# COOPERATIVE MONITORING EVALUATION AND RESEARCH 04-406

Pacific Northwest Forested Wetland
Literature Survey Synthesis Paper

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**SUBMITTED BY COOKE SCIENTIFIC SERVICES, INC.**
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# Pacific Northwest Forested Wetland Literature Survey Synthesis Paper

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Prepared by:


Css
Cooke Scientific Services Inc.
4231 NE 110th St.
Seattle, WA 98125
Phone: (206) 695-2267
Fax: (206) 368-5430
Cookescientific.com

# Forested Wetland Literature Review, Literature Synthesis and Workshop Project

**Project Goal:** To perform a literature review and synthesis of relevant forested wetland research with an emphasis on interactions of commercial forest management activities and forested wetland functions emphasizing topics listed in the WDNR Forests and Fish Report (WDNR 1999). This review and synthesis contains scientific information relevant to forested wetland functions in the Pacific Northwest with emphasis on the interaction of forest management activities and forest wetland functions. We have limited our coverage of riparian areas as that information will be addressed by The Riparian Science Advisory Group. A companion-annotated bibliography has been produced that includes references utilized in this paper and related supporting documents.

### Authors List


| | |
|---|---|
| Sarah Spear Cooke | Cooke Scientific Services, Inc. |
| Gretchen Herron | Cooke Scientific Services, Inc. |
| Esther Howard | Cooke Scientific Services, Inc. |
| Suzanne Tomassi | Cooke Scientific Services, Inc. |
| Scott Rozenbaum | Rozewood Consulting |


### Reviewers
### WETSAG committee

| | |
|---|---|
| Richard Bigley | Washington Department of Natural Resources |
| Heather Cole | Washington Department of Natural Resources |
| Marc Hayes | Washington Department of Fish and Wildlife |
| Jessica Josephs | Rayonier, Inc. |
| Andy McMillan | Washington Department of Ecology |
| Dave Parks | Washington Department of Natural Resources, |
| Dawn Pucci | Suquamish Tribe |
| Ralph Rogers | U.S. Environmental Protection Agency |
| Jill Silver | 10,000 Years Institute |

### Scientific Review Committee

| | |
|---|---|
| CMER Technical | University of Washington Review Panel |
| Kern Ewing | University of Washington, College of Forest Resources |
| Blake Rowe | Longview Fiber Company |

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# I. Introduction

## *A. Summary of Washington Forest Practices Rules/Forests and Fish Report*

The Washington Forest practices rules (WAC 222) describe the existing policy and regulatory framework defining and regulating forest practices in forested wetlands in the state of Washington. These rules include current definitions of forested wetlands and the methods for delineating wetlands (Washington Forest practices Board Manual). Washington Forest practices rules also include a process of adaptive management for the evaluation of the efficacy of existing rules, with respect to resource conditions, and for the adjustment of the rules by using science-based recommendations and technical information (WAC 222-08-035 and WAC 222-12-045).

The Adaptive Management Program was created to provide science-based recommendations and technical information to assist the Washington Forest practices Board in determining if and when it is necessary or advisable to adjust rules and guidance for aquatic resources to achieve resource goals and objectives [WAC 222-12-045 (1)(2)].

A component of the adaptive management program is the establishment of key questions relating to resource objectives and aquatic resources, including “an assessment of the functions served by forested wetlands and the potential impacts of harvest activities in forested wetlands” To facilitate the investigation of key questions relating to wetlands, a wetland scientific advisory group (WETSAG) was established to advise the Cooperative Monitoring Evaluation and Research (CMER) committee regarding wetland issues. The WETSAG objectives are primarily intended to:

- further define the functions of forested wetlands
- revise the wetland classification system based on wetland functions
- evaluate the regeneration and recovery capacity of forested wetlands and Wetland Management Zones
- determine the relationship between the shading of wetlands and the surface and subsurface water temperatures in wetlands and associated streams

## *B. Goals and Products of this Study*

The purpose of this document is to compile scientific information relating to forested wetlands and the impacts of forest management from existing literature, databases, and regional experts into a single-source publication. This will serve as the basis for decision-making and for identifying future research areas that test specific hypotheses regarding the efficacy of current forest practices rules, with respect to the linkages between commercial forest practices and forested wetland functions in Washington State.

The final products of this study include an annotated bibliography, a forested wetland workshop (and workshop materials, including a video and PowerPoint presentations), in addition to this literature review and synthesis of relevant forested wetland-related research and timber management practices in forested wetlands of the Pacific Northwest (PNW). In all these products, emphasis is placed on the interaction between commercial forest management activities and forested wetland functions in the PNW, including characterization of forested wetlands, a discussion of forest practices, and a characterization of timber management effects on PNW forested wetlands. A summary of remarks from the forested wetland workshop are included as an Appendices A, B, and C in this paper.

***Important note:*** *This paper is limited in scope to an evaluation of forested wetlands other than those that lie within currently regulated riparian management zones and as such, does not cover floodplain wetlands or any topic more specifically related to riparian forests (including use by fish and recruitment of large woody debris). A separate working group, the Riparian Scientific Advisory Group (RSAG) is tasked with evaluating effects of current forest practices on riparian and floodplain forests and associated wetlands that lie within these zones. This paper is expected to complement topics covered by the RSAG committee.*

*WETSAG recognizes fish use of stream-associated forested wetlands as a topic important to forest practices as well as an important ecological function. There exists a considerable body of literature related to riverine forested floodplains and their use by aquatic and terrestrial organisms. In fact, because wetlands are an expression of hydrological connectivity between upland water sources and streams, some stream-associated wetlands may extend beyond riparian management zones as currently defined or delineated. We regret the constraints and limitations placed on us by the artificial portioning of the hydrologic continuum, but accept that these topics are outside the scope of this paper. The dearth of literature regarding fish use of smaller stream-associated and headwater wetlands was noted in this review, and resulted in an abbreviated section related to this topic.*

## *C. The Literature May Not Adequately Address Forested Wetlands*

A common theme in the literature examining both forested wetland functions and characterization and the impacts of timber harvest in forested wetlands is the lack of relevant, current, and detailed information. As the reader proceeds with this paper, it will become clear how little is either known or documented about certain aspects of these valuable habitats. Much of our knowledge is included in the category “generally accepted” and has not been documented in peer-reviewed journals or books. We have, therefore, included some information that is apparent to practitioners of a particular area of expertise, but has not been documented specifically for PNW forested habitats. We include qualifiers in these instances to ensure the reader understands this information should be further investigated.

The final section of this paper, “Chapter VII: Research Needed,” is a compilation of the apparent knowledge gaps, including recommendations for additional research. Of particular interest, but lacking when this paper was written, is direct information regarding fish and wildlife use of forested wetlands or of large woody debris (LWD) recruitment specifically in forested wetland systems. While there is a large body of general and related information on both these topics, there is little work that is forested wetland–specific, or that separates forested wetlands from the forests in which they occur. The authors acknowledge this gap, and we hope this information is being investigated and will be available in the near future. Additionally, because other advisory groups are dealing with these issues, it was decided that general information on these subjects would not be covered in the present paper.

The reader should understand that forested wetlands contain a unique set of attributes including the presence of water, high humidity, thermal attenuation of climatic extremes, and often increased diversity of vegetation types as compared to less complex upland and emergent wetland communities. These attributes may provide refugia for many species of plants and animals. Forested wetlands have rarely been separated out of riparian or upland habitats for study.

# II. Temperate Forested Wetlands, General Characteristics—What is Known

## *A. Forested Wetlands Characterization*

Forested wetlands are defined under the current Forest practices Rules as "any wetland or portion thereof that has, or if the trees were mature would have, a crown closure of 30 percent or more" (WAC 222-16-035 (2)), and that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions such as swamps, bogs, fens, and similar areas. This includes wetlands created, restored, or enhanced as part of a mitigation procedure. This does not include constructed wetlands or the following surface waters of the state intentionally constructed from wetland sites: Irrigation and drainage ditches, grass lined swales, canals, agricultural detention facilities, farm ponds, and landscape amenities (WAC 222-16-010).

Forested wetlands, as classified according to Cowardin et al. (1979), include coniferous, deciduous, and mixed coniferous/deciduous types of wetlands. These also include peatlands (bogs and fens) in cool, moisture-rich boreal zones (Mitsch and Gosselink 2000). The character of each forested wetland is influenced by the manner in which the landscape was formed and the time that has passed since the landscape has developed without a major catastrophic event. Climate and the glaciated nature of the north limit the extent of forested wetlands.

In North America, forested wetlands consist of coniferous swamps and mixed hardwood swamps. In the northern contiguous United States, black spruce(*Picea mariana*), tamarack (*Larix laricina*), northern white cedar (*Thuja occidentalis*), and balsam fir (*Abies lasiocarpa)* dominate wet boreal coniferous forest. Mixed coniferous-hardwood swamps are generally seasonally flooded, occur on mineral soils or clays, and include (roughly from east to midwest) spruce-fir (*Picea-Abies*), northern hardwoods (*Acer-Betula-Fagus-Tsuga*), northern hardwoods-spruce (*Acer-Betula-Fagus-Picea-Tsuga*), beech-maple (*Fagus-Acer*), elm-ash (*Ulmus-Fraximus*), conifer bog (*Larix-Picea-Thuja*), northern hardwoods-fir (*Acer-Betula-Abies-Tsuga*), maple-basswood (*Acer-Tilia*), and black spruce-fir (*Picea-Abies*) (Trettin et al. 1997).

In the PNW, forested wetlands can be dominated by any of the following in the western Puget Basin lowlands: western red-cedar (*Thuja plicata*), Sitka spruce (*Picea sitchensis*), red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa* spp. *balsamifera*), and Pacific willow

(*Salix lucida* var. *lasiandra*); less common wetland species include white pine (*Pinus monticola*), coast pine (*Pinus contort,*) western hemlock (*Tsuga heterophylla*), and Pacific yew (*Taxus brevifolia*) with Oregon ash, (*Fraxinus latifolia*) in the southern part of the range and paper birch (*Betula papyrifera*) in the northern part of the range. Engelmann's spruce (*Picea engelmannii*) replaces Sitka spruce east of the Cascade Range. The understory vegetation can be variable. Detailed information on PNW forested communities is included in sections III A (page 9) and Appendix D.

### B. Status and Trends

In southern Canada and the lower 48 states, forest harvest activities and settlement began to alter the landscape in the early 1800s, affecting primarily uplands. By the early 1900s, wetland species, white pine in particular, were being logged. Black spruce and tamarack supplemented the demand as white pine was depleted, and forest management presently focuses primarily on black spruce (Trettin et al. 1997). Large-scale harvest of virgin timber continued in the lower 48 states until the early 1940s.

The net effect of timber management globally has been a decline in the amount of older forests that have not been altered by agriculture or other cultural disturbance. In the PNW, the amount of old-growth forest has declined over 50 percent in the last 60 years (Bolsinger and Wadell 1993) and remaining older growth forest has become highly fragmented in the last 20 years (Spies et al. 1994). Forested wetlands provide unique habitats that are required during portions of the life cycle for a variety of wildlife species. Because forested wetlands comprise a relatively small percentage of the total PNW landscape, better ecological management of this resource is now being examined by the management and scientific communities.

Forested wetlands are not always correctly identified in the field and are seldom inventoried. Therefore, it is difficult to determine how much acreage may have been lost or impacted in the past 200 years that timber harvest has occurred in Washington State. It is not possible to perform an accurate paper inventory of forested wetlands in Washington State since the National Wetlands Inventory maps are least accurate for forested systems. Groups such as WETSAG and RSAG and ongoing research identified in Section VII of this paper will improve the identification and understanding of forested wetlands, and assist with identifying priorities and prescriptions for restoration of these habitats in the future.

# III. Pacific Northwest Forested Wetlands and Managed Forested Areas

### A. Vegetation

The vegetation of the PNW is among the most diverse in North America. It includes plant communities characteristic of wet coastal mountain ranges, dry interior mountain ranges, interior valleys and basins, and high desert plateaus. Washington and Oregon constitute the central part of the region and will be discussed in the most detail.

Although there has been some recognition of the unique ecological and societal values of forested wetlands in Washington, a statewide classification scheme has not been formally adopted or widely recognized, though there are several regulatory arenas where types of forested wetlands are differentiated. The Washington Department of Ecology's rating system for wetlands classifies mature forested wetlands as Category 1 due to their increasing rarity on the landscape, and their benefits to ecological diversity (DOE, 2004). In 1990, the Washington State legislature passed the Growth Management Act (GMA), requiring local governments to adopt regulations to protect environmentally critical or sensitive areas including all wetland types within urban growth boundaries. Lands managed for silviculture are regulated primarily under the Washington Forest Practices Act. Therefore, forested wetlands, and especially forested bogs, are defined and recognized in both local government regulations and state forest practices laws that regulate timber harvesting. However, these definitions are based largely on the presence of indicator plant species for bogs, such as shrubs of the family Ericaceae (*Ledum*, *Kalmia*, and *Vaccinium*), some trees (*Pinus monticola* and *Tsuga heterophylla*), and mosses within the Sphagnum genus. The most applicable statewide or regional wetland forest classification is for bogs as included in the *Preliminary Classification of Native, Low Elevation, Freshwater Wetland Vegetation in Western Washington* (Kunze 1994), published by the Washington Department of Natural Resources.

