Western Scrub-Jay	*Aphelocoma californica*	R	None	None	None	None	X			X	X	XX	X	X	X
B	Gray Jay	*Perisoreus canadensis*	R	None	None	None	None	X			X	X	X			X
B	American Crow	*Corvus brachyrhynchos*	R	None	None	None	None	X		X	X	X	X	X	XX	XX
B	Common Raven	*Corvus corax*	R	None	None	None	None	X		X	X	X	X	X	X	X
B	Streaked Horned Lark	*Eremophila alpestris strigata*	S	SoC	SC	G5T2/S2?	2							XX	X	X
B	Purple Martin	*Progne subis*	N	SoC	SC	G5/S3B	2	XX	XX	X	X	X	X	X		X
B	Tree Swallow	*Tachycineta bicolor*	N	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
B	Violet-green Swallow	*Tachycineta thalassina*	N	None	None	None	None	X	X	X	X	X	X	X	X	X
B	Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	N	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
B	Cliff Swallow	*Petrochelidon pyrrhonota*	N	None	None	None	None	XX	XX	X	XX	X	X	X	X	X
B	Barn Swallow	*Hirundo rustica*	N	None	None	None	None	XX	XX	XX	XX	X	X	X	XX	X
B	Black-capped Chickadee	*Poecile atricapilla*	R	None	None	None	None	X		X	X	X	X	X	X	X
B	Mountain Chickadee	*Poecile gambeli*	W / M	None	None	None	None	X			X	X	X			X
B	Chestnut-backed Chickadee	*Poecile rufescens*	R	None	None	None	None	X			X	X	X		X	X
B	Bushtit	*Psaltriparus minimus*	R	None	None	None	None	X			X	X	X		X	X
B	Red-breasted Nuthatch	*Sitta canadensis*	R	None	None	None	None	X			X	X	X		X	X
B	White-breasted Nuthatch	*Sitta carolinensis*	R	None	None	None	None	X			X		X	X	X	X
B	Brown Creeper	*Certhia americana*	R	None	None	None	None	X			X	X	X	X	X	X
B	Bewick's Wren	*Thryomanes bewickii*	R	None	None	None	None	X		X	X	X	X		X	X
B	House Wren	*Troglodytes aedon*	N	None	None	None	None	X			X	X	X	X	X	X
B	Winter Wren	*Troglodytes troglodytes*	R	None	None	None	None	X			X	X	X			X
B	Marsh Wren	*Cistothorus palustris*	N	None	None	None	None	XX		XX						
B	American Dipper	*Cinclus mexicanus*	R / S	None	None	None	None	XX	XX	X	XX					
B	Golden-crowned Kinglet	*Regulus satrapa*	R	None	None	None	None	X			X	XX	X			X
B	Ruby-crowned Kinglet	*Regulus calendula*	W / M	None	None	None	None	X		X	X	X	X	X	X	X
B	Western Bluebird	*Sialia mexicana*	S	None	SV	G5/S4B, S4N	4					XX	XX	X	X	X
B	Townsend's Solitaire	*Myadestes townsendi*	W / M	None	None	None	None	X			X	X	X		X	X
B	Swainson's Thrush	*Catharus ustulatus*	N	None	None	None	None	X			X	X	X		X	X
B	Hermit Thrush	*Catharus guttatus*	S	None	None	None	None	X			X	X	X		X	X
B	American Robin	*Turdus migratorius*	S	None	None	None	None	X		X	X	X	X	X	X	X
B	Varied Thrush	*Ixoreus naevius*	W / M	None	None	None	None					XX	X		X	X
B*	European Starling*	*Sturnus vulgaris*	R / S	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX		X	XX	X	X	X	X	XX

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Code[1]	Common Name	Genus/Species	Status[2]	Status[3]	Status[4]	Rank[5]	List[6]	Assn.[7]	WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
B	American Pipit	*Anthus rubescens*	W / M	None	None	None	None	X		X				X	XX	
B	Cedar Waxwing	*Bombycilla cedrorum*	S	None	None	None	None	X		X	X	X	X		X	X
B	Orange-crowned Warbler	*Vermivora celata*	N	None	None	None	None	X			X	X	X	X	X	X
B	Nashville Warbler	*Vermivora ruficapilla*	N	None	None	None	None	X			X	X	X		X	
B	Yellow Warbler	*Dendroica petechia*	N	None	None	None	None	XX			XX					
B	Yellow-rumped Warbler	*Dendroica coronata*	S	None	None	None	None	X		X	X	X	X		X	X
B	Black-throated Gray Warbler	*Dendroica nigrescens*	N	None	None	None	None	XX			XX	XX	XX		X	X
B	Townsend's Warbler	*Dendroica townsendi*	S / N	None	None	None	None	X			X	X	X		X	X
B	Hermit Warbler	*Dendroica occidentalis*	N	None	None	None	None	X			X	XX	X			
B	MacGillivray's Warbler	*Oporornis tolmiei*	N	None	None	None	None	X			X	X	X		X	
B	Common Yellowthroat	*Geothlypis trichas*	N	None	None	None	None	XX		XX	XX	X	X	X		X
B	Wilson's Warbler	*Wilsonia pusilla*	N	None	None	None	None	XX			XX	XX	X		X	X
B	Yellow-breasted Chat	*Icteria virens*	N	SoC	SC	G5/S4?	4	XX			XX	X	X		X	
B	Western Tanager	*Piranga ludoviciana*	N	None	None	None	None	X			X	XX	XX			X
B	Spotted Towhee	*Pipilo maculatus*	R	None	None	None	None	X			X	X	XX		X	X
B	Chipping Sparrow	*Spizella passerina*	N	None	None	None	None	X			X	X	X	X	X	X
B	Oregon Vesper Sparrow	*Pooecetes gramineus affinis*	S / N	SoC	SC	G5T3/S2B, S2N	2							XX	XX	
B	Savannah Sparrow	*Passerculus sandwichensis*	S / N	None	None	None	None	X		X	X			XX	XX	X
B	Fox Sparrow	*Passerella iliaca*	W / M	None	None	None	None	X			X	X	X		X	X
B	Song Sparrow	*Melospiza melodia*	R	None	None	None	None	X		X	X	X	X	X	X	X
B	Lincoln's Sparrow	*Melospiza lincolnii*	S / N	None	None	None	None	XX		XX	XX	X			X	
B	Swamp Sparrow	*Melospiza georgiana*	W / M	None	None	None	None	XX		XX	XX				X	
B	White-throated Sparrow	*Zonotrichia albicollis*	W / M	None	None	None	None								X	X
B	Harris's Sparrow	*Zonotrichia querula*	W / M	None	None	None	None								X	X
B	White-crowned Sparrow	*Zonotrichia leucophrys*	S	None	None	None	None	X		X	X	X	X	X	X	X
B	Golden-crowned Sparrow	*Zonotrichia atricapilla*	R	None	None	None	None	X		X	X	X	X	X	X	X
B	Dark-eyed Junco	*Junco hyemalis*	S	None	None	None	None	X			X	X	X		X	X
B	Black-headed Grosbeak	*Pheucticus melanocephalus*	N	None	None	None	None	X			X	X	X		X	X
B	Lazuli Bunting	*Passerina amoena*	N	None	None	None	None	X			X	X	X	X	XX	X
B	Red-winged Blackbird	*Agelaius phoeniceus*	S	None	None	None	None	XX		XX	X			X	X	X
B	Tricolored Blackbird	*Agelaius tricolor*	S	SoC	SP	G3/S2B	2	XX		XX					X	
B	Western Meadowlark (extirpated as breeding species)	*Sturnella neglecta*	W / M	None	SC	G5/S5	4	X		X				XX	XX	
B	Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	N	None	None	None	None	XX		XX					X	
B	Brewer's Blackbird	*Euphagus cyanocephalus*	S	None	None	None	None	X		X	X		X	X	XX	X
B	Brown-headed Cowbird	*Molothrus ater*	S / N	None	None	None	None	X		X	X	X	X	X	XX	X
B	Bullock's Oriole	*Icterus bullockii*	N	None	None	None	None	XX			XX		XX		X	X