It is common for forest in the northwest to contain a mosaic of upland and wetland habitats. It is important, therefore to have an understanding of the adjacent upland communities, because they are crucial in providing components of many wetland functions, especially wildlife habitat-based functions.

## 1. West Side Upland Forests

The lowlands west of the Cascade Mountains are characterized by evergreen trees, including Douglas fir (*Pseudotsuga menziesii*), western hemlock, and western red-cedar. Franklin and Dyrness (1973) describe this as the *Tsuga heterophylla* zone. Sitka spruce characterizes forests in outer coastal areas. Common understory species throughout this zone include salal (*Gaultheria shallon*), Oregon grape (*Berberis nervosa*), salmonberry (*Rubus spectabilis*), elderberry (*Sambucus* spp.), evergreen huckleberry (*Vaccinium ovatum*), red huckleberry (*Vaccinium parvifolium*), sword fern (*Polystichum munitum*), and vine maple (*Acer circinatum*) (Johnson and O'Neil 2001). Typically, middle-aged forests are dominated by Douglas fir, with a variable deciduous component of red, bigleaf maple (*Acer macrophyllum*), and black cottonwood in the northern part of the region, and Pacific madrone (*Arbutus menziesii*) and oaks (*Quercus* spp.) in the southern portion. Paper birch is also common in the northern portion of this region. Young forests typically are dominated by red alder and Douglas fir or have a higher ratio of deciduous trees to coniferous trees, and the understory is more likely to contain early successional species, such as creeping blackberry (*Rubus ursinus*) and non-native Himalayan blackberry (*Rubus armenicus*) and cut-leaf blackberry (*Rubus laciniatus*). In addition, species diversity tends to be higher in these younger forests (Spies 1991).

The PNW contains some of the last old-growth forest in the United States. This forest includes Douglas fir, coastal Sitka spruce, western hemlock, and lodgepole pine *(Pinus contorta)*- or western red-cedar-dominated forested bogs (Franklin and Dyrness 1973). Old-growth Douglas fir forests in northwestern California and southwestern Oregon display several distinctive structural features, including large live trees, large snags, and large downed logs (Bingham and Sawyer 1991). Douglas fir stands in western Oregon and Washington begin to exhibit these characteristics after approximately 200 years (Halpern and Spies 1995).

## 2. East Side Upland Forests

The climate east of the Cascade crest is considerably drier than that of areas west of the Cascades. Although Douglas fir and western hemlock are still prevalent and western red-cedar is still present, this region is characterized by ponderosa pine (*Pinus ponderosa*). Deciduous trees in the inland portion of the PNW are quaking aspen (*Populus tremuloides*) and black cottonwood as an early seral tree. Forests in this region are, in general, fairly open and have an understory made up of sparse shrubs or grasses. Typical understory species include snowberry (*Symphoricarpos albus*), bitterbrush (*Purshia tridentata*), mallow ninebark (*Physocarpus malvaceus*), and pachistima (*Pachistima myrsinites*) (Daubenmire and Daubenmire 1984). Common understory grasses are Idaho fescue (*Festuca idahoensis*) and needlegrasses (*Stipa* spp.). Douglas fir is found at slightly higher gradients of elevation and moisture than is ponderosa pine (Daubenmire and Daubenmire 1984).

## 3. Forested Wetlands

Forested wetland communities include mixed coniferous/deciduous, coniferous, and hardwood bottomlands (willow, alder, cottonwood, and ash) (Dixon and Johnson 1999, Frenkel and Heinitz 1987, Kovalchik et al. 1988, and Kunze 1994). To maintain consistency with the work of Kunze (*Preliminary Classification of Low Elevation, Freshwater Vegetation in Western Washington*, 1994), the term "community type" is used in the following discussion to refer to plant associations. Regional comparisons are made among ecosystems in western and eastern Washington, Oregon, and British Columbia. In addition, apparent successional patterns, endangered, threatened or rare vascular plants, and introduced or invasive species are noted. These observations are based on the published information from numerous sources, including state and federal natural resource management agencies, local government, academia, and consulting firms.

In forested wetlands of this region, the most common canopy species are red alder, western red-cedar, black cottonwood, Sitka spruce, Oregon ash, and occasionally tree-sized willows (Pacific willow) with paper birch common in the northern portion of the range (Skagit and Whatcom Counties), and quaking aspen common on the east side of the Cascade Mountains. The understory typical of the lowlands east of the Cascade Mountains is made up of salmonberry, redstem dogwood (*Cornus sericea*), and willows.The understory east of the Cascade Mountains can be dominated by black hawthorn (*Crataegus douglasii*), western crabapple (*Malus fusca*), willows, and snowberry.

Kunze (1994) classified low elevation wetlands in the Puget Sound and separated them based on their geographic distribution—northern Puget trough region, southern Puget trough region, western Olympic Peninsula, and southwest Washington lowlands. There has been no such study done for east side Washington or Oregon wetlands and the best information we have comes from Franklin and Dyrness (1973) and Daubenmire and Daubenmire (1968). The Northern Puget trough wetlands have 10 Sphagnum bog types and 26 minerotrophic types, of which four of the Sphagnum bogs (*Pinus contorta, P. monticola*, *Tsuga heterophylla*) and five of the minerotrophic types are forested communities. The southern Puget trough and Columbia River region have three kinds of wetlands. Six Columbia River Gorge types, 20 overflow plain types and 15 surge plain types have been identified. Of these, none of the Columbia River, four of the overflow plain, and only one of the surge plain types are forest-dominated communities. The Olympic Peninsula and southwest Washington region have three wetland types with 14 Sphagnum bogs, 24 minerotrophic and eight surge plain types. Of these, four Sphagnum bog, three minerotrophic, and two surge plain wetland types are forest-dominated communities.

In addition to this preliminary classification scheme, there is a considerable amount of early work on the morphology, stratigraphy, and plant communities of peatlands in western Washington. Much of the pioneer work was done by Rigg (1925, 1940, 1950, 1958), Rigg and Richardson (1934), and Hansen (1941, 1943, 1947). In addition to these works, a few masters' theses (Fitzgerald 1966; Fors 1979) describe the vegetation communities in western Washington peatland ecosystems.

A detailed breakdown of the northern Puget trough region wetland community types has been described in Kunze and is summarized in Appendix D. These have been broken into the following categories:

<u>Northern Puget Trough Forested Wetland Community Types</u>

Forested Bogs

- *Pinus contorta/Ledum groenlandicum/Sphagnum spp*.
- *Pinus monticola/Ledum groenlandicum/Sphagnum spp*.
- *Tsuga heterophylla/Ledum groenlandicum/ Kalmia microphylla/Sphagnum* spp.
- *Tsuga heterophylla/Sphagnum spp*.

Minerotrophic Wetlands

- *Alnus rubra/Lysichitum americanum.*
- *Alnus rubra/Rubus spectabilis.*
- *Alnus rubra/Rubus spectabilis.*
- *Fraxinus latifolia/Carex obnupta*.
- *Fraxinus latifolia/Symphoricarpos albus/Rubus ursinus*.
- *Thuja plicata/Tsuga heterophylla/Lysichiton americanum*.

<u>Southern Puget Trough and Lower Columbia River Lowland Forested Wetland Community Types</u>

Overflow Plain

- *Salix lucida/Urtica dioica*.
- *Fraxinus latifolia/Urtica dioica.*
- *Fraxinus latifolia/Populus trichocarpa/Cornus sericea/ Urtica dioica.*
- *Fraxinus latifolia/Populus trichocarpa/Symphoricarpos albus/Urtica dioica*.

Surge Plain Wetlands

- *Populus trichocarpa/Cornus sericea/Impatiens capensis.*

<u>Native freshwater Wetlands of the Western Olympic Peninsula and Southwest Washington Lowlands</u>

Low elevation Sphagnum Bog

- *Pinus contorta/Ledum groenlandicum/Sphagnum* spp.
- *Pinus contorta-Thuja plicata/Myrica gale/Sphagnum* spp.
- *Thuja plicata-Tsuga heterophylla/Gaultheria shallon/Lysichiton americanum/Sphagnum* spp.
- *Tsuga heterophylla/Ledum groenlandicum/Sphagnum* spp.

Low Elevation Minerotrophic Wetlands

- *Picea sitchensis/Alnus rubra/Lysichitum americanum*.
- *Pyrus fusca/Calamagrostis canadensis.*
- *Pyrus fusca/Carex obnupta.*
- *Pyrus fusca/Salix hookeriana/Carex obnupta*.
- *Thuja plicata/Tsuga heterophylla/Lysichitum americanum*.

Surge Plain Wetlands

- *Alnus rubra/Rubus spectabilis/Carex obnupta/Lysichitum americanum*.
  *Picea sitchensis/Alnus rubra/Rubus spectabilis/Carex obnupta*.

## *B. Soils*

Forested wetlands are more widespread and extensive in the northern portion of the PNW and historically in the floodplains along many major rivers throughout the region.

Soils in forested wetlands within the PNW region tend to be highly diverse in their composition due to the widely varying parent materials from which the soil has developed. Wetland soils can be broadly separated into organic and mineral types.

### 1. Organic Forested Wetland Soils

Organic soils are defined as soils that are saturated for long periods of time and have an organic carbon content (by weight, excluding live roots) that ranges from at least 12 percent if the mineral component of the soil contains no clay, to 18 percent or more organic carbon if the mineral component of the soils contains 60 percent or more clay (USDA NRCS 1998). Organic soils are taxonomically classified as Histosols under U.S. Soil Taxonomy and are commonly referred to as peat, muck, or mucky peat. Peat, also called fibric material, is organic material that is only slightly decomposed. In contrast, muck, also called sapric material, is organic material that is highly decomposed, with few or no recognizable plant remains. Mucky peat, or hemic material, is intermediate between fibric and sapric material. Mucky peat is organic soil material in which a notable portion of the original plant remains are recognizable and a portion are decomposed and not recognizable; between 1/6 and 3/4 of the plant fibers remain recognizable after rubbing between fingers. Bulk density of organic soil is usually very low and water holding capacity very high. Organic soil areas are commonly termed as “peatlands;” however, it would be incorrect to assume that the majority of these areas are dominated by true “peat” or fibric material, except in extreme northern climates; hemic organic materials are generally more common and widespread. In the southern portions of the PNW, large organic deposits can also be composed of sapric or muck soils.

Organic soils develop in prolonged saturated or inundated environments where organic accumulations occur due to inhibition of microbial decomposition of plant material. Studies specific to the PNW found rates of organic soil formation are highly variable and based on overlying vegetation type, elevation, and depth and duration of soil saturation. Organic soil formation is relatively slow. Studies conducted in northern Eurasia (Russia) have found peat soils accumulating at rates from 0.07 to 1.1 mm/year (Trettin et al. 1997). Saturated soil conditions are typically not suitable for most tree species; therefore, a relatively small number of tree species grow in saturated soils. In the southern half of the PNW (Oregon, Washington, Idaho, Montana, and southern British Columbia), tree species tolerant of saturated organic soils include lodgepole pine, western red-cedar , western hemlock, western white pine, and along the Pacific coastline, Sitka spruce. These tree species could vary from normal height to stunted specimens, depending on the depth to water table, pH, and nutrient content of the organic soils.

In the northern half of the PNW, including the northern half of British Columbia and Alaska, inland forested wetlands occurring on organic soils are typically dominated by black spruce and to a lesser extent, tamarack; along moist coastal areas, forested organic-soil wetlands contain western hemlock, lodgepole pine, Alaska cedar (*Chamaecyparis nootkatenis*), western red-cedar, Sitka spruce, and mountain hemlock (*Tsuga mertensiana*) (Loggy pers. comm., USDA 2002, Trettin et al. 1997).

In the southern half of the PNW, organic soils occur most commonly in depressions (such as kettles in the glaciated portion) surrounded by better-drained upland topography; they also occur in linear or sinuous belts and depressions within alluvial floodplains (USDA 2002). Also locally in the southern portion of the PNW, some areas with organic soils have been cleared and support agricultural production of vegetables, berries and hay (Snyder et al. 1973).

Larger expanses of forested organic soils occur in the northeast corner of British Columbia and through the central and southeast portions of Alaska. Canada reportedly has 130 million hectares (321 million acres) of peatlands, much of which is forested (Pritchet and Fisher 1987); however, much of this is in the central and eastern portions of the country, and some of these “forested” peatlands are covered in stunted, scraggly black spruce. In the 1.2 million-acre study area for the Ketchikan Area Soil Survey of southeastern Alaska, approximately 43 percent of the study area is covered in organic soils, with about 132,000 hectares (326,040 acres) of coniferous forested wetlands occurring on organic soils (USDA 2002). In the northern PNW region, organic soil areas typically range in size from 5 to 800 hectares (12.35 to 1976 acres) in flat to moderately sloping (20- to 22-degree) topography (USDA 2002, Krosse, pers. comm.). In mountainous terrain within southeast Alaska, wet, organic soils can also develop on extreme slopes in excess of 80 percent (Loggy pers. comm.) and are generally associated with mountain slope seepages and drainages. In the northern PNW, organic soils can be forested (Sitka spruce or hemlock-cedar forests) or covered in shrub-herb-moss vegetation.

### 2. Mineral Forested Wetland Soils

In the southern portion of the PNW (Washington, Oregon, Idaho, Montana, and the southern half of British Columbia), a majority of forested wetlands occur on mineral soils, or have relatively thin organic surface layers overlying mineral subsoils. Forested wetland mineral soils occur in a wide variety of landscape positions and geomorphic settings: alluvial floodplains, mountainside and hillside seepages, slight depressions on broad glacial till plains, within former lake plains and basins, and within coastal plains and terraces. The parent materials of these forested hydric soils are widely varying, and include alluvium, residuum, colluvium, lacustrine deposits, loess (windblown silts), volcanic ash, and glacial material (including glacial till, glacial outwash, glaciomarine and glaciolacustrine deposits). Soil types vary from fine-grained clay loams and silty clay loams, up to coarser loamy sands and gravelly sandy loams, depending on parent material and pedogenic processes. In many wetter settings, a thin 2-40 cm thick layer of decomposed organic material (usually sapric material or muck) has developed on top of the mineral surface, creating a thin organic surface horizon. Forested mineral soils typically are not inundated or saturated for as long a duration as organic soils; many forested mineral soils have a seasonal dry period, which in the PNW usually occurs sometime during the summer.

More diverse tree species occur in forested wetlands containing mineral soils than organic soils. In the southern PNW, western hemlock, western red-cedar, Sitka spruce, and lodgepole pine are joined by black cottonwood, red alder, Oregon ash , and quaking aspen.

## *C. Hydrology*

It is generally accepted that hydrology is the most important factor influencing wetlands (Mitsch and Gosselink 2000). In wetlands, the depth, duration and frequency of flooding controls the development of clearly distinguishable communities along a moisture and topographic gradient (Teskey and Hinckley 1980, Mitsch and Gosselink 2000, Azous and Horner 2001). The U.S. Fish and Wildlife Service classification system for freshwater wetlands (Cowardin et al. 1979) identifies wetlands based on their associated hydrologic regime. Permanently shallowly inundated areas generally develop communities of aquatic macrophytes. Plant communities dominated by emergent plants inhabit both permanently and seasonally flooded and permanently and seasonally saturated areas; scrub-shrub and forested community types are typically associated with seasonally inundated and/or saturated areas. Many wetlands receive water from, and contribute water to streams, both through surficial and subsurface pathways.

Anaerobic conditions resulting from increased duration and frequency of inundation or saturation influence water quality and chemistry, microclimate, nutrient cycling and availability, and, therefore, also influence plant community composition (Azous and Horner 2001). Increased development within watersheds often changes the amount, quantity, and quality of surface water and groundwater input into receiving waters and wetlands. Conversion of upland areas into impervious surfaces results in reduced groundwater recharge and increased surface water flow, which may reduce shallow groundwater discharges to wetlands during critical low-flow periods (Azous and Horner 2001).

The rate of decomposition and character of nutrient cycling and nutrient availability is to a large extent controlled by the hydrologic regime and surface and groundwater inputs to wetlands usually contributes to altering historic conditions of these processes. The anaerobic and often acidic conditions found in wetlands in the PNW are conducive to the development of very specific communities of decomposers and relatively low decomposition and nutrient cycling rates. As long as these processes remain unchanged, organic material (peat) accumulates and there is a natural successional process towards a climax forest (Kulzer et al. 2001).

Some baseline information on forested wetland hydrology exists for the PNW. Kulzer et al. (2001) examined and recorded water balances in coastal forests in British Columbia. Harr (1975) characterized the hydrology of small forest streams in western Oregon. Existing data on Alaskan water balances indicate that rainfall exceeds evapotranspiration and that permafrost impedes drainage, creating community characteristics that would be considered wetland (Ford and Bedford 1987 in Kulzer et al. 2001). Recharge and discharge functions of wetlands near Juneau have been examined by Siegel (1988 in Kulzer et al. 2001), who found that recharge from wetlands to viable aquifers was very small, and the amount groundwater discharge to streams from wetlands was too small to measure.

## *D. Water Quality*

### 1. Rainwater Chemistry in Western Washington

Rainwater is the primary source of water for wetlands in Washington. Kulzer et al. (2001) describes the contribution of rainwater to wetlands in the PNW and their chemistry. They describe how rainwater is chemically different from ground and surface waters that are enriched by contact with mineral soils, bedrock, and biological processes. Rainwater is predominantly influenced by atmospheric gases, especially carbon dioxide ($CO_2$) which tends to be slightly acidic because $CO_2$ dissociates to form carbonic acid. Nitrogen (N), another dominant atmospheric gas, does not dissociate readily in water, so nitric acids are not typically present in rainwater from unpolluted areas. Precipitation reaching western Washington from the Pacific Ocean tends to show relatively low concentrations of any soil-derived cations (positively charged ions). Rainwater contains varying amounts of anthropogenic contaminants. When clouds pass over areas of human activity, especially those dominated by motor vehicle traffic or industrial plant emissions, concentrations of soil derived cations can influence the composition of urban rainwater.

Data from western Washington (annual averages from 1995 and 1998 for Olympia and Bellingham, Washington), collected as part of the National Atmospheric Deposition Study (NOAA website May 2000), are given in Appendix F Table 1 (from Kulzer et al. 2001). The rainfall data indicate a moderately acidic pH of about 5, with low cation concentrations. No macronutrient data for Phosphorus (P) and N were identified in this literature survey. Calcium (Ca) ranges between 0.02 and 0.03 mg/L; Magnesium (Mg) concentrations average 0.02 mg/L; sodium (Na) is at a concentration of about 0.15 mg/L to 0.16 mg/L; chlorine (Cl) averages concentrations between 0.22 and 0.32 mg/L; potassium (K) concentrations range from 0.009 to 0.017 mg/L; and sulfate concentrations average 0.2 to 0.35 mg/L.

Rainfall data were collected at two locations in the Seattle area by the Puget Sound Wetlands and Stormwater Management Research Program (PSWSMRP) from mid-1988 to 1990 (unpublished in Kulzer et al. 2001). Some of the data (Factoria area near Bellevue, Washington) represent a very urban environment and other data come from a more rural location (near Covington, Washington) that would be more indicative of forest areas closer to small towns. Kulzer concluded from the data that urbanization can increase the nutrient concentration of precipitation.

The pH ranges from 3.8 to 6.4 and N data (all forms, $NO_3$, $NO_2$+$NO_3$ and TKN) are similar for both urban and more rural areas. Nitrate ($NO_3$) ranges between 0.245 mg/L and 0.280 mg/L; ammonia ($NH_3$) is found in concentrations ranging from 0.129 mg/L to 0.145 mg/L; total Kjedahl nitrogen (TKN) concentrations are high (0.579 to 0.648 mg/L). The more urban area shows high values for conductivity and phosphorus (Ph), especially when comparisons are made to lake water in western Washington. Conductivity ranges from 28.2 μS/cm (0.21.7 corrected for hydrogen ion) in the urban site to only 12.3 μS/cm (5.8 μS/cm corrected for hydrogen ion) in the more rural site. Total phosphorus (TP) concentration averages between 0.03 and 0.069 mg/L, and soluble reactive Ph (SRP) is also high magnitude lower.

## 2. Groundwater Chemistry in Western Washington

Groundwater constitutes the second main source of water for forested wetlands. Two western Washington groundwater data sets (a glaciated ridgetop in the Issaquah area and the Maple Valley plateau) were compiled by Kulzer et al. (2001) (Appendix F, Table 2). The Issaquah data are typical of shallow groundwater wells with depths of 4 to 5 feet in glacial till areas of King County. Groundwater pH is consistently between 5.5 and 6.5 with a few points higher and lower depending on how much of the soil is glacial associated (higher pH) and organic soil associated (lower pH). Alkalinity varied between two sites within the Lower Cedar River Watershed, ranging widely from 5.8 to 55.3 mg Calcium Carbonate ($CaCO_{3)}$/L, and up to 70.5 mg $CaCO_3$/L at the Issaquah site. Hardness varied most widely between the two Cedar River Watershed sites, from 14.8 to 78.4 mg/L. Ca, Mg, Na, and Cl were also all higher at Cedar River Watershed Site 2 than Site 1. Mg, Na, and K were highest at the Issaquah site. Sulfate ($SO_4$)level was related to substrate origin and was five times higher at Cedar River Watershed site than any other site. TP was much higher at the Issaquah site than at the Cedar River Watershed sites (3.26 mg/L at Issaquah, compared to 0.103 and 0.035 mg/L at Cedar River).

## 3. Wetland Chemistry in Western Washington

Data compiled by the Puget Sound Wetlands and Storm Water monitoring research Program for 50 wetlands in the King County area (Azous and Horner 2001) (Appendix F, Table 3) were divided by degree of urbanization. Wetlands in the study were classified as associated with watersheds that were non-urban (less than 4 percent impervious surface and at least 40 percent forest cover), moderately urban, or highly urban (at least 7 percent forest cover and 20 percent impervious surface). For non-urban wetlands (those wetlands that most closely resemble the forested wetlands we are evaluating), pH averaged 6.4, dissolved oxygen averaged 5.7 mg/L, conductivity averaged 73 μS/cm, TP concentrations averaged

0.05 mg/L, and $NO_3$ plus nitrite ($NO_2$)concentrations were fairly constant, averaging about 0.4 mg/L.

## 4. Small Stream Chemistry in Western Washington

The chemistry of small streams has been evaluated in western Washington, but little information has been found for eastern Washington. Streams typically have higher dissolved oxygen (D.O.) than wetlands due to the flowing water and lower nutrient concentrations. Data from two small streams in Issaquah (Appendix F, Table 4, from Kulzer et al. 2001) show average pH measurements of around 7.0 (neutral) and D.O. concentrations of 10-12 mg/L in the fall and spring and 5-6 mg/L in summer as flows decreased and temperatures increased. TP was usually below the detection limit of 0.01 mg/L, but occasionally reached 0.2 mg/L. $NO_3$ concentrations were relatively high, ranging from 0.3 mg/L to 4.5 mg/L. Monthly data were collected from 50 western King County streams (Metro 1994) on pH, hardness, conductivity, and nutrient concentrations from 1991 to 1993 (from Kulzer et al. 2001). Typically, these streams have low phosphorus and relatively high N concentrations. Half of the sites had a pH of 7.5 or higher, conductivity of 130 μS/cm or higher, and D.O. of 10 mg/L or above. Hardness ranged from 20 to 90 mg/L, nutrient concentrations for half of the streams averaged 0.048 mg/L TP or higher, 0.63mg/L $NO_2$+$NO_3$ or greater, and 0.015 mg/L or greater $NH_3$ concentrations.

## 5. Lakes

Data on the chemistry of small lakes was available for King County but not for the rest of Washington (Metro 1994). In general, data for 1991 to 1993 shows that small lakes in King County have lower nutrient concentrations than do streams, with an average of 0.005 to 0.05 mg/L. The pH ranges from a low of 6.7 to about 8.0. Conductivity ranges from 35 to 170 μS/cm. The darker the tannin staining in the lake, the lower the conductivities. No alkalinity measurements are available.

The Lake Washington watershed has experienced large-scale development since the 1950s. Various researchers at the University of Washington have monitored the lake since the 1960s. Alkalinity concentrations have shown a long-term increase over time. The data from 1991 to 1992 ranged from about 36.5 to 38.5 mg $CaCO_3$/L. The pH was slightly basic, ranging from 7.5 to 8.69 (Metro 1994). Limited cation data showed Ca concentrations at about 8.8 mg/L, Mg at 3.4 mg/L, Na at 4.2 mg/L, and K at 1.1 mg/L (Personal communication, S. Abella, May, 1996). There is nutrient data only for the period 1991-92 and it showed TP concentrations ranging from 0.007 to 0.026 mg/L. $NO_3$ was much more variable, ranging from below the detection level of 0.002 mg/L to 0.27 mg/L.

## 6. Water Quality in Forested Wetlands

Although few studies in the PNW have addressed the specific role of forested wetlands in water quality improvement, water-quality processes have been described for forested streams. Two ephemeral streams in southwest Washington trapped coarse sediments introduced upstream (Duncan et al. 1987). Material recovered at the stream mouths increased with stream flow, but very little sediment reached the stream mouths during low flow periods. Finer materials achieved higher export rates and were retained only during low flow periods.

Although no forested wetland-associated water chemistry data could be located during the literature search, stream water chemistry information, including pH, specific conductance, alkalinity, nitrogen, phosphorus, cations, dissolved silica, and sediment, is available for two undisturbed watersheds in the Cascade Mountains of Oregon (Martin and Harr 1988) (Appendix F, Table 5). Fredriksen (1975) measured dust deposition and associated nitrogen and phosphorus inputs in three watersheds in the Oregon Cascades. In addition, baseline and real-time water quality data are available for water bodies throughout the PNW through the USGS (http://waterdata.usgs.gov). Because forested streams and forested wetlands may have some water quality functions (sediment-trapping in particular) in common, these data may provide some insight into the effects of debris, water velocity, and other factors on water quality in forested wetlands. The data may also act as a baseline for downstream wetlands.