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B	Purple Finch	*Carpodacus purpureus*	S	None	None	None	None	XX			XX	X	XX		X	X
B	House Finch	*Carpodacus mexicanus*	R	None	None	None	None	X		X	X	X	X	X	XX	XX
B	Red Crossbill	*Loxia curvirostra*	R / S	None	None	None	None	X			X	X	X			X
B	Pine Siskin	*Carduelis pinus*	S	None	None	None	None	X		X	X	X	X		X	X
B	Lesser Goldfinch	*Carduelis psaltria*	S	None	None	None	None	XX			XX	X	XX	X	X	X
B	American Goldfinch	*Carduelis tristis*	S	None	None	None	None	X		X	X	X	X	X	X	X
B	Evening Grosbeak	*Coccothraustes vespertinus*	W / M	None	None	None	None	X			X	X	X			X
B*	House Sparrow*	*Passer domesticus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien								XX	XX
M*	Virginia Opossum*	*Didelphis virginiana*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	X			X	X	X	X	XX	XX
M	Vagrant Shrew	*Sorex vagrans*	R	None	None	None	None	X		X	X	X	X	X	X	X
M	Pacific Water Shrew	*Sorex bendirii*	R	None	None	None	None	XX		X	XX	X	X			
M	Water Shrew	*Sorex palustris*	R	None	None	None	None	XX			XX	X				
M	Trowbridge's Shrew	*Sorex trowbridgii*	R	None	None	None	None	X			X	XX	X		X	X
M	Shrew-mole	*Neurotrichus gibbsii*	R	None	None	None	None	X		X	X	XX	X		X	X
M	Townsend's Mole	*Scapanus townsendii*	R	None	None	None	None	X		X	X	X	X	X	X	X
M	Coast Mole	*Scapanus orarius*	R	None	None	None	None	X			X	XX	X	X	X	X
M	Yuma Myotis	*Myotis yumanensis*	R / S	SoC	None	G5/S3	4	XX	XX	XX	XX	X	X	X	X	X
M	Little Brown Myotis	*Myotis lucifugus*	R / S	None	None	None	None	X	X	X	X	X	X	X	X	X
M	Long-legged Myotis	*Myotis volans*	R / S	SoC	SU	G5/S3	4	X	X	X	X	XX	X	X	X	X
M	Fringed Myotis	*Myotis thysanodes*	R / S	SoC	SV	G4G5/S2?	2	X	X	X	X	X	X		X	X
M	Long-eared Myotis	*Myotis evotis*	R / S	SoC	SU	G5/S3	4	X	X	X	X	X	X	X	X	X
M	Silver-haired Bat	*Lasionycteris noctivagans*	L	SoC	SU	G5/S4?	4	X	X	X	X	XX	X	X	X	X
M	Big Brown Bat	*Eptesicus fuscus*	R / S	None	None	None	None	X	X	X	X	X	XX	X	XX	XX
M	Hoary Bat	*Lasiuris cinereus*	L	None	None	G5/S4?	4	X	X	X	X	X	X	X	X	X
M	Pacific Western Big-eared Bat	*Corynorhinus townsendii townsendii*	R / S	SoC	SC	G4T3T4/S2?	2	XX	XX	X	X	X	X	X	X	X
M	Brush Rabbit	*Sylvilagus bachmani*	R	None	None	None	None	X			X	X	X	X	X	X
M*	Eastern Cottontail*	*Sylvilagus floridanus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	X			X				X	X
M	Mountain Beaver	*Aplodontia rufa*	R	None	None	None	None	XX			XX	XX				
M	Townsend's Chipmunk	*Tamias townsendii*	R	None	None	None	None	X			X	XX	X			X
M	California Ground Squirrel	*Spermophilus beecheyi*	R	None	None	None	None					X	X	X	X	X
M*	Eastern Fox Squirrel*	*Sciurus niger*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien							XX	XX	XX
M*	Eastern Gray Squirrel*	*Sciurus carolinensis*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien						XX		X	XX
M	Western Gray Squirrel	*Sciurus griseus*	R	None	SU	G5/S4?	3					X	XX		X	X
M	Douglas' Squirrel	*Tamiasciurus douglasii*	R	None	None	None	None		XX	XX	X					
M	Northern Flying Squirrel	*Glaucomys sabrinus*	R	None	None	None	None	X			X	XX	XX			X
(M)	(Western pocket gopher)	*(Thomomys mazama)*	(R)	None	None	None	None					(XX)	(XX)	(X)	(X)	(X)
M	Camas Pocket Gopher	*Thomomys bulbivorus*	R	SoC	None	G3G4/S3 S4	3							XX	XX	X