Most existing research regarding water quality functions of forested wetlands in the United States was conducted in the East. In the southeast United States, the degree to which forested wetlands improved water quality depended upon their size and health, but they were generally highly effective at removing suspended sediment and nutrients, as are many types of non-forested wetlands. Forested wetlands retained nonpoint source nitrogen and phosphorus (Kuenzler, date unknown); in the same study, freshwater wetlands also removed point source nutrients, but were less efficient at doing so when receiving heavy loads. Forested wetlands stored a disproportionately high percentage of nitrogen, most of which was stored in the soil, in a watershed in the Adirondack Mountains of New York (Bischoff et al. 2001). In this study, vegetative nitrogen demands were supported by internal nitrogen production, and thus nitrogen needs were not a significant factor in retention of atmospherically-derived nitrogen. However, the wetlands were a nitrogen sink because vegetative uptake exceeded nitrogen production in this undisturbed catchment. Many attributes and functions of forested wetlands are also exhibited by other types of wetlands. Streams in forested areas may also show similar characteristics. Five streams in undisturbed boreal forests in Quebec, Canada exported most of their annual sediment load during a two-month spring freshet, and dissolved organic carbon concentrations appeared to depend less on physical processes and more on instream processing and retention devices (Naiman 1982).

## *E. Wildlife*

Overviews of wildlife habitat types in the PNW generally do not include detailed descriptions of forested wetlands and their associated wildlife. However, there are three wildlife habitat types that contain or likely contain forested wetlands in Washington and Oregon, as described by Johnson and O'Neil (2001). They include Montane Coniferous Wetlands, Westside (west of the Cascade Mountain Range) Riparian-Wetlands, and Eastside (east of the Cascade Mountain Range) Riparian-Wetlands. Montane Coniferous Wetlands encompass approximately 297,549 acres in Washington and Oregon. Westside Riparian-Wetlands encompass 516,525 acres, and Eastside Riparian-Wetland encompass approximately 131,884 acres (Johnson and O'Neil 2001).

No studies found have specifically identified wildlife of PNW forested wetlands or characterized their life histories. The majority of wildlife studies from the PNW region have been conducted in upland forest communities, in riparian areas, and to a lesser extent, in emergent wetlands. Upland forest, riparian zones, and wetlands vary in their composition, size, and structure (Johnson and O'Neil 2001), but may contain forested wetlands within their boundaries. Based on this inherent variation and the paucity of forested wetland characterization, it is difficult to specifically define wildlife habitat relationships to forested wetlands in the PNW. However, information from upland or riparian studies is useful in characterizing probable habitat associations of wildlife and forested wetlands. There is a discussion of how timber management may affect wildlife associated with forested wetlands in Section V.

Several studies outside of the PNW (MacArthur and MacArthur 1961, Shugart and James 1973, Anderson and Shugart 1974) and within the PNW (Hansen et al. 1994, 1995) have documented relationships between organisms and habitat structure. Many of these habitat features or structures identified are found in upland and forested wetland environments. Principal forest attributes that determine the suitability of habitat of wildlife include vegetation, canopy structure, microclimate, and large organic material, including snags and downed wood. In turn, the removal of trees and understory from forested uplands, or similarly structured forested wetlands, and altering other site characteristics have a dramatic effect on habitat by eliminating habitat niches and instigating a vegetation and wildlife species shift by excluding the wildlife that require the original habitat features (Wigley and Roberts 1994, King and Degraff 2000, Mannan and Meslow 1984, Corn and Bury 1991).

In the PNW, wildlife habitat associations in forested wetlands, which are particularly common in headwater areas and large river bottoms, have not been widely studied, and little is known about the level of association between wildlife species and forested wetland habitats. The following information is a summary of PNW wildlife species and their associations with upland forested habitat features or forested wetlands when available.

### 1. Amphibians

There are 460 species of amphibians in North America. Thirty-three occur in the PNW. Only two groups of amphibian, the Caudata and Anura, are found in the PNW. Within the PNW, there are three families of salamanders, including mole salamander (Ambystomatidae), lungless salamanders (Plethodontidae), and newts (Salamandridae). The order Anura contains five families of frogs and toads, including toads (Bufonidae), treefrogs (Hyliade), bell toads (Leiopelmatidae), spadefoot toads (Pelobatidae), and true frogs (Ranidae). A list of PNW amphibian species is located in Appendix I, Table 1 (Nussbaum et al. 1983).

Many amphibians are adapted to live in moist, cool, forested environments, which are well developed in the PNW (Nussbaum et al. 1983). Amphibians have unique life history characteristics that are considered to make them a valuable indicator taxon for environmental change and health of wetland and/or aquatic systems. These characteristics predispose amphibians to be especially sensitive to pollution and loss of habitat through land use or vegetation cover changes (Nussbaum et al. 1983, Hayes et al. 2002, Beebee 1996, Hall 1980, Wyman 1990, Blaustein and Olson 1991, Blaustein 1994, Blaustein et al. 1995, Corn 1994). They are associated with aquatic, wetland, and shaded terrestrial environments; small home ranges; and have moist, permeable eggs, gills, and skin (deMaynadier and Hunter 1995, Johnson and O'Neil 2001). Amphibians are often the predominant carnivores in headwater streams in the PNW (Bury et al. 1991), represent the largest proportion of total vertebrate biomass (Bury and Raphael 1983), and provide important energy cycling functions as detritivores, herbivores, insectivores, and carnivores within many ecological systems. Amphibian densities and biomass were found to be 10 and 4 times greater, respectively, than those reported for salmonid fishes in small streams in the PNW (Bormann and Likens 1979, Johnson and O'Neil 2001).

Salamanders are the dominant component of the PNW herpetofauna, with 18 species. All PNW species have internal fertilization. Salamanders lay their eggs in water, wetlands, or moist places on land. Some species lay eggs on land and have direct development with no larval stage; these hatchlings have the form of miniature terrestrial adults (Nussbaum et al. 1983).

Frogs and toads (15 PNW species) are the only amphibians that lack tails and have fully developed limbs. In the PNW, all species mate and lay eggs in water in the early spring (Nussbaum et al. 1983).

Nineteen amphibian species in Washington have a high likelihood of using forested wetland habitat for at least one of their life stages (Hayes 2002, Nussbaum et al. 1983). All amphibians covered in the Forest and Fish Report (FFR) have been documented using forested wetland habitat for at least one of their life stages (Hayes 2002). This association may be strengthened in summer months when upland soils are dry. From October to March, almost all parts of the PNW receive abundant precipitation; therefore water is not a limiting factor for most wildlife during this period. However, the dry season (from mid/late spring to early fall) can be a time of water stress for many species of animals. This aridity may concentrate wildlife near streams and rivers or forested wetlands, particularly in interior areas of northern California and southern Oregon (Bury 1988). Montane coniferous riparian areas provide habitat for 20 percent (13 species) of the amphibians and reptiles in Oregon and Washington (Johnson and O'Neil 2001). Of those 13 species, seven are considered closely associated with Montane Coniferous Wetlands, three are considered present, and three are considered associated (Johnson and O'Neil 2001) with these habitat types. Within Westside Riparian-Wetland habitats, 31 species of herpetofauna are associated with this habitat type, four are considered present, nine are considered associated, and 17 are closely associated. Eastside Riparian-Wetlands have 10 species of closely associated amphibians, 10 species associated, and five species considered present within the habitat type (Johnson and O'Neil 2001).

The Forest and Fish Report (WDNR 1999) designates selected species for monitoring and protection in Washington State. Forest and Fish species include stream-associated taxa identified as being potentially vulnerable to forestry practices (Wahbe 2001). Amphibian species that have been given a FFR designation (222-16 WAC) are listed below:

- Tailed frogs (*Ascaphus* spp.)
    - Pacific tailed frog (*A. truei*)
    - Rocky mountain tailed frog (*A. montanus*)

- Torrent salamanders, also called seep salamanders (formerly Olympic salamanders) (*Rhyacotriton* spp.) (Corkran and Thoms 1996)
  - Cascade torrent salamander (*R. cascadae*)
  - Columbia torrent salamander (*R. kezeri*)
  - Olympic torrent salamander (*R. olympicus*)
- Van Dyke's salamander (*Plethodon vandykei*)
- Dunn's salamander (*Plethodon dunni*)

Detailed biological information is available on these species in Appendix F.

## 2. Birds

Many studies have evaluated the timber management in upland forest and riparian areas and their use by bird species in the PNW (Huff and Raley 1991, Lundquist and Mariani 1991, Chambers et al. 1999, Manuwal 1991, Carey et al. 1991, Dickson 1978, Huff and Raley 1991, Hansen et al. 1995). However, no studies in the PNW have specifically investigated avian communities within forested wetlands or the effect of timber management within forested wetlands on bird species. The following is provided as a summary of avian habitat associations within a variety of habitat types (upland, riparian, and wetland communities) and how timber management within these communities may affect bird species.

In general, avian diversity in riparian and non-forested wetland ecosystems of Oregon and Washington is high relative to upland ecosystems. Of the 367 species of birds in Oregon and Washington, 72 percent use freshwater, riparian, and wetland habitats (including all wetland classes). Seventy-seven percent of the 266 species of inland birds that breed in Oregon and Washington do so in riparian and wetland environments. Of these, 103 species are considered closely associated, 89 species are generally associated, and 12 species are considered present in the riparian-wetland habitat type (Johnson and O'Neil 2001). Similarly, riparian and wetland ecosystems in Oregon and Washington support more species of sensitive birds then do any other habitat type. Approximately 80 percent of bird species listed as sensitive in Oregon and Washington occur in riparian and wetland habitats (Marshall et al. 1996). McGarigal and McComb (1992) found that bird community composition and structure differed between streamside and upslope areas in the PNW. However, upslope areas supported 61 percent of the total number of bird species along streams and exclusively supported 33 percent of the species. Streamside areas exclusively contributed only 9 percent of the species.

East- and Westside Riparian-Wetland habitats are of great importance to migratory land birds (MLB) and resident land birds (RLB) in Oregon and Washington. Eastside Riparian-Wetlands provide habitat for 55 percent of MLB and 71 percent of RLB in Oregon and Washington. Approximately 75 percent of the MLB and 90 percent of the RLB that occur in Eastside Riparian-Wetland habitat use this habitat for breeding. Species such as calliope hummingbird, western wood-pewee, and MacGillivray's warbler are considered riparian dependent (Johnson and O'Neil 2001). Many land birds present in Eastside Riparian-Wetland habitats are considered to be associated or present within the habitat, and it is likely that their population would decline significantly without this habitat (Johnson and O'Neil 2001). Patterns seen in Eastside Riparian-Wetland habitat also occur in Westside Riparian-Wetland habitat. However, within Montane Coniferous Wetland habitat, few species are considered closely associated with this habitat type (Johnson and O'Neil 2001). This may be due to the similarity of structure and composition between Montane Coniferous Wetlands and adjacent upland (McGarigal and McComb 1992).

The presence of bird species in forested communities is thought to be strongly associated with habitat features within forest stands (Lehmkuhl et al. 1991, Hansen et al. 1995). Many bird habitat associations support individual species' habitat requirements, including open-canopy, open-canopy with dispersed large trees, structurally complex closed-canopy, and structurally simple closed canopy. In PNW coniferous forests, structural complexity is distributed over the course of succession. Complexity tends to be high in the early and late-seral stages (Spies et al. 1988) when structural features are retained after fire, wind, or during timber harvest and incorporated into subsequent regrowth communities. Specialized species within upland forests preferred habitat features including large dominant trees, mixed tree species composition, multilayered canopy, irregular crown structure, patches of dense foliage, large standing dead wood, and abundant woody debris on the forest floor (Mannan and Meslow 1984, Hansen et al 1994, Manuwal 1991, Manuwal and Huff 1987, O'Connell et al. 1993). However, Lundquist and Mariani (1991) did not find many bird habitat relationships. The availability of snags and large-diameter, old trees with loose bark for nesting and as habitat for invertebrate food sources likely contributes to the high densities of birds in late successional stages (Mannan and Meslow 1984, Thomas 1979, Verner 1980, Mannan 1982, Anthony 1984, Zarnowitz and Manuwal 1985, Lundquist and Manuwal 1990, Manuwal 1991). Several habitat features that birds use in upland forests and riparian areas are also present in forested wetlands: food sources, snags, large diameter trees, multilayered canopy, patches of dense foliage, and abundant woody debris.

Vegetative diversity and complexity in habitat types provides nesting habitat components for avian species. A cottonwood forest with senescent trees and snags furnishes substrates for primary and secondary cavity nesters in riparian areas. In Oregon uplands, Carey et al. (1991) demonstrated that all cavity-nesting bird species selected very large snags for nesting, and these species were more dependent on old-growth forests. Martin (1998) demonstrated that the relationship between vegetation complexity and avian diversity was better explained by nest site diversity than by forage site diversity. Close association between bird and plant species may be best explained by nesting substrate requirements, which are usually narrower than the specialization in use of foraging sites (Martin 1993, 1995).

Studies conducted in upland forests in the PNW found some habitat association between soil moisture and bird species (Carey et al. 1991, Manuwal 1991). In riparian and wetland areas, the diversity and abundance of birds may be a result of the high levels of plant and insect productivity associated with more saturated soil conditions. In the southwestern United States, high habitat productivity was found to diminish competition for food (Bock 1992) and can also influence avian diversity by depressing competition and reducing space requirements. Abundant, high-quality food decreases energy expended during food acquisition (Martin 1986), and for upland species, such decreases permit contraction of territories (Newton 1988). The high productivity of riparian and wetland ecosystems also provides resources to migrating species. High-energy expenditure associated with seasonal migration requires that stopover sites contain abundant, energy-rich insect and plant food (Alerstam and Lindstrom 1990, Moore et al. 1995). Thus, interior wetland complexes provide critical habitats for an abundance and diversity of migrating birds (Davis and Smith 1998).

### 3. Mammals

The PNW has approximately 156 species of mammals, excluding marine mammals (Johnson and O'Neil 2001). Although a few are dependent on aquatic and wetland habitats, such as beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus)*, mink (*Mustela vison)*, nutria (*Myocastor coypus)*, and river otter (*Lontra canadensis)*, many other species use wetlands and riparian areas as sources of food, water, and cover at some point in their life cycles. Riparian areas and wetland/aquatic areas are particularly important in arid portions of the region east of the Cascade Mountains. However, little information specific to PNW forested wetlands and mammal habitat associations has been published. Further discussion of mammals and effects of timber management is found in Section V.G.4. of this report.

Several studies in the PNW have investigated the use of upland and riparian forest habitats in the PNW by mammals and timber management's effect on these species in these habitats. Generally, these studies have produced results similar to those studies of birds and amphibians, in that specific habitat requirements attract individual species to habitats that possess those characteristics. Little information specific to PNW forested wetlands and mammal habitat associations has been published. As a result, the following information is provided as a summary of mammal habitat associations within a variety of habitat types (upland, riparian, and wetland communities) and may be used as preliminary identification of mammal habitat requirements.

Riparian areas in Oregon and Washington are used by mammals for food, shelter, sources of water, and movement (O'Connell et al. 1993). Riparian habitat types in Washington and Oregon include Eastside Riparian-Wetlands, Westside Riparian Wetlands, Montane Coniferous Wetlands, Herbaceous Wetland, and Open Water (Johnson and O'Neil 2001). Excluding Open Water habitats, approximately 50 percent of the mammal species using the five riparian habitats breed and feed in those habitat types. More than 50 mammal species breed and feed in Montane Coniferous Wetlands, more than 60 species breed and feed in Westside Riparian-Wetlands, and more than 70 species breed and feed in eastside riparian wetlands (Johnson and O'Neil 2001).

In general, certain species are more closely associated with riparian habitat types that include streamside or wetland habitats. Timber harvesting effects are variable depending on the type of harvest and the habitat requirements of the associated mammal species. Riparian zones typically have higher structural diversity compared to adjacent upland habitats and have high spatial heterogeneity due to frequent natural disturbances (Johnson and O'Neil 2001). Riparian zones, and similarly, forested wetlands, offer a source of water, favorable microclimates, and high plant diversity and varied and abundant forage supply (McGarigal and McComb 1992, Oakley et al. 1985).

Small mammals that are closely associated with wetter deciduous forest conditions include the white-footed vole *(Arborimus albipes)*, Pacific jumping mouse *(Zapus trinotatus)*,, western jumping mouse *(Zapus princeps)*, western harvest mouse *(Reithrodontomys megalotis)*, Richard's water vole *(Arvicola terrestris)*, Pacific water shrew *(Sorex bendrii)*, shrew-mole *(Neurotrichus gibbsii)*, broad footed mole *(Scapanus latimanus)*, dusky shrew *(Sorex vagrans obscurus)*, montane shrew *(Sorex monticolus)*, and bats (*Myotis spp.*) (Cross 1988, Corn and Bury 1991, Gilbert and Allwine 1991, West 1991, McComb et al. 1992, Corn et al. 1988). Several bat species rely heavily on riparian habitats for the foraging of abundant insect prey associated with aquatic environments (O'Connell et al. 1993, Cross 1998); others are associated with dense vegetation and or downed wood (McGrigal and McComb 1993) and would likely be associated with habitats that contain similar characteristics such as a mature forested wetland area.

Little is known about the life history characteristics of most riparian-obligate mammals (Johnson and O'Neil 2001). Riparian areas used by large mammals in the PNW include species that are dependent on riparian areas for many habitat requirements. These closely associated riparian mammals include beaver, muskrat, mink, river otter, raccoon *(Procyon lotor)*, elk *(Cervus elaphus)*, and mule deer *(Odocoileus hemionus)*. Grizzly bear *(Ursus arctos)*, western spotted skunk *(Spilogale gracilis)*, white-tailed deer *(Odocoileus virginianus)*, and moose *(Alces alces)* were classified as more abundant in riparian areas than uplands (Raedeke et al. 1988).

## 4. Fish

Fish strongly influence other species of wildlife as both predators and prey in open water and stream habitats. In particular, salmonids are the most influential as a group in terms of their economic and ecological importance. Although salmon reside, breed, and rear their young in streams and riparian areas, many of these areas are found in and adjacent to forested wetlands. Forested wetlands supply detritus and large woody debris for habitat structure and nutrients, dense thin-stemmed vegetation and organic substrates to decrease sediment rates and turbidity to adjacent receiving waters, and canopied vegetation for shade over streams.

Studies of salmonids in this region constitute a large body of literature. Habitat loss and forest practices as a factor influencing stock declines is well-documented (Swanson et al. 1987, Swanson and Dyrness 1975). However, little is known about salmonids' relationships with forested wetlands other than in floodplain and riparian environments, or on the effects of forest practices on forested wetlands. Preliminary studies by researchers at Oregon State University and other schools indicate that floodplain forests are important for winter/early spring feeding and rearing access for many resident and anadromous species.

The salmonid fauna of western Oregon and Washington is represented by 16 species of five genera of the family Salmonidae (11 native and five introduced species), and more than 50 species of non-salmonid fishes (Everest et al. 1985). A high percentage of the salmonids are anadromous (Table 1 in Appendix J). The salmonids are adapted to cold temperatures of lakes and streams of the northwest, and their migratory abilities and salinity tolerances have permitted colonization of nearly all accessible waters (Everest et al. 1985), including many streams that are adjacent to and pass through forested wetland systems.

Five species of native Pacific salmon [Pink (*Oncorhynchus gorbuscha*), Chum (*Oncorhynchus keta*), Coho (*Oncorhynchus kisutch*), Chinook (*Oncorhynchus tshawytscha*), Sockeye (*Oncorhynchus nerka*)]; three species of anadromous trout [steelhead = anadromous rainbow trout (*Salmo gairdneri),* cutthroat trout (*Salmo clarki*), dolly varden (*Salvelinus malma)];* and three species of resident trout [rainbow trout (*Salmo gairdneri*), bull trout (*Salmo confluentus*), mountain whitefish (*Prosopium williamsoni)*] utilize streams and rivers for reproducing or rearing in the PNW.

Wetland occurrence, local geology, stream gradient, and land use were significantly correlated with adult coho abundance and median adult coho densities in forest –dominated areas were 1.5 to 3.5 times the densities in rural, urban, and agricultural areas in the Snohomish River Basin of western Washington (Pess et al. 2002). The authors also found a positive correlation between salmonid abundance and percentage of peat (organic soils) at both the watershed and reach scales. No other peer-reviewed studies for other fish taxa were found.

## *F. Classification and Characterization of Forested Wetlands*

Three primary forested wetland communities occur in Washington and Oregon, as described by Johnson and O'Neil (2001): Montane Coniferous Wetlands, Westside (of the Cascade Mountain Range) Riparian-Wetlands, and Eastside (of the Cascade Mountain Range) Riparian-Wetlands.

Montane Coniferous Wetlands commonly occur on mountains, steep slopes, and flat valley bottoms at elevations of 2,000 feet to 9,500 feet above mean sea level (msl) in the Cascade, Olympic, Okanogan, Blue, and Wallowa Mountains of Washington and Oregon. These wetlands are characterized as forested wetlands or floodplains with a winter snow pack. The climate varies but includes moderately cool and very wet to very cold and moderately dry. Mean annual precipitation in these environs ranges from 35 to more than 200 inches. These forested wetlands are typically found along streams or as small patches within a matrix of upland mixed conifers or lodgepole pine forest. They also occur adjacent to other wetland habitats such as riparian wetlands and herbaceous wetlands (Chappel and Kagan 2001).

The Eastside Riparian-Wetland community is located along streams and rivers between 100 and 9,500 feet msl and includes impounded wetlands along lakes and ponds. These riparian and wetland forests occur as narrow bands along montane or valley streams, seeps, and lakes. On the eastside of the Cascade Range, these communities are located within 100-200 feet of the stream corridor or water source. Irrigation from toeslopes and overbank flow is the primary water input and provides more water than precipitation (Crawford and Kagan 2001). The community contains shrublands, woodlands, and forest communities. This habitat is considered palustrine scrub-shrub and forested wetland (Cowardin et al. 1979).

The Westside Riparian-Wetland community type is located west of the Cascade Crest, as far south as northwestern California and extending north into British Columbia. They are found on flat or gently sloping terrain or on steep slopes at lower elevations, usually below 3,000 feet above msl, but sometimes as high as 5,500 feet above msl. It is less commonly identified in the mid to higher elevations of the Cascade and Olympic ranges. This community type is characterized by wetland hydrology or soils, periodic riverine flooding, or perennial flowing water occurring in patches or along stream corridors within upland mixed conifer-hardwood forests. This community ranges from very wet and warm to moderately dry and cold. It is characterized as including palustrine scrub-shrub and forested wetlands (Cowardin et al. 1979). Bogs and non-wetland riparian areas are considered part of this community type ( and Kagan 2001).

# IV. Functions of Forested Wetlands

Ecologic functions are the physical, chemical and biologic attributes that contribute to the self-maintenance of wetland ecosystems (Brinson 1993, Smith et al. 1995). Some of these processes have importance to society because they have an economic, cultural, or aesthetic value. Wetland processes occur at all scales, from microscopic to landscape. Functions usually are described as a group of related processes that are on a similar temporal and spatial scale (Hruby et al. 1999). Carbon cyling is added here to the usual list outlined in the Washington State Functional Assessment as it is considered an important function of forested wetland ecosystems (Costanza et al. 1997).

## *A. Water Quality Improvement*

Water quality improvement is a basic wetland function and includes aspects of physical, biological (i.e., microbial uptake, conversion of nutrients, and breakdown of pollutants), and chemical processes. Commonly evaluated aspects of water quality improvement include nutrient removal and conversion to more useful forms (i.e., conversion of inorganic nutrients to organic forms), sediment removal, chemical detoxification, and maintenance of cool temperatures. A wetland’s ability to improve water quality can be measured using indicators such as suspended sediment, dissolved oxygen, temperature, turbidity, fecal coliform bacteria, total phosphate, total Kjeldahl nitrogen, nitrite and nitrate nitrogen, ammonium nitrogen, and pH. Nitrogen and phosphorus are most commonly studied, because they are critically limiting for algae and are therefore important in eutrophication control.

Wetland water chemistry and water quality functions are related to a wetland’s physical setting, water balance, local climate, quality of inflowing water, type of soils and vegetation, quantity of vegetation, and nearby human activity (i.e., land use in the area draining to the wetland). The position of a wetland in a basin influences water quality downstream of that wetland. For example, wetlands upstream of salmonid-bearing streams can minimize the effects of sedimentation on fish habitat. Vegetation within a wetland contributes to water quality improvement processes by decreasing water velocity thereby promoting sediment removal, by directly taking up dissolved nutrients and particles, and by trapping suspended organic and inorganic material (Kuenzler 1989). Plants also provide oxygen to oxygen-deficient wetland soils through their roots, creating an oxidized zone where transformation of nitrogenous compounds can occur (Good and Patrick 1987).

Sediment removal is a wetland process in which sediment is retained within a wetland, delaying the amount of sediment released, and/or the timing of the release to downstream waters. A wetland performs this function if there is a net annual decrease of sediment load to downstream surface waters within the watershed. Reduction in water velocity and filtration are the major processes by which sediment is removed from surface water, from stream flow, or from sheet flow in wetlands (Mitsch and Gosselink 1993, 2000). When water velocity is reduced, particles in the water tend to settle out. The size of the particles that settle out is directly related to the reduction in velocity achieved within the wetland. Filtration is the physical blockage of sediment by erect vegetation (Hruby et al. 1999).

The function of nutrient removal includes wetland processes that remove nutrients (particularly phosphorus and nitrogen) from incoming water and thereby limit the export of these nutrients to downstream waters. A wetland can be shown to perform this function if there is a net annual decrease in the amount of nitrogen and/or phosphorus reaching downstream waters (either surfaceor gr oundwater) flowing into the wetland. The major processes by which wetlands reduce nutrients are:

- trapping sediment containing bound phosphorus;
- removing phosphorus by adsorption to soils that are high in clay content or organic matter;
- removing nitrogen through nitrification and denitrification in alternating oxic and anoxic conditions (Mitsch and Gosselink 1993); and
- concentrating inorganic nutrients entering the wetland and converting them to organic nutrients, which are more accessible to detritivores and herbivores in down-gradient waters.

Similarly, a wetland's removal of metals and toxic organic compounds limits the ability of these substances to travel to downstream waters within the watershed. A wetland is shown to perform this function if there is a decrease in the amount of metals and toxic organics flowing to downstream waters (either surface or groundwater). Wetlands have the ability to reduce metals and toxic organic loading downstream by chemical precipitation, by adsorption, by plant uptake, and by trapping sediments that are bound to particulate metals. Adsorption is promoted by soils with a high clay content or organic matter. Chemical precipitation of many toxic compounds is promoted by wetland areas that are flooded and remain anaerobic, as well as by those with pH values below 5 (Mengel and Kirkby 1982). Uptake by plants is maximized when there is significant wetland coverage by emergent plants (Kulzer 1990).