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M	American Beaver	*Castor canadensis*	R	None	None	None	None	XX	XX	XX	XX	X	X		X	X
M	Deer Mouse	*Peromyscus maniculatus*	R	None	None	None	None	XX		XX	XX	XX	XX	XX	XX	XX
M	Bushy-tailed Woodrat	*Neotoma cinerea*	R	None	None	None	None	X			X	XX	XX		XX	X
M	Western Red-backed Vole	*Clethrionomys californicus*	R	None	None	None	None	X			X	X				
M	Heather Vole	*Phenacomys intermedius*	R	None	None	None	None	X			X		X			
M	White-footed Vole	*Arborimus (= Phenacomys) albipes*	R	SoC	SU	G3G4/S3	4	XX			XX	XX				
M	Red Tree Vole	*Arborimus (= Phenacomys) longicaudus*	R	SoC	None	G3G4/S3S4	3	X			X	XX	XX			
M	Gray-tailed Vole	*Microtus canicaudus*	R	None	None	None	None							XX	XX	
M	Townsend's Vole	*Microtus townsendii*	R	None	None	None	None	XX		XX	X	X	X	X	X	
M	Long-tailed Vole	*Microtus longicaudus*	R	None	None	None	None	XX		XX	XX	X	X	X	X	
M	Creeping Vole	*Microtus oregoni*	R	None	None	None	None	X			X	X	X	X	X	X
M	Water Vole	*Microtus richardsoni*	R	None	None	None	None	X			X	X				
M	Common Muskrat	*Ondatra zibethicus*	R	None	None	None	None	XX	XX	XX	XX				X	X
M*	Black Rat*	*Rattus rattus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien								X	XX
M*	Norway Rat*	*Rattus norvegicus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien								X	XX
M*	House Mouse*	*Mus musculus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien								XX	XX
M	Pacific Jumping Mouse	*Zapus trinotatus*	R	None	None	None	None	XX		X	XX	X	X		X	
M	Common Porcupine	*Erethizon dorsatum*	R	None	None	None	None	XX		X	XX	XX	XX		X	X
M*	Nutria*	*Myocastor coypus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	XX	XX	XX	XX				X	X
M	Coyote	*Canis latrans*	R	None	None	None	None	X		X	X	X	X	X	X	X
M	Red Fox	*Vulpes vulpes*	R	None	None	None	None	X			X	X	X	XX	X	X
M	Gray Fox	*Urocyon cinereoargenteus*	R	None	None	None	None	X			X	XX	X	X	X	
(M)	(Gray Wolf - extirpated)	*(Canis lupus)*	S	None	None	None	None	(X)			(X)	(X)	(X)	(X)		
M	Black Bear	*Ursus americanus*	S	None	None	None	None	X		X	X	X	X	X	X	X
(M)	(Grizzly Bear)	*(Ursus arctos)*	(R)	LT	None	G4/SX	2-ex	(X)			(X)	(X)		(X)		
M	Common Raccoon	*Procyon lotor*	R	None	None	None	None	XX	X	XX	XX	X	X	X	XX	XX
M	Ermine	*Mustela erminea*	R	None	None	None	None	X			X	X	X	X	X	
M	Long-tailed Weasel	*Mustela frenata*	R	None	None	None	None	X		X	X	X	X	X	X	X
M	Mink	*Mustela vison*	R	None	None	None	None	XX	XX	XX	XX	X	X	X	X	X
M	Striped Skunk	*Mephitis mephitis*	R	None	None	None	None	X		X	X	X	X	X	X	X
M	Western Spotted Skunk	*Spilogale gracilis*	R	None	None	None	None	X			X	X	X	X	X	X
M	Northern River Otter	*Lontra canadensis*	R	None	None	None	None	XX	XX	XX	XX					X
M	Mountain Lion (Cougar)	*Puma concolor*	S	None	None	None	None	X		X	X	X	X		X	X
M	Bobcat	*Lynx rufus*	S	None	None	None	None	X		X	X	X	X	X	X	X
M*	Domestic Cat (feral)*	*Felis domesticus*	R	N/A - alien	N/A - alien	N/A - alien	N/A - alien	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
M	California Sea Lion	*Zalophus californianus*	S	None	None	None	None	XX	XX							

Appendix 1. Species list and habitat associations for species normally occurring within the Metro region. Study area is the Metro jurisdictional boundary plus 1 mile buffer, plus UGB study areas.

			Migratory	Federal	ODFW	ORNHP	ORNHP	Riparian	Habitat Type[8]							
Code[1]	Common Name	Genus/Species	Status[2]	Status[3]	Status[4]	Rank[5]	List[6]	Assn.[7]	WATR	HWET	RWET	WLCH	WODF	WEGR	AGPA	URBN
M	Roosevelt Elk	*Cervus elaphus roosevelti*	S	None	None	None	None	X		X	X	X	X	X	X	X
(M)	(Columbian White-tailed Deer)	*(Odocoileus virginiana leucurus)*	(R)	LE	SV	G5T2QS2	1	(X)		(X)	(X)	(X)	(XX)	(X)	(X)	(X)
M	Mule Deer	*Odocoileus hemionus*	R	None	None	None	None	X		X	X	X	X	X	X	X
[a] Bald eagle is currently proposed for de-listing at the federal level.																
I:\gm\long_range_planning\Goal 5\Goal 5 report revision\Science Review\Current Chapters & appxs\Appx 1 Species list - Verts.doc																

Appendix 2. Review of key findings of urban stream studies examining the relationship of urbanization on stream quality.

Reference	Location	Biological Parameter	Key Finding
Benke, Willeke, Parrish and Stites 1981	Atlanta	Aquatic insects	Negative relationship between number of insect species and urbanization in 21 streams
Black and Veatch 1994	Maryland	Fish/insects	Fish, insect and habitat scores were all ranked as poor in 5 subwatersheds that were greater than 30% TIA
Booth 1991	Seattle, WA	Fish habitat / channel stability	Channel stability and fish habitat quality declined rapidly after 10% TIA
Booth et al. 1996	Washington	Aquatic habitat	There is a decrease in the quantity of large woody debris found in urban streams at around 10% TIA
Couch et al. 1997	Atlanta, Georgia	Fish, habitat	As watershed population density increased, there was a negative impact on urban fish and habitat
Crawford & Lenat 1989	North Carolina	Aquatic insects and fish	A comparison of three stream types found urban streams had lowest diversity and richness
Galli 1991	Maryland	Stream temperature (aquatic habitat)	Stream temperature increased directly with subwatershed impervious cover
Galli 1994	Maryland	Brown trout	Abundance and recruitment of brown trout declined sharply at 10-15% TIA
Garie and McIntosh 1986	New Jersey	Aquatic insects	Drop in insect taxa from 13 to 4 noted in urban streams
Hicks and Larson 1997	Connecticut	Aquatic insects	A significant decline in various indicators of wetland aquatic macroinvertebrate community health was observed as TIA increased to levels of 8-9%
Horner et al. 1996	Puget Sound, Washington	Insects, fish, water quality, riparian zone	Steepest decline of biological functioning after 6% TIA. There was a steady decline, with approximately 50% of initial biotic integrity at 45% TIA
Jones and Clark 1987	Northern Virginia	Aquatic insects	Urban streams had sharply lower diversity of aquatic insects when human population density exceeded 4 persons/acre (estimated 10-25% TIA)
Jones et al. 1996	Northern Virginia	Aquatic insects and fish	Unable to show improvements at 8 sites downstream of BMPs as compared to reference conditions
Klein 1979	Maryland	Aquatic insects/fish	Macroinvertebrate and fish diversity declines rapidly after 10% TIA
Limburg and Schmidt 1990	New York	Fish spawning	Resident and anadromous fish eggs and larvae declined sharply in 16 tributary streams greater than 10% TIA
Luchetti and Fuersteburg 1993	Seattle	Fish	Marked shift from less tolerant coho salmon to more tolerant cutthroat trout populations noted at 10-15% TIA at 9 sites
MacRae 1996	British Columbia	Stream channel stability (aquatic habitat)	Urban stream channels often enlarge their cross-sectional area by a factor of 2 to 5. Enlargement begins at relatively low levels of TIA.
Maxted and Shaver 1996	Delaware	Aquatic insects and habitat	No significant differences in biological and physical metrics for 8 BMP sites versus 31 sites without BMPs (with varying TIA)
May et al. 1997	Washington	Insects, fish, water quality, riparian zone	Physical and biological stream indicators declined most rapidly during the initial phase of the urbanization process as the TIA exceeded the 5-10% range
MWCOG 1992	Washington, D.C.	Aquatic insects and fish	There was a significant decline in the diversity of aquatic insects and fish at 10% TIA
Pedersen and Perkins 1986	Seattle	Aquatic insects	Macroinvertebrate community shifted to chironomid, oligochaetes and amphipod species tolerant of unstable conditions.