Surface water temperatures within forested wetlands may be moderated by overhead shading and by inputs of cooler groundwater through discharge. Shaded wetlands keep expressed groundwater cooler than surface water traveling downstream via overland flow or through an unvegetated channel (Hruby et al. 1999).

### *B. Base Flow Support (Aquifer Recharge and Discharge)*

Groundwater recharge is the wetland process by which surface water is infiltrated into the groundwater system. Groundwater infiltration primarily occurs in wetlands in two ways: as transport of surface water to subsurface unconfined aquifers, or as shallow subsurface interflow to streams near or within the wetland system during the dry season. Wetlands recharge groundwater by storing precipitation and surface flows, thereby increasing infiltration. Groundwater discharge occurs when groundwater emerges to the surface as a spring or exits from the toe of a slope as a seep (Hruby et al. 1999), or when a seasonal rise in groundwater expresses as surface water within a basin that lies below the surface of a shallow aquifer.

## C. Peak Flow Reduction and Erosion Control

Reduced peak flows occur when surface water input from a major storm is delayed from entering waterways, thus reducing flooding and streambank erosion. Relevant to basin morphology, wetlands have a greater storm-water holding capacity than typical upland environments, because they can physically retain the storm water. Wetlands also reduce peak flows on streams and rivers by slowing and storing overbank flow and by holding upslope storm water runoff (Reinelt and Horner 1990).

Decreased downstream erosion is the wetland process by which high flows are detained during storm events and the quantity and the duration of erosive flows are reduced. A wetland performs this function by storing excess runoff during and after storm events and then slowly releasing it to downstream surface waters. It also performs this function through rooted vegetation that binds soil particles.

Downstream erosion is reduced through the reduction of overland flow and stream velocity. Wetlands retain overland flow and reduce downstream flows during storms by retaining surface water longer than a stream could. The amount of detention provided is dependent on the available storage area and the runoff release rate. The function of decreasing downstream erosion is closely related to that of reducing peak flows, because a reduction in peak flows will also result in a reduction of velocity (Hruby et al. 1999)

## D. Organic Matter Production and Organic Matter Export

Primary production of plant material and the organic export from a wetland via surface water are functions that affect nutrient movement through the ecosystem (i.e., nutrient and carbon cycling, nutrient and carbon sinks, and nutrient and carbon sources). Wetlands are known for their high primary productivity (measured in gm carbon/$m^2$/year, or as total biomass) and in many cases are responsible for the subsequent export of organic matter to adjacent aquatic ecosystems (Mitsch and Gosselink 1993, 2000). Wetlands may retain the organic material they produce or they may export some or most of it to downstream receiving waters. The organic matter provides an important source of food for resident wetland grazers or for members of downstream aquatic ecosystems (Mitsch and Gosselink 1993, 2000). The highest performance of this function requires that organic material is produced and that a mechanism is available to move the organic matter to adjacent or contiguous aquatic ecosystems (Hruby et al. 1999).

## E. Nutrient Cycling

Nutrients are carried into wetlands by the hydrogeologic inputs of precipitation, river flooding, litter fall, and surface- and groundwater inputs. Outflows of nutrients are controlled primarily by the outflow of water. These hydrologic and nutrient flows are catalysts for productivity and decomposition within the wetland system. Nutrient cycling within the system includes both decomposition and primary productivity. In systems with flowing or pulsing hydrologic inputs, productivity and decomposition are usually high, a result of the influx of nutrients with surface water and the temporal changes in soil oxidation and reduction. In hydrologic environments with less-fluctation, productivity and decomposition processes are slow due to reduced nutrient inflow from groundwater and the longer temporal cycles of soil oxidation and reduction (Mitsch and Gosselink 2000).

Wetland hydroperiod has a significant effect on nutrient transformation, on the availability of nutrients to vegetation, and on loss of nutrients from wetland soils in gaseous forms. One of the most limiting nutrients in wetlands is nitrogen. Nitrogen is altered under reduced conditions of wetland soils, is transformed through nitrification and denitrification, and is released as di-nitrogen gas and ammonium nitrogen (Mitsch and Gosselink 2000).

Flooding alters soil water pH and soil redox potential, which often determines nutrient availability. When soils are flooded, their waters tend toward a pH of 7. The redox potential measures the intensity of oxidation or reduction in a system, and indicates the state of nutrient availability (oxidation). Phosphorus is more soluble under anaerobic conditions, due to decreased pH and hydrolysis and the reduction of ferric and aluminum phosphates to more soluble compounds. The availability of major ions such as potassium and magnesium, and of several trace nutrients such as iron, manganese, and sulfur, also is affected by hydrologic conditions in wetlands. When water within soil pores has reduced pH levels, the increased acidity solubilizes nutrients and elements, making them available for plant uptake (Mitsch and Gosselink 2000).

### *F. Carbon Cycling and Biomass Forest Production*

Plants take up atmospheric carbon and produce plant tissues. Some of the carbon remains in the living plant, some remains in woody debris once the plant dies or becomes the organic component of soil, and some is released back into the atmosphere over time. Estimates of carbon uptake in the northern hemisphere vary greatly, but an inventory of forested lands and comparisons of forest sector budgets for carbon in Canada, the United States, Russia, and China determined that in the early 90's, northern forests and woodlands provide a total sink of 0.6 to 0.7 Pg (1 Pg = $10^{15}$ g) (Goodale et al. 2002). The breakdown of this carbon is 0.21 Pg C/yr in living biomass, 0.08 Pg C/yr in forest products, 0.15 Pg C/yr in dead wood, and 0.13 PG C/yr in the forest floor and organic matter in the soil.

Temperate forests supply by far the largest carbon sink (80% in the northern hemisphere), however, they supply only 1/3 of the forest area. This is enhanced by forest fire suppression, conversion of farmland to forested land, and plantation forestry.

Carbon sequestration is considered a potential tool to address global warming due to increases from carbon emissions. Some simple ways to increase carbon sequestration is through: increasing the area of forest land, increasing agroforestry, and increasing carbon in durable wood products through efficient utilization of raw material.

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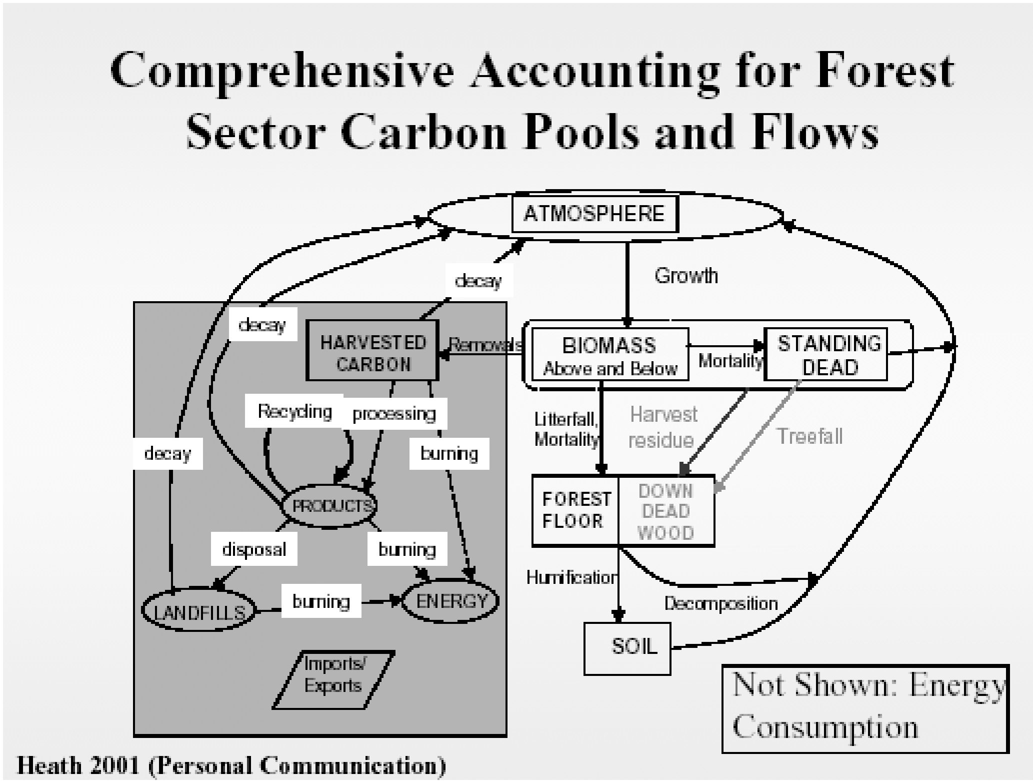


From Heath 2001 in Birdsey 2001

### G. Wildlife Habitat

Wildlife habitat function comprises the characteristics or processes present within a wetland that indicate a general suitability as habitat for a broad range of animal species. It also includes processes or characteristics within a wetland that help maintain ecosystem resilience. Several wildlife guilds and their habitat functions are described below.

Providing quality habitat for invertebrates can be defined as the wetland process and characteristics that help maintain a high number of invertebrate species within the wetland. Invertebrates include Insecta (insects), Amphipoda (scuds, sideswimmers), Eubranchiopoda (fairy, tadpole, and clam shrimps), Decapoda (crayfish, shrimps), Gastropoda (snails, limpets), Pelecypoda (clams, mussels), Hydrocarina (water mites), Arachnida (spiders), and Annelida (worms and leeches). Invertebrates are diverse and abundant zoological components of wetlands and other aquatic systems. Species richness within a wetland is generally more ecologically important than high abundance of one or two species. Wetlands with high species richness tend to be more important in maintaining the regional biodiversity of invertebrate populations, providing a genetic source and refuge that helps maintain ecosystem integrity. In turn, there are wetlands with a high abundance of a few species that may be important to individual wildlife species that feed on these invertebrates.

Habitat functions for amphibians are the wetland processes and characteristics that contribute to the feeding, breeding, or refuge needs of amphibian species that use wetlands. Amphibians are a vertebrate group that includes wetland-breeding frogs, toads, and salamanders. Their species richness, abundance, and niche occupation make them extremely important in wetland trophic organization. Many native species only remain for a short time in wetlands, as metamorphosed juveniles, while adults live in upland areas; however, some species require water during their early development. Wetlands play an important role in the life cycle of amphibians by providing the quiet waters and food sources needed for early stages of development. Amphibian habitat in wetlands is assessed by characterizing the conditions in a wetland that support the development of eggs and larvae and that provide protection and food for adults moving into and out of the wetland.

In general, the suitability of a wetland as amphibian habitat increases with an increase in the number and availability of appropriate habitat characteristics, including shallow water, thin-stemmed emergent vegetation, and woody debris. Because amphibians move on the ground, suitable wetlands must include safe migration corridors for amphibians to immigrate to and emigrate from the habitat. The highest function for amphibian habitat would include conditions that support many different amphibian species and migration corridors.

Habitat suitability for fish includes the wetland processes and characteristics that contribute to the feeding, breeding, or refuge needs of resident native and anadromous fish that use wetlands. Habitat suitability is based on structural elements, physical components, and other wetland characteristics that are considered to be important elements of fish habitat. In general, the suitability of a wetland as fish habitat is assumed to improve as the number of beneficial habitat characteristics increases. Many wetlands provide cover, sufficient water depth, surface area, food sources, and other attributes necessary for overwintering anadromous fish, such as coho salmon. Other fish noted in studies of ponded systems associated with off-channel habitat include cutthroat trout and steelhead (Peterson 1982).

Habitat suitability for wetland-associated birds comprises the processes and environmental conditions in a wetland that provide habitats or life resources for these species. Wetland-associated bird species depend on aspects of the wetland ecosystem for some part of their life needs: food, shelter, breeding, or resting. The guilds of wetland-dependent birds often include waterfowl, shorebirds, herons, and many upland species that use forested wetlands during migration, nesting, or foraging (O'Connell et al. 1993). In general, the suitability of a wetland as bird habitat increases as the number of appropriate habitat characteristics increases. Wetlands that provide habitat for the greater number of bird species or bird guilds (i.e., those that have greater ecosystem diversity) are generally considered to function more effectively than those that have fewer species.

Habitat suitability for wetland-associated mammals is defined as wetland features and processes that support one or more life requirements of aquatic or semi-aquatic mammals. Mammalian species whose habitat requirements are considered closely linked to wetland areas include beaver, muskrat, river otter, and mink. In addition, many terrestrial mammals use wetlands, if they are available, to meet some of their life maintenance requirements. Wetlands that provide habitat for the greatest number of wetland-associated mammal species function at a higher level than those meeting the habitat needs of fewer species.

# V. Effects of Forest practices on Forested Wetlands

There is little research that examines forest practices on forested wetlands alone. More commonly forested wetlands are included in studies that look at broader landscapes. Much of the information that follows was not conducted specifically in forested wetlands. However, it is included as management in forested wetlands is not significantly different from upland stand management (WAC 222-30).

## *A. Regulation of Timber Management Practices in Forested Wetlands-*

Known effects of forest practices in wetlands include removal of nutrients, reduction of soil productivity resulting from extraction methods (road construction, skid trails, and staging areas), increased sedimentation, increased soil temperature, alteration in water yield and stream flow patterns, and reductions in available wildlife habitat (Trettin et al. 1997).