Appendix 2 (continued)

Reference	Location	Biological Parameter	Key Finding
Pedersen and Perkins 1986	Seattle	Aquatic insects	Macroinvertebrate community shifted to chironomid, oligochaetes and amphipod species tolerant of unstable conditions.
Richards et al. 1993	Minnesota	Aquatic insects	As watershed development levels increased, the macroinvertebrate community diversity decreased
Schueler and Galli 1992	Maryland	Fish	Fish diversity declined sharply with increasing TIA; loss in diversity began at 10-12% TIA
Schueler and Galli 1992	Maryland	Aquatic insects	Insect diversity metrics in 24 subwatersheds shifted from good to poor over 15% TIA
Shaver, Maxted, Curtis and Carter 1995	Delaware	Aquatic insects	Insect diversity at 19 stream sites dropped sharply at 8 to 15% TIA.
Shaver, Maxted, Curtis and Carter 1995	Delaware	Habitat quality	Strong relationship between insect diversity and habitat quality; majority of 53 urban streams had poor habitat
Steedman 1988	Ontario	Aquatic Insects	Strong negative relationship between biotic integrity and increasing urban land use/riparian condition at 209 stream sites. Degradation begins at about 10% TIA
Steward 1983	Seattle	Salmon	Marked reduction in coho salmon population noted at 10-15% TIA at 9 sites
Taylor 1993	Seattle	Wetland plants / amphibians	Mean annual water fluctuation was inversely correlated to plant and amphibian density in urban wetlands. Sharp declines noted over 10% TIA
Taylor et al. 1995	Washington	Wetland water quality	There is a significant increase in water level fluctuation, conductivity, fecal coliform bacteria, and total phosphorus in urban wetlands as TIA exceeds 3.5%
Trimble 1997	California	Sediment loads (aquatic habitat)	About 2/3 of sediment delivered into urban streams comes from channel erosion
U.S. EPA 1983	National	Water quality / pollutant concentration	Annual phosphorus, nitrogen, and metal loads increased in direct proportion with increasing TIA
Weaver 1991	Virginia	Fish	As watershed development increased to about 10%, fish communities simplified to more habitat and trophic generalists
Yoder 1991	Ohio	Aquatic insects / fish	100% of 40 urban sites sampled had fair to very poor index of biotic integrity scores

Sources: Schueler 1994, Caraco et al. 1998

APPENDIX 3.

SOCIETY FOR ECOLOGICAL RESTORATION

Guidelines for Developing and Managing Ecological Restoration Projects

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June 24, 2000

The following guidelines are suggested for conceiving, organizing, conducting, and assessing ecological restoration projects. Adherence to these guidelines will reduce errors of omission and commission that compromise project quality. The guidelines are applicable to any ecosystem, terrestrial or aquatic. They are useful in any context – public works projects, stewardship programs, mitigation projects, private land initiatives, etc. The guidelines are generic and were developed as essential background for managers, policy makers, and the interested public as well as for professional and volunteer restoration practitioners. Design issues and the details for planning and implementing restoration projects lie beyond the scope of these guidelines. We leave such complexities to the authors of manuals and the presenters of workshops who address these topics.

The mission of every ecological restoration project is to reestablish a functional ecosystem of a designated type that contains sufficient biodiversity to continue its maturation by natural processes and to evolve over longer time spans in response to changing environmental conditions. The two attributes of biodiversity that are most readily attained by restoration are species richness and community structure. The restoration ecologist must assure adequate species composition and species abundance to allow the development of suitable community structure and to initiate characteristic ecosystem processes. Concomitantly, the restorationist must provide appropriate physical conditions to sustain these species.

If restoration cannot be fully achieved, then the project should be re-designed as *rehabilitation*, which we define as any ecologically beneficial treatment short of full restoration. Management actions that cause ecological damage do not qualify as restoration. Unfortunately, *restoration* is applied inappropriately to projects that sacrifice biodiversity and impair ecological functions to accomplish single-species management or to attain economic objectives. Continued indiscriminate use will cause *ecological restoration* to lose its meaning as a creditable conservation strategy. Restoration projects can accommodate particular species and can satisfy economic objectives as long as ecosystem integrity is not compromised.

Once a project site is restored, it may require periodic management, as do many other natural areas, to maintain ecosystem health in response to continuing human-mediated impacts. These guidelines do not address post-project management specifically, although some of the guidelines are readily adaptable for that purpose.

The project guidelines are numbered for convenience; they do not necessarily have to be initiated in numerical order. We recommend that a narrative be written in response to the issues raised in each guideline. Collectively, these narratives will comprise a comprehensive guidance document for planning and executing the project.

CONCEPTUAL PLANNING

Conceptual planning identifies the reasons why restoration is needed and the general strategy for conducting it. Conceptual planning is conducted when restoration appears to be a feasible option but before a decision has been made to exercise that option. The written conceptual plan captures the essence and character of the potential restoration.

1. Identify the project site location and its boundaries. Project boundaries are delineated, preferably on a large-scale aerial photograph and also on soil and topographic maps that show the watershed and other aspects of the surrounding landscape.

2. Identify ownership. The name and address of the landowner is given. If an organization or institution owns or manages the land, the names and titles of key personnel are listed. The auspices under which the project will be conducted are noted – public works, mitigation, etc.

3. Identify the need for restoration. Tell what happened at the site that warrants restoration. State the intended benefits of restoration.

4. Identify the kind of ecosystem to be restored and the type of restoration project. The ecosystem to be restored is designated along with any particular habitats and plant or animal communities of that ecosystem that are targeted for restoration. The type of restoration is selected from the following list of five options. It is important to make this initial distinction to avoid misunderstandings later. Restoration projects at diverse project sites may include more than one of these options:

1) *Repair of a damaged ecosystem.* This option attempts to return a site to its historic or preexisting condition. Commonly a few minor aspects of the preexisting ecosystem cannot be fully restored. These should be identified and accepted as exceptions. Restoration work takes place at the same site where damage occurred. Such restoration has been termed *in-kind* (the historic type of ecosystem is restored) and *onsite* (restoration occurs at the same location where the historic ecosystem was damaged). Restoration with respect to the following four options is not necessarily *on-site*, and some are not *in-kind*.

2) *Creation of a new ecosystem of the same kind to replace one that was entirely removed.* The term *creation* signifies that the restored ecosystem must be entirely reconstructed on a site denuded of its vegetation (terrestrial systems) or its benthos (aquatic systems). Creations are commonly conducted on surface mined lands and in brownfields (severely damaged urban and industrial lands).

3) *Creation of another kind of regional ecosystem to replace one which was removed from a landscape that became irreversibly altered.* This option is important for restoring natural areas in an urban context where, for example, original hydrologic conditions cannot be restored.

4) *Creation of a replacement ecosystem where an altered environment can no longer support any previously occurring type of regional ecosystem.* The replacement ecosystem may consist of novel combinations of indigenous species that are assembled to suit novel site conditions as, for example, at a retired solid waste disposal site.

5) *Creation of a replacement ecosystem, because no reference system exists to serve as a model for restoration.* This option is relevant in densely populated regions of Eurasia, where many centuries of land use have obliterated all remnants of original ecosystems.

5. Identify restoration goals, if any, that pertain to social and cultural values. Goals are the ideals that a restoration project attempts to achieve. Goals relating to social and cultural values may be prescribed as long as they are congruent with the primary goal of reestablishing a functional ecosystem that contains sufficient biodiversity to continue its maturation by natural processes and to evolve over longer time spans in response to changing environmental conditions. Social values are largely economic. They may consist of the production of goods such as timber, forage, and fisheries at restored sites. Or they may comprise natural services including the protection of recharge areas and potable water supplies, detention of floodwaters, attenuation of erosion and sedimentation, noise reduction, immobilization of contaminants, transformation of excess nutrients, generation of pollinators for crops, generation of predators of crop pests, and provision of recreational opportunities and consequent tourism. They can also conserve germ plasm of economic species and serve as refugia for wildlife and for rare species. Cultural values include aesthetic amenities and the revival of historical environments as aspects of preserving cultural heritage. If the goal is to restore a fixed cultural landscape, then the project may have to be re-designated as rehabilitation.

6. Identify physical site conditions in need of repair. Some examples of conditions that are amenable to restoration are improvements in water quality, removal of structures to reestablish a more natural hydrologic regime, and improvements to the soil in terms of compaction, organic matter content, and nutrient content.

7. Identify stressors in need of regulation or re-initiation. Stressors are re-occurring external conditions that maintain the integrity of an ecosystem by discouraging the establishment of competitive species that cannot tolerate particular stress events. Examples are fires, anoxia caused by flooding or prolonged hydroperiods, periodic drought, salinity shocks associated with tides and coastal aerosols, freezing temperatures, and unstable substrates caused by water, wind or gravity as on beaches, dunes, and flood plains.

8. Identify biotic interventions that are needed. Some characteristic species of plants and animals may require reintroduction or their existing populations need to be augmented. Nuisance species and exotic species may require removal or control. Mycorrhizal fungi, N-fixing bacteria, and other microbial species may need to be introduced.

9. Identify landscape restrictions, present and future. The biota at a project site is affected by off-site conditions, particularly land usage. Restoration should not be attempted in landscapes that can no longer support the kind of ecosystem designated for restoration or which will likely be compromised later by the effects of land usage offsite. To the extent possible, future threats to the integrity of the restored ecosystem should be minimized by mechanisms such as zoning or binding commitments from neighboring landowners.

Some aquatic ecosystem restoration depends entirely on improving the watershed, and all restoration work is accomplished offsite. Examples of impacts from offsite include water pollution, turbidity, and agricultural runoff. The hydrologic regime in any project site can be altered offsite by dams, drainage projects, diversions of runoff caused by highways and other public works, and by the impervious surfaces characteristic of developed land. Water tables are lowered by transpiration from trees and are raised, sometimes dramatically, by timber harvest. Fire frequency is reduced by intentional suppression and by landscape fragmentation that interrupts the cover of flammable vegetation. Exotic species colonization onsite is commonly traced to infestations offsite. The presence or abundance of birds and other mobile animals depends on the health of other ecosystems in the landscape upon which they partially depend.

10. Identify project-funding sources. Potential external funding sources should be listed if internal funding is inadequate.

11. Identify labor sources and equipment needs. New personnel may have to be hired, volunteers invited, and other labor contracted. The availability of special equipment must be determined.

12. Identify biotic resource needs. Biotic resources include seeds, other plant propagules, nursery-grown planting stocks, and animals for establishment at the project site.

13. Identify the need for securing permits required by government agencies. Dredge and fill permits may be required for tasks involving rivers and wetlands. Other permits may be applicable for the protection of endangered species, historic sites, etc.

14. Identify permit specifications, deed restrictions, and other legal constraints. If restoration is being conducted as mitigation, compliance with permit specifications must be incorporated into the restoration plan or re-negotiated. Restrictive covenants and zoning regulations may preclude certain restoration activities. Legal restrictions on ingress and egress could prevent some restoration tasks from being accomplished. If the restoration is being placed under conservation easement, the timing of the easement must be satisfied.

15. Identify project duration. Short-term restoration projects are generally more costly than longer-term projects. The longer the project, the more the practitioner can rely on natural processes and volunteer labor to accomplish specific restoration objectives that are identified below in Guideline #27. In accelerated restoration programs such as mitigation projects, costly interventions must substitute for these natural processes.

16. Identify strategies for long-term protection and management. Restoration is futile without reasonable assurance that the project site will be protected and properly managed into the indefinite future. Protection could be secured with conservation easements or the legal transfer of the property to a public resource agency or non-governmental organization.

PRELIMINARY TASKS

Preliminary tasks are those upon which project planning depends. These tasks form the foundation for well-conceived restoration designs and programs. Preliminary tasks are fulfilled after conceptual planning results in the decision to proceed with the restoration project.

17. Appoint a restoration ecologist who is responsible for technical aspects of restoration. Restoration projects are complex, require the coordination of diverse activities, and demand numerous decisions owing in part to the stochastic nature of ecological processes. For these reasons, leadership should be vested in an individual who maintains overview of the entire project and who has the authority to act quickly and decisively. The restoration ecologist may delegate specific tasks but retains the ultimate responsibility for the attainment of objectives. Nonetheless, restoration responsibilities are sometimes divided according to the organizational charts of larger corporations and government bureaus. Pluralistic leadership augments the potential for errors in project design and implementation. In mitigation projects, agency personnel become silent co-partners with the restoration ecologist when they mandate particular restoration activities as permit specifications. This practice reduces the restoration ecologist's capacity for flexibility and innovation, including the prompt implementation of adaptive management actions. The preparation of a written guidance document, based upon responses to these guidelines, will help promote the judicious execution of the restoration project in cases of pluralistic leadership and in negotiating permit specifications with government agencies.

18. Appoint the restoration team. The team includes the restoration ecologist, the project manager, other technical personnel who may contribute to the project, and anyone else whose input will critically affect the project. It is essential that the responsibilities of each individual are clearly assigned and that each person be given concomitant authority. The restoration ecologist and the project manager should maintain open lines of communication. If restoration is one component of a larger project, the restoration ecologist should enjoy equal status with other project planners to prevent actions that could compromise restoration quality or inflate costs.

19. Prepare a budget to accommodate the completion of preliminary tasks. Time and resources as well as funding need to be allocated for these tasks.

20. Document existing project site conditions and describe the biota. Project evaluation depends in part upon being able to contrast the project site before and after restoration. Properly labeled and archived photographs are fundamental. Camera locations should be recorded, so that before and after photos can be compared. Videotapes, aerial photographs, and oblique aerial photos from a low-flying aircraft are helpful. Soils and other physical site conditions should be described. To the extent possible, species composition should be listed and species abundance estimated. The structure of all component communities should be described in sufficient detail to permit objective means of evaluating the performance of projects subsequent to their implementation.