Although there is a considerable body of knowledge regarding silvicultural practices for the drier end of the forested wetlands continuum (e.g., wet pine flats), and a limited amount of silvicultural research regarding moderately well drained to poorly drained bottomland hardwoods, there has been little research into optimum silvicultural practices for the wetter portion of the forested wetlands continuum (Stokes and Schilling 1997). Results of studies outside the PNW suggest that proper harvesting techniques can minimize impacts to forested wetlands (Jackson and Stokes 1990; Shepard 1994; Stokes and Schilling 1997). Precautions used with silvicultural application of fertilizers and pesticides (e.g., buffers and assessment of wind conditions) can also decrease or prevent impacts (Trettin et al. 1997).

Many states have implemented voluntary guidelines for low-impact timber harvesting (Ice 1989). Examples of harvesting practices that can reduce impacts to hydrology and soils include the following: limiting harvest to periods of low soil moisture or frozen conditions, using low impact harvesting techniques or cable harvest systems, partial suspension of logs during yarding (when possible), and avoiding the use of tractor and wheeled skidders in wetland areas when soil moisture content is so high that unreasonable soil compaction, soil disturbance or wetland, stream, lake or pond siltation would result (WDNR 1995).

Forested wetlands, with the exception of forested bogs, may be harvested. Regulations in the Washington Forest Practices Act (2001) are designed to protect wetland functions when measured over the length of a harvest rotation. The regulations encourage the landowners to reduce impacts to hydrology and soils in forested wetland areas by limiting harvest methods to low impact harvest and cable systems unless approved in writing by WDNR and by encouraging landowners to minimize the placement and size of landings within forested wetlands.

## *B. Timber Management Practices*

Common timber management practices utilized in PNW uplands are divided into two broad categories: even-aged stand management and uneven-aged stand management. Each timber management practice changes current stand conditions, fish and wildlife habitat, and stand composition of the regenerating forest differently, based on the standing vegetation community and management activity. Any particular stand management technique will have advantages and/or disadvantages to the resident or targeted wildlife species. The following information summarizes some methods of timber management, which varies among landscapes and ownerships.

The majority of timber management practices in western Oregon and Washington utilize even-aged management (Hall et al. 1985). Even-aged stand management is defined as a forest or stand composed of trees having little to no differences in age (within a 10- to 20-year range). This practice, also known as clearcutting or plantation forestry, creates open conditions and uniform stands during succession. Forest managers using even-aged stand management techniques alter the forest community and habitat value, shortening the length of the growth cycle (affecting tree height and diameter), and decreasing the presence or absence of snags by prescribing salvage cutting or snag falling (Hall et al. 1985).

Clearcut patches within old-growth forest displace, reduce, or eliminate wildlife of old-growth communities and provide habitat for wildlife requiring open grass or shrub communities for feeding and reproduction (Hall et al. 1985). Edges created by clearcut in old growth are important to wildlife species that exploit more open conditions for feeding and nesting, but can be deleterious to species adapted to older conditions.

Uneven-aged stand management is defined as a forest or stand composed of a variety of tree ages. Uneven-age management maintains different age classes of trees within the stand and promotes structural diversity. Trees are harvested selectively based on size and age, or in small groups or patches. Forest communities selected for uneven-aged stand management often include shade-tolerant species that reproduce and grow under a canopy.

Uneven-aged stand management results in wildlife habitat types with more spatial homogeneity. Grass or shrub communities are not present; however, the stand contains a multilayered forest of different tree sizes and shade tolerant shrub layer that provides heterogeneous habitat for those species that exploit these conditions throughout their life cycles. The habitat value for wildlife within these stands is related to the target tree size. In some cases stands are maintained by periodic harvest of all tree sizes until the largest trees reach a certain diameter at breast height (DBH). This practice often eliminates old-growth structure within the stand, decreasing habitat diversity.

### *C. Effects of Forest Management on Forested Wetland Hydrology*

Potential impacts of forest management practices on forested wetland hydrology include changes in peak flow, baseflows, and water fluctuation; disruption of surface- and groundwater drainage patterns; and groundwater exchange reductions. Removal of trees within a wetland causes changes in solar radiation, transpiration, and the hydrologic regime. Similarly, harvesting forest adjacent to a forested wetland allows increased solar radiation and decreased transpiration in the groundwater contributing area, which may lead to a rise in the water table and possibly to nitrogen release in the wetland itself. Hydroperiod changes would be most pronounced in isolated, groundwater-fed, flat wetlands with low rainfall and small groundwater-contributing areas, particularly those experiencing a high amount of input from impervious surface runoff. In western Washington, rainfall and evapotranspiration occur at levels that should allow for less extreme hydrologic impacts than those observed in wetland forests of the eastern United States (Beschta 2002).

Increases in peak flow after clearcutting (including site preparation, road building, and cable logging) occurred in watersheds in the western Cascades of Oregon (Beschta et al. 2000; Jones and Grant 1996). Changes were attributed to several factors, including roads, slash burning, and succession changes. The reported magnitude of these effects varies by study (Beschta et al. 2000), and the results of peak flow studies, as well as the interpretation of these, also are variable in the literature (Thomas and Megahan 1998).

Filling springs, compacting soils, and reducing point of recharge and discharge may all result from forest practices and may reduce groundwater exchange (Canning and Stevens 1990). Reduction of base flow, resulting from the introduction of early successional species such as cottonwood which utilize more water and lose it through evapotranspiration, was observed in riparian areas of the western Cascades (McKee 1994). Water level fluctuations in watersheds have also been shown to increase with forest cover loss. In a study of watersheds subject to various levels of deforestation, those with less than 14 percent forested area showed increased water-level fluctuations (Taylor 1993). Hydrologic effects, on average, last for seven years; solar insolation reductions last for fifteen to twenty years; and rutting is semi-permanent. By comparison, rotation length is normally thirty-five to sixty years (Beschta 2002). It may be necessary to measure effects within the framework of rotation length when making management decisions.

Teskey and Hinckley (1980) discuss the impacts of changes of water levels on plant communities including forests through natural and managed activities. These include both short- and long-term changes to the root, stem and leaves of the plants. Flooding in the root zone results in an anaerobic environment that interferes with normal root functions and causes stresses that affect water and nutrient uptake, xylem and phloem transport photosynthesis and transpiration. These in turn affect growth and ultimately survival of the plant. Although most species exhibit reduced growth under flooding or soil water field capacity conditions, there are some species that have tolerance mechanisms that allow for better growth under soil saturation conditions than if the soil is at the typical wilting point (Hosner 1960, and Ewing 1999). The tolerance mechanisms exhibited fall into two categories - physical and metabolic.

There are conflicting reports about the effects of flooding frequency that can be affected by timber harvesting activities on growth rates. Some researchers found that there was no affect to trees greater than 4cm in diameter, while other researchers found that for floods greater than 5-days in duration, the time of occurrence can be crucial to changes in basal area of the species. Water depth changes can also result in a shift in germination of seedlings and height growth (Teskey and Hinckley 1980, Ewing, 1999),

### *D. Effects of Forest Management on Wetland Water Quality*

Where specific data addressing forested wetlands do not exist, water quality impacts may be inferred from studies of silvicultural practices in riparian areas and in forested watersheds. Results of harvest generally include loss of shading (Cannings and Stevens 1990), slash deposition, loss of large woody debris (McKee 1994), bank destabilization (Amaranthus et al. 1985; McKee 1994) and land-use changes (Canning and Stevens 1990). Other changes that occur with harvest activities, and that might be expected to affect water quality in wetlands, include sediment and nutrient release, drainage, fertilizer and herbicide runoff, and rutting. Opening the canopy can reduce temperature buffering, which is needed for protection from high summer temperatures and winter icing (Canning and Stevens 1990). Similar to the paucity of studies directly addressing water quality in forested wetlands, little research has been aimed specifically at the effects of forest management practices on forested wetlands.

Shepard (1994) reviewed the literature, most of which pertained to the southeast United States, on changes in surface water quality of wetlands after silvicultural practices (thinning, clearcutting, site preparation, bedding, planting, drainage, and fertilization). Five studies (Askew and Williams 1984, 1986; Fisher 1981; Hollis et al. 1978; and Riekerk 1985) out of seven (the above studies, plus Lockeby et al. 1994 and Trettin and Sheets 1987) revealed a trend toward significant increases in suspended sediment after timber harvest, relative to undisturbed watersheds, particularly when the combined effects of draining, forest harvest activities, planting, and skidding were considered. Drainage alone affected cations, anions, and metals to varying degrees, and two studies found at least one of these was higher in drainage ditches, compared with the natural drainage waters (Askew and Williams 1986, Trettin and Sheets 1987), while other concentrations did not vary significantly. Four of five studies found that fertilization elevated nitrogen and phosphorus parameters, and the application method seemed to affect results (Bissen et al. 1992; Campbell 1989; Fromm 1992; Herrmann and White 1983). There is disagreement in the literature as to whether nitrogen and phosphorus become elevated as a result of watershed disturbance from silvicultural operations. Four of nine studies (Ewel 1985, Fisher 1981, Hollis et al. 1978, Riekerk 1985), found nitrogen and phosphorus parameters elevated relative to undisturbed watersheds. Some parameters remained unaffected in each study. Silvicultural practices resulted in elevated pH in the single study in which this parameter was measured (Shepard 1994). The author concluded that because effects were often small and because water quality parameters returned to pre-disturbance levels within several weeks to several years, properly conducted silvicultural operations did not constitute a permanent threat to the water-quality functions of forested wetlands.

Much additional research has been conducted on streams and watersheds. Stream temperature change is the most-often studied result of timber harvest in the PNW. Shifts in stream temperature and timing of maxima could potentially impact sensitive stages of aquatic biota, including cold-water fishes, and may affect the rates of many biotic and abiotic processes.

Maximum stream temperature and spring diurnal fluctuation increased after removal of riparian vegetation in basins in the western Cascades of Oregon and returned to pre-harvest levels after fifteen years (Johnson and Jones 2000). Maximum and minimum stream temperatures in another basin in the region rose 6 degrees Celsius over a thirty-year period, and the increase was highly correlated with forest harvest activities (Beschta and Taylor 1988). In the Oregon Coast Range, annual maximum stream temperatures increased by 14 degrees Fahrenheit in a small stream after clearcut harvesting in the densely forested stream basin, where no buffer remained after harvest. No temperature changes could be attributed to clearcut harvesting in a nearby basin that was patch cut with several clearcut units, where 75 percent of the basin was left uncut and strips of vegetation were preserved along the stream (Brown and Krugier 1970).

Literature published prior to 1995 indicates that removal of riparian vegetation led to increased summer stream temperatures (Teti 1998). The research included in Teti's (1998) review also provides evidence that the downstream effects of water temperature increases may be small, and that riparian buffers provide diminishing benefits on non–fish-bearing streams the farther upstream they occurred. The time required for recovery depended on stream physical characteristics, topography, and revegetation.

Sediment generated by bottomland forest roads installed for management purposes in Alabama did not significantly impact total suspended solids of floodwater, due primarily to area that served as sediment sinks (Rummer 1999). In a separate study, sedimentation rates varied between harvested plots and controls based on inundation period length but not on treatment (Lockaby et al. 1997). In Ontario, Canada, harvesting and road improvement increased inorganic sediment loads and deposition rates, but did not appear to affect the bedload of organic sediments (Kreutzweiser and Capell 2001). The authors found that riparian buffer zones were not necessary to reduce sedimentation,

Forest harvest was followed by a minor increase in calcium and potassium sink activity in a floodplain forest in Georgia (Clawson et al. 1999).

Ludwa (1994) examined the relationship between water quality and urbanization in wetlands and their watersheds and reported total suspended solids in excess of water-quality criteria in watersheds comprising less than 14.7 percent forest. The study also used aquatic insect taxa richness as an indicator of quality. Taxa richness was inversely correlated with the amount of impacted habitat in the watershed.

Increased flooding that can result from timber harvest through soil compaction and other activities associated with timber harvesting has been observed to be associated with a decrease in pH in already acidic soils. The redox potential decreases from greater than +200mv (in unflooded state) to as low as 0. This reduction in both pH and redox potential results in significant changes in chemical states and, therefore, nutrient availability (Teskey and Hinckley 1980). Some nutrients are actually more available (phosphorus, nitrogen, Magnesium, and sulphur for macro nutrients and Iron, Manganese, molybdenum, cobolt, and copper for micronutrients) during flooding, while some become less available (potassium, calcium). In some instances, nutrient availability may increase to a point where the nutrient becomes toxic to the plant.

Bogs in forestland, in particular, show a response to changing water quality; for instance, increases in nutrients or pH can permanently and irreversibly impact these systems (Canning and Stevens 1990).

## *E. Effects of Forest Management on Wetland Soils*

Effects on forested wetland soils due to forest harvest activities can be separated into several different categories: disruption of surface duff and/or topsoil layers, soil compaction, erosion, liquidification, alterations to organic soils, and specialized concerns for frozen soils. Each of these is discussed below.