21. Document the project site history that led to the need for restoration. The years in which impacts occurred should be recorded. Historical aerial photos are helpful. Disturbance features should be photographed.

22. Conduct pre-project monitoring as needed. Sometimes it is useful or requisite to obtain baseline measurements on such parameters as water quality and groundwater levels for a year or more prior to initial project installation. If so, these measurements will continue after the project begins as part of the monitoring program.

23. Gather baseline ecological information and conceptualize a reference ecosystem from it upon which the restoration will be modeled and evaluated. The kind of ecosystem that has been selected for restoration must be described in sufficient detail to develop restoration objectives and to serve as a comparison for evaluating the completed restoration project. Documentation of the pre-project site conditions (Guideline #20) may contribute substantially to the reference. Generally, no one site contains the range of variability that is representative of the ecosystem designated for restoration. Therefore, the reference system should be conceptualized from the collective attributes of several sites. These attributes should include both the biotic and abiotic (physical) components. They should include seral (developmental) descriptions, because a comparison between an ecologically young restoration site and a mature reference system requires assumptions that are difficult to substantiate. The description of the reference system can be the citation of existing documents, a report of baseline ecological studies conducted by the restoration team, or a combination thereof.

24. Gather pertinent autecological information for key species. The restoration ecologist should have access to whatever knowledge is available regarding the recruitment, maintenance, and reproduction of key species. If necessary, trials and tests can be conducted by the restoration team prior to project installation.

25. Conduct investigations as needed to assess the effectiveness of restoration methods. Novel and unusual restoration methods may require testing prior to their implementation at the project site.

26. Decide if ecosystem goals are realistic or if they need modification. On the basis of information gained from carrying out the aforementioned guidelines, the project team should conduct a feasibility study to determine if the type of restoration (Guideline #4) and the original project goals (Guideline #5) were realistic. If not, modifications should be proposed.

27. Prepare a list of objectives designed to achieve restoration goals. Objectives are the specific activities to be undertaken for the satisfaction of project goals. The restoration ecologist should list all objectives needed to achieve each project goal. Objectives may be executed directly through the establishment of project features or passively through suitable project design. In either case, objectives are explicit, measurable, and have a designated time element. Objectives can cover a wide array of specific actions. They may be hydrological, e.g., the filling of a drainage ditch to improve sheet flow; pedological, e.g., the amendment of organic matter to improve soil texture; or biological, e.g., the prompt removal of a particular exotic species that threatens ecosystem integrity. Other objectives may pertain to re-introducing fire according to a specific prescription, removing an abandoned road, or establishing a windbreak. Certain objectives may require actions that take place offsite to improve conditions onsite. Some restoration projects can be accomplished with one or few objectives. For example, perhaps all that is needed is to install culverts beneath a road to improve drainage, assuming the vegetation can recover passively.

28. Secure permits required by regulatory and zoning authorities. These are the permits identified in guidelines #13 and #14.

29. Establish liaison with other interested governmental agencies. Potential interested agencies should be notified of the project. Later, site tours can be conducted for agency personnel and progress reports dispatched to them. This networking could expedite assistance, should it become needed.

30. Establish liaison with the public and publicize the project. Local residents automatically become stakeholders in the restoration. They need to know how the restored ecosystem can benefit them personally. For example, the restoration may attract ecotourism that will benefit local businesses, or it may serve as an environmental education venue for local schools. If residents favor the restoration, they will protect it and vest it with their political support. If they dislike the restoration, they may vandalize or otherwise disrespect it.

31. Arrange for public participation in project planning and implementation. The restoration team should make every effort to involve local residents or other interested members of the public to participate in project planning and installation. By doing so, the participants develop a feeling of ownership, and they will be more likely to assume a stewardship role for the completed project. Volunteer labor by local residents or by ecotourists may reduce overall project costs. However, such labor requires coordination, special supervision, and additional liability insurance.

32. Install roads and other infrastructure needed to facilitate project implementation. The degree to which infrastructure is provided should be weighed against the costs of down time caused by its absence and against considerations of safety and opportunities for public relations tours.

33. Engage and train personnel who will supervise and conduct project installation tasks. Project personnel who lack restoration experience or knowledge of particular methods will benefit from attending workshops and conferences that provide background information. Otherwise, the restoration ecologist should provide training.

INSTALLATION PLANNING

Installation plans describe how the project will be implemented, i.e., project design. The care and thoroughness with which installation planning is conducted will be reflected by how aptly project objectives are realized.

34. Describe the interventions that will be implemented to attain each objective. The restoration ecologist should identify all actions and treatments needed to accomplish each objective listed in Guideline #27. Detailed instructions are prepared for implementing each of these interventions. Concomitantly, the needs for labor, equipment, supplies, and biotic stocks are identified.

Restoration projects should be designed to reduce the need for mid-course corrections that inflate costs and cause delays. Special care should be given to describing site preparation activities, i.e., those interventions that precede the introduction of biotic resources. Once biotic resources are introduced, it may become exceedingly difficult to repair dysfunctional aspects of the physical environment.

Some interventions can be accomplished concurrently and others must be done in sequence. The need for sequencing should be clearly identified. Some restoration activities require follow-up activities or continuing periodic maintenance following installation. These tasks are predictable and can be written into the implementation plans under their respective objectives. Examples of maintenance tasks include the repair of erosion on freshly graded land and the removal of competitive weeds and vines from around young plantings.

35 State how much of the restoration can be accomplished passively. Restoration tasks initiate or accelerate natural processes. Nearly all manifestations of restoration are accomplished by these processes and not by the direct artifice of the restorationist. For example, a small quantity of plants may be introduced as nursery stock with the expectation that these plants will propagate and increase substantially in density. Many restoration projects make no provision for introducing species of animals. The assumption is that, 'if we build it, they will come.' The restoration plan should acknowledge those aspects that are expected to develop passively, i.e., without intervention. If passive restoration is not realized, then additional interventions must be prescribed (see Guideline #47).

36. Prepare performance standards and monitoring protocols to measure the attainment of each objective. A performance standard (also called a design_criterion) provides evidence on whether or not an objective has been attained. This evidence is gathered by monitoring in accord with a prescribed protocol or methodology. Performance standards require careful selection for their power to measure the completion of an objective. Monitoring tells the restoration ecologist to what degree a given objective has been attained. It is essential that performance standards and monitoring protocols be selected prior to any project installation activity. Otherwise, the objectivity of the performance standard will be compromised by the initial results of installation. Monitoring protocols must be geared specifically to performance standards. Other information is extraneous and inflates project costs. Monitoring protocols should be designed so that data are readily gathered, thereby reducing monitoring costs. They should be empirical to facilitate their objective interpretation.