### 1. Disruption of Surface Duff and Topsoil Horizons

Forests create their own surface horizons and topsoil layers with the accumulation of needles, leaves, twigs, and branches on the soil surface, and the creation of topsoil layers (A horizons) or eluviated layers (E horizons) under the forest litter (or “duff”) layer. These surface and near-surface horizons provide a relatively fertile, friable, rooting medium for newly spouted tree seedlings, and the duff layer can function either as a rooting medium or a moisture-conserving mulch layer. Soil organic matter, especially decaying wood and humus at or near the soil surface, plays an important role in soil nutrient availability and cycling, gas exchange, water supply, soil structure, disease incidence, mycorrhizal root development, seedling establishment and growth, and site productivity (Jurgensen et al. 1990; Blake and Ruark 1992, Harvey et al. 1987, Henderson 1995, Powers et al. 1990, Page-Dumroese et al. 2001). By comparison, the underlying subsoil layers (B and C horizons) are less fertile, have a greater bulk density (meaning they are denser and less friable, thus affecting root growth), and often contain accumulations of iron oxides, aluminum oxides, clays, or carbonates that may be limiting to soil nutrient availability and uptake and in certain concentrations could be outright toxic to plant roots (Curran 1999).

Forest harvest activities often disrupt or disturb the forest floor, resulting in the loss of duff and/or topsoil layers in localized areas or the mixing of duff, topsoil and subsoil layers over broader areas. Studies from the northwestern United States have shown that loss of organic matter after harvesting or site preparation can have profound effects on soil physical, chemical, and biological properties and reduce soil productivity (Perry et al. 1989, Powers et al. 1990, Everett et al. 1994, Harvey et al. 1994, Jurgensen et al. 1997, Page-Dumroese et al. 2001). With the inadvertent disruption or removal of duff and surface soils, soil nutrient pools are depleted, and nutrient cycling processes are impaired by the removal of nutrients and microbial inoculum (Bulmer 1998). In the drier inland PNW forests of southeast British Columbia, western Montana, Idaho, eastern Washington, and eastern Oregon, this disruption or removal of soil organic layers and decomposing woody debris is especially significant, since beneficial ectomycorrhizal root activity is intricately connected with soil organic matter and site productivity (Jurgensen et al. 1990). All of these soil disruptions impact tree regeneration. Some species, such as western hemlock, produce more seedlings and their survival rate is significantly higher when a duff layer is intact, especially in areas with relatively dry summers.

Surface duff layers and soil organic matter also contribute to the stability of soil structure. Coarse-sized pores (macropores) are important in soils because they facilitate infiltration of rainwater, drainage of excess water, and allow oxygen to enter into, and diffuse through, the soil profile for soil fauna and for plant root growth. The amount of macropores in coarser-textured soils is dependent upon the arrangement of sand and silt grains. In medium- to fine-textured soils, macropores result when silt and clay particles are arranged into larger structural units called “aggregates” (Bulmer et al. 1998). Such aggregates and their associated macropores are stabilized in surface soils largely by organic matter, bacteria, plant roots, and fungal hyphae (British Columbia Forest Science Program 2002). In lower horizons, clay binding, aluminum and iron hydroxides, and to a lesser extent organic matter, play a major role in creating and stabilizing soil aggregates. Timber harvest activity that disrupts soil layers, inputs of organic matter and the movement of organic matter, clays, and sequioxides can be slowed or interrupted, thus interfering with the natural process that stabilizes and preserves soil aggregates (Bulmer 1998). Macropores collapse, resulting in decreases in air and rainwater infiltration and movement within the soil profile.

## 2. Soil Compaction

Soil compaction is a common consequence of harvesting trees with ground-based harvest equipment. Compaction increases bulk density and decreases porosity (the proportion of the soil volume occupied by macropores), decreases infiltration rates, and decreases hydraulic conductivity (Bulmer et al. 1998, Froehlich and McNabb 1984, McNabb et al.

2001). Soil compaction often reduces the regeneration and growth of trees (Greacen and Sands 1980, Miller et al. 1996), and a reduction in tree growth can persist for several decades (Wert and Thomas 1981, McNabb et al. 2001). Compaction frequently leads to physiological stress on existing trees and seedlings, decreases shoot growth on trees, and can cause increased competition by weedy or less-desirable vegetation (Froehlich and McNabb 1984, McNabb and Campbell 1985, Conlin and van den Driessche 1996). By reducing infiltration rates and decreasing hydraulic conductivity, soil compaction from forest harvest activities can also lead to increases in soil erosion and changes in landscape hydrology that can affect stream flows (Harr et al. 1979) and wetland hydrology levels. Soil compaction also adversely affects soil biological processes and reduces soil microbial populations (Dick et al. 1988).

McNabb et al. (2001) studied the affects of forest harvesting traffic on soil and soil wetness on porosity and bulk density on 14 boreal forest soils in the Rocky Mountains of Alberta under three, seven, and 12 cycles (individual loaded trips) of skidding with mostly wide-tired skidders. They concluded that significant increases in bulk density occurred after three cycles where soil water potential was higher than -15 kPa (close to field capacity in sandy loam-textured soils), and increases in bulk density were significant to depths of at least 22 cm (8.7 inches). While bulk densities continued to increase at seven and 12 skidding cycles, the overall increase was not significantly different from bulk densities at three cycles. They concluded that soil compaction occurred only when the soils were at or wetter than field capacity, and one effective tactic to avoid significant soil compaction by wide-tired skidders would be to conduct tree-felling operations during drier seasons and after maximum transpiration by trees took place to reduce soil wetness levels. For seasonally saturated wetlands that thoroughly dry out during a dry season, this information is useful to help lessen soil compaction during timber harvests; however, for wetlands that have continually moist or saturated conditions, these results imply that significant soil compaction would occur during forest harvest activities unless the activities were conducted when the soils were frozen (Alaska). This study also demonstrated that a significant increase in bulk density due to skidder activity did not affect the parameters of field capacity, permanent wilting point, and available water holding capacity because the changes in soil porosity were essentially confined to the macro (larger) pore space while the micropore space remained unaffected (Startsev and McNabb 2001).

Conlin and van den Driessche (1996) found that under laboratory conditions, seedlings of lodgepole pine, interior Douglas fir, and white spruce growing in compacted soils had reduced uptake in nitrogen, phosphorus, potassium, manganese, boron, copper, magnesium, and zinc. Iron and calcium were unaffected. Within these same studies, it was concluded that soil compaction also leads to increased levels of soil carbon dioxide levels in the soil atmosphere, and seasonal variations in the levels of ethylene. While it is documented that large concentrations of carbon dioxide decreases respiration in young Douglas fir roots (Qi et al. 1994), it is yet undetermined if the increased levels of soil carbon dioxide or the seasonal fluctuations of ethylene in compacted soils are enough to truly inhibit plant growth.

Bulmer (1998) and the British Columbia Forest Science Program (2002) discuss various remediation treatments that can be implemented to improve stripped, compacted soils on skid trails, landings, and decommissioned forest roads for reforestation. Most of the restoration techniques implement some form of tillage, and possible inclusions of soil amendments and native or agronomic vegetation understory or groundcovers. Such restoration techniques often account for one-third to one-half of overall project costs. Bulmer (1998) discusses the need for additional research in evaluating numerous different soil remediation techniques, including tillage, woody and nutrient-rich residues, mulches, revegetation testing, and microbial additions.

### 3. Liquidification

Forested wetland soils have soil characteristics that are problematic for forest harvest activities, such as the construction and operation of spur and haul roads, log landings, and log transfer sites. Soils with poor drainage, a high water table, and low soil strength that are subjected to uneven weight and vibrations from heavy equipment can often result in liquidification. Liquidification is a process in which the stability of the soil matrix breaks down and the soil becomes a saturated, semi-liquid mass. In wetter environments, such as southeast Alaska, soil liquidification is one of the primary problems with forest harvest actvities, especially in sloped terrains (Loggy pers. comm., Krosse pers. comm.). Little was found in the literature on liquidification in forested wetland soils, aside from anecdotal discussions with field scientists and its mention in the Ketchikan Area Soil Survey User Guide (USDA 2002).

### 4. Erosion

Soil erosion is dependent on soil internal properties (organic matter, soil texture, and soil structure), external properties (vegetative cover, slope, rainfall, slope length), and type of soil disturbance. On sloped ground, the removal of tree canopy, disruption of forest floor, and rutting by harvesting equipment, often leads to various levels of initial soil erosion until ground or understory vegetation can become re-established. Erosion rates are usually highest immediately following disturbance, and loss of soil and nutrients are frequently one to two orders of magnitude less by the second year (Robichaud and Brown 1999, Page-Dumroese et al. 2001). It does not always follow that sites with the most annual precipitation or greatest slope have the greatest erosion sediment yields. Page-Dumroese et al. (2001) found considerable variability based on soil types and degree of disturbance. Coarse-textured soils, for example, allow greater infiltration and consequently have less erosion. The average natural soil formation rate for forest soils in the PNW is 2.5 Mg (2.5 metric tonnes) per hectare (Troeh et al. 1980). In severely disturbed logged slopes (those with only 10 percent soil cover remaining), sediment yields for certain soils were modeled between 4.9 to 44.7 Mg/hectare (Page-Dumroese et al. 2001). In comparison, for logged slopes with intact forest floor alone, or forest floor and tree crowns (slash) left on the soil surface with no compaction, sediment estimations downslope were <2.0 Mg/hectare (Elliot et al. 1998, Page-Dumroese et al. 2001). Logged slopes with 90 percent soil cover (vegetation or non-compacted forested floor) at midslope and toe-slope positions produced less than 1 Mg/hectare sediment (Page-Dumroese et al. 2001). Under extreme or accelerated soil erosion rates, topsoil is removed and re-deposited downslope, resulting in localized areas of increased productivity. Studies do show, however, that overall site productivity declines because of loss of nutrients, rooting depth, and available water holding capacity (Lal et al. 1998, Page-Dumroese et al. 2001).

While removal of forest canopy and wide-scale disturbance of the forest floor contributes to soil erosion, site preparation can also add to this problem. Broad-scale burning of a site in preparation of reforestation can result in a loss in soil organic matter from volatilization by fire and can create a shallow hydrophobic (water-repellent) layer in the soil profile, which can increase the risk of substantial soil erosion (Robichaud and Waldrop 1994, Poff 1996, Page-Dumroese 2001).

During the 1970s and 1980s, soil disturbances of special concern associated with forest harvest activities in the interior of British Columbia were primarily excavated and bladed trails (or skid roads). During this time period, skid road soil disturbance levels of over 20 percent were not uncommon (Curran and Kockx 2002). In an effort to control the displacement of fertile topsoil through erosion, minimize off-site impacts, lessen soil compaction, and preserve site productivity, interim harvesting guidelines were enacted in 1989 which allowed, on less-sensitive sites, 15 percent soil disturbance (including landings). Surveys done in 1990 and 1991 demonstrated that soil disturbance guidelines had been successful, and many blocks surveyed were below 13 percent soil disturbance for ground-based harvesting (Curran and Kockx 2002). In 1993, British Columbia's Ministry of Forests finalized the Harvesting Guidelines with a guideline disturbance maximum of 13 percent and included provisions for rehabilitation of excavated and bladed trails. Building on disturbance guidelines in BC, the Washington Forest Practices Act of 1995 lowered the soil disturbance guideline limit to 10 percent and included a requirement to rehabilitate excavated and bladed trails. On forested wetland sites, a soil disturbance limit of only 5 percent is allowable (Curran pers. comm.).

## 5. Alterations to Organic Soils from Forest harvest activities

During forest harvest activities, the construction of roads, skid trails, and landings can result in changes in surface or near-surface hydrology of localized areas, thereby changing runoff or drainage patterns. In some circumstances, wetland depressions or drainage corridors could have their hydrology source substantially reduced, thereby drying the wetland area. In addition, construction of roads and landings can lead to the draining of some wetland areas. If the wetland area is dominated by organic soils, such drained or drier soils can lead to the decomposition and oxidation of the organic material and result in subsidence of the soil surface (Trettin et al. 1997). In other circumstances, land alterations could result in more water being routed into wetland depressions. Such increased hydrology can result in a seasonal or permanent increase in the localized water table, which could adversely affect tree growth and the ability for tree seedlings to re-establish in the given area or result in a shift to more wet tolerant tree species, depending on the hydrologic change in quantity, timing, and duration. Under such circumstances, the wetland area may convert from a forested to a shrub- or herbaceous-dominated wetland system.

Increased soil temperatures following a timber harvest on organic soils can lead to an increased potential for decomposition (Trettin and Jurgensen 1992), which can result in increased nutrient concentrations in drainage waters. Knighton and Stiegler (1980) studied phosphorus dynamics following spruce harvests and slash burning on organic soils and found that phosphorus increased in streamflows resulting in soil losses of up to 3.5 kg per hectare. They also concluded that fluctuating water levels and associated wetting and drying cycles following timber harvests may enhance phosphorus loss from soils as soils decompose and oxidize. Therefore tree harvest and subsequent aeration and oxidation of organic soils not only leads to subsidence, but loss of essential soil nutrients.

Timber harvest removes the biomass and subsequently removes some of the nutrient source for future tree growth. In settings where no fertilization is used, studies show that natural replacement of phosphorus and potassium to pre-harvest fertility levels vary from decades to multiple centuries (Trettin et al. 1997). Micronutrients are not generally deficient within organic soils.

## *F. Effects of Forest Management on Forested Wetland Vegetation and Vegetation Communities*

### 1. Direct Effects to the Vegetation

Timber harvest in conifer or mixed Westside Riparian-Wetlands decreases species diversity and often encourages the establishment of red alder and salmonberry stands. In addition, harvest decreases the amount of large woody debris on the forest floor as well as eliminating