37. Schedule the tasks needed to fulfill each objective. Scheduling can be complex. Planted nursery stock may have to be contract-grown months or longer in advance of planting and must be delivered in prime condition. Older, root-bound stocks are generally worthless. If direct seeding is prescribed, seed collecting sites will have to be identified. The seed must be collected when ripe, possibly stored, and perhaps pre-treated. Site preparation for terrestrial systems cannot be scheduled when conditions are unsuitable. For example, soil manipulations cannot be accomplished if flooding is likely,_and prescribed burning must be planned and conducted in accordance with applicable fire codes. The availability of labor and equipment can further complicate scheduling. Workdays may have to be shortened for safety during especially hot weather and in lightening storms. Wet weather may cause equipment to bog down. Schedules should reflect these eventualities.

Most objectives are implemented within the first or second year of installation. Some objectives may have to be delayed. For example, the re-introduction of plants and animals with specialized habitat requirements may have to be postponed several years until habitat conditions become suitable.

38. Procure equipment, supplies, and biotic resources. Care should be taken to assure that regional ecotypes of biotic resources are obtained to increase the chances for genetic fitness and to prevent needless and harmful introductions of non-indigenous ecotypes and species.

39. Prepare a budget for installation tasks, maintenance events, and contingencies. Budgeting for planned objectives is obvious. However, budgeting for unknown contingencies is just as important. No restoration project has ever been accomplished exactly as it was planned. Restoration is a multivariate undertaking, and it is impossible to account for all eventualities. Examples of contingencies are severe weather events, depredations of deer and other herbivores on a freshly planted site, colonization by invasive species, vandalism, and unanticipated events elsewhere in the landscape that impact the project site. The need to conduct at least some remediation is a near certainty. Generally, the cost of remediation increases in relation to the time it takes to respond after its need is discovered. For these reasons, contingency funds should be available on short notice.

INSTALLATION TASKS

Project installation fulfills installation plans. If planning was thorough and supervision adequate, installation will generally proceed smoothly and within budget.

40. Mark boundaries and secure the project area. The project site should be staked or marked conspicuously in the field. Fencing and fire lanes should be installed as needed. This guideline is sometimes ignored until it results in a contingency, such as a neighbor's cattle escaping into a freshly planted project site.

41. Install monitoring features. Permanent transect lines, staff gauges, piezometer wells, etc., need to be installed and marked.

42. Implement restoration objectives. Restoration tasks were identified in Guideline #34. The restoration ecologist must supervise project installation or delegate supervision to project team members. Responsibility for proper implementation should not be entrusted to subcontractors, volunteers, and labors crews who are doing the work. The cost of retrofitting exceeds the cost of appropriate supervision.

POST-INSTALLATION TASKS

The attainment of objectives may depend as much on follow-up activities as it does to the care given to initial installation activities. The importance of post-installation work cannot be overemphasized.

43. Protect the project site against vandals and herbivory. Project sites attract dirt bike riders, feral swine, deer, geese, nutria, etc. Beaver can destroy a newly planted site by plugging streams and culverts. Appropriate preventive actions should be taken.

44. Perform post-implementation maintenance. Conduct maintenance activities that were described in Guideline #34.

45. Reconnoiter the project site regularly to identify needs for mid-course corrections. The restoration ecologist needs to inspect the project site frequently, particularly during the first year or two following an intervention, to schedule maintenance as needed and to react promptly to contingencies.

46. Perform monitoring as required to document the attainment of performance standards. Measurements of water levels and certain water quality parameters are generally conducted on a regular schedule. Otherwise, monitoring should not be required until monitoring data will be meaningful for decision-making. Monitoring and the reporting of monitoring data are expensive. Regular reconnaissance (Guideline #45) negates the need for frequent monitoring.

47. Implement adaptive management procedures as needed. Adaptive management as a restoration strategy is essential, because what happens at one stage in restoration dictates what needs to happen next. A restoration plan must contain built-in flexibility. If reconnaissance or monitoring reveal that objectives are not being met, then alternative interventions may have to be attempted. The project manager should realize that restoration objectives may never be realized for reasons that lie beyond the control of the restoration ecologist. If so, then new goals (Guideline #5) and objectives (Guideline #27) may have to be adopted if a functional ecosystem is to be returned to the project site.

EVALUATION

The installation of a project does not guarantee that its objectives will be attained or its goals achieved. Restoration differs from most civil engineering projects for which the results are more predictable. Restored ecosystems are dynamic and require evaluation within the context of an indefinite temporal dimension.

48. Assess monitoring data to determine if performance standards are being met. If performance standards are not being met within a reasonable period of time, refer to Guideline #47.

49. Describe aspects of the restored ecosystem that are not covered by monitoring data. This description should commence when project work has been essentially completed. The description should compliment the documentation that was conducted prior to the initiation of restoration activities (Guideline #20) to allow before and after comparisons.

50. Determine if project goals were met, including those for social and cultural values. Based on monitoring data and other documentation (Guidelines #46, #49), evaluate the restoration with respect to its project goals. These will include the primary goal to restore a functional ecosystem that emulates the reference ecosystem at a comparable ecological age (Guideline #4). They will also include any secondary goals with respect to social and cultural values (Guideline #5).

51. Publish an account of the restoration project and otherwise publicize it. Publicity and documentation should be incorporated into every restoration project for the following reasons: Published accountings are fundamental for instituting the long-term protection and stewardship of a completed project site. Policy makers and the public need to be appraised of the fiscal and resource costs, so that future restoration projects can be planned and budgeted appropriately. Restoration ecologists improve their craft by becoming familiar with how restoration objectives were accomplished.

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Appendix 4.

Selected restoration activities and potential indicators of the effects of management activities, based on ecosystem function. Please read the Restoration chapter and take note of cautionary advice regarding planning and implementing restoration activities in an urban setting, particularly instream modifications.

Function or Value	Selected Potential Restoration Activities	Some Potential Indicators of Management Activity Effects
Water quality (sediment filtering, nutrient/pollutant filtering, erosion control and stream bank stability)	• Increase riparian and upland vegetation (especially woody vegetation) in watershed • Vegetative filter strips (VFS) • Control sediment inputs through BMPs and regulatory measures • Promote development of healthy soils through native plant communities (increases soil retention and filtering capacity) • Limit development and impervious surfaces near stream • Remove or modify sewer outfalls • Artificial wetlands (bioswales and water detention structures) • Public education to keep toxins out of storm drains • Reduce or eliminate industrial discharges • Promote alternatives to pesticides and chemical fertilizers • Promote passage of more water through wetlands and undeveloped floodplains • Retain/increase springs, seeps and wetlands • Increase late summer flows	• Benthic index of biological integrity (B-IBI) (Booth 1991; Spence et al. 1996; Karr and Chu 2000; Booth et al. 2001) • Piezometers or small wells to test groundwater and hyporheic water quality (Fernald et al. 2000) • Water quality tests such as temperature, sediment/turbidity, pH, dissolved oxygen, conductivity, nitrogen and phosphorus, herbicides/pesticides, suspended/floating matter, trash loading, odor, and chemical contamination (National Marine Fisheries Service 1996; Spence et al. 1996; FIRSWG 1998; Hollenback and Ory 1999) • Percent catchment in various types of vegetation and wetland cover (Spence et al. 1996) • Total impervious area, effective impervious area, or road density and location (National Marine Fisheries Service 1996; Schueler 1994; May et al. 1997b) • Intergravel dissolved oxygen in sites where fine particulate organic matter is present (Spence et al. 1996)
Microclimate and shade	• Terrestrial: reduce microclimatic edge effects by addressing size, shape of habitat patches • Aquatic: provide vegetative shade over stream • Terrestrial and aquatic: increase forest width	• Terrestrial: measures of air temperature, relative humidity, soil moisture and temperature, solar radiation, and wind speed (Spence et al. 1996; Saunders et al. 1999; Gehlhausen et al. 2000; Laurance et al. 2000) • Aquatic: water temperature (Budd et al. 1987; Beschta et al. 1988)
Sources of stream flow and flood storage (hydrology)	• Reduce impervious surfaces in watershed • Remove or modify sewer outfalls • Add riparian and upland vegetation; increase riparian forest width • Reconnect streams to floodplain • Retain/increase springs, seeps and wetlands (sources of cold water) • Allow channel meanders • Limit development near stream • Control water inputs artificially to mimic natural conditions • Protect natural and create new detention ponds to detain increased peak runoff • Groundwater recharge (increases late summer flows) • Dam removal/modification to more closely mimic natural flow regime	• B-IBI (urban land cover correlates equally well in Pacific Northwest with B-IBI at subbasin, riparian, and local scales) (Booth 1991; Spence et al. 1996; Karr and Chu 2000; Booth et al. 2001) • Hydrographs (historic vs present) and stream gauges (Brookes 1987; Hollenbach & Ory 1999) • Annual and interannual streamflow patterns such as T_{qmean}, $T_{0.5}$ yr and CV_{AMF}, quality and timing of peak and low flows (Spence et al. 1996; Booth et al. 2001) • Channel scour (Spence et al. 1996) • Discharge (Spence et al. 1996) • Width/depth ratio, streambank condition, floodplain

Function or Value	Selected Potential Restoration Activities	Some Potential Indicators of Management Activity Effects
	• Reintroduce/allow beaver (increases water storage) • Increase late summer flows	connectivity, change in peak/base flows, increase in drainage network (National Marine Fisheries Service 1996)
Organic materials	• Increase native vegetation, particularly in riparian areas (although note that small mammals and amphibians require woody debris, thus this should also be addressed in uplands) • In riparian areas, increase conifer:hardwood ratio (large wood from coniferous trees lasts longer instream) • Increase stream connectivity with and ecological integrity of floodplain (floodplain delivers organic materials to stream and riparian areas during flood events) • Addition of fish carcasses to stream	• Measure woody debris and leaf litter or retention time of same (relatively straightforward; Webster and Meyer 1997) • Measure instream nutrient retention time, nutrient spiraling, nutrient cycling (relatively complex; Allan 1995; Cederholm et al. 2000; Cederholm et al. 2001) • GIS: measure forest width and conifer:hardwood ratio or amount and types of vegetative cover (Schueler 1994; Xiang 1996)
Channel dynamics	• Reconnect isolated habitats (instream and terrestrial) • Use a variety of methods (TIA reduction, forest canopy increase, sediment control) to modify flow and sediment regimes to resemble undisturbed conditions • Reduce stream crossings • Control sediment inputs • Remove or modify fish passage barriers • Road removal or alteration • Structural additions (large wood, boulders) • Bank stabilization (vegetation plantings, gabion structures, etc.) • Fencing to avoid livestock grazing • Rest-rotation or grazing strategy • Conifer conversion • Dam removal/modification • Addition of large wood, boulders	• Benthic index of biological integrity (Spence et al. 1996; Karr and Chu 2000; Booth et al. 2001) • Fish-IBI (Regier et al. 1989) • Fraction of bed sediment below a threshold size (measures potentially lethal reductions in permeability allowing flow of oxygenated water to substrate) (Booth et al. 2001) • Cross section and bankfull channel boundary measurements, flood stage surveys, width-to-depth ratios, rates of bank or bed erosion (FIRSWG 1998; Prichard 1998) • Relative Bed Stability Index (Olsen et al. 1997, from Booth et al. 2001) • Riparian forest width measures (Spence et al. 1996) • Channel sinuosity measures (Spence et al. 1996) • Connectivity measures (aerial photography or fragmentation program such as FRAGSTATS) (FIRSWG 1998; FRAGSTATS available at http://www.umass.edu/landeco/research/fragstats/fragstats.html)
Habitat and connectivity	• Reconnect isolated habitats • Consider habitat patch size and shape • Increase native canopy and shrub cover • Control invasive and nonnative plants • Add water sources for wildlife • Plant food resources for wildlife • Manage to increase instream and terrestrial large woody debris • Introduce controlled fire regime to mimic natural disturbances • Improve fish passage	• Bird and wildlife use (FIRSWG 1998) • Large woody debris, instream and terrestrial (Beschta 1979; Dooley and Paulson 1988; FIRSWG 1988; Booth et al. 1997) • Riparian-dependent birds (Spence et al. 1996; Bureau of Land Management 2001) • Aerial photography (FIRSWG 1998) • B-IBI (Booth 1991; Spence et al. 1996; Karr and Chu 2000; Booth et al. 2001) • Sensitive fish (e.g., salmonids) (Spence et al. 1996) • Presence of area-sensitive species (needing large habitat patches) (Keller et al. 1993; Hodges and Krementz 1996; Wenger 1999) • Instream habitat elements: substrate, large woody debris,

Function or Value	Selected Potential Restoration Activities	Some Potential Indicators of Management Activity Effects
		pool frequency and quality, off-channel habitat, and refugia; % road crossings with inadequate culverts, % unscreened diversions, % impassable dams, frequency of off-channel habitats and LWD in riparian zone (National Marine Fisheries Service 1996; Spence et al. 1996) • Terrestrial habitat elements: percent vegetative cover, species density, size and age class distribution, planting survival and reproductive vigor (FIRSWG 1998) • Physical barriers such as culverts (National Marine Fisheries Service 1996) • Nonnative species (Spence et al. 1996) • % riparian zone within 100 m with natural riparian woody plants (Spence et al. 1996) • Beaver sign (Spence et al. 1996)
Reducing human disturbance	• Reduce edge effects • Reduce road effects • Limit trails (especially paved) in large habitat patches for Neotropical migratory birds, which are disturbance-sensitive • Reduce nonnative species through direct removal and/or habitat manipulations • Preserve endangered habitats and habitats critical to endangered species	• Presence, abundance, diversity of sensitive species, or sensitive species index such as B-IBI or Neotropical migratory breeding bird surveys (Spence et al. 1996; Karr and Chu 2000; Booth et al. 2001; Moore et al. 1993; Friesen et al. 1995; Nilon et al. 1995; Theobald et al. 1997; Mancke and Gavin 2000; Hennings 2001; Hennings and Edge 2003) • Bird nesting success studies and studies on associated predators (Small and Hunter 1988; Marzluff et al. 1998; Heske et al. 2001) • Vegetation surveys (Hennings 2001; Hennings and Edge 2003; Roni et al. 2002) • Recreational use surveys (FIRSWG 1998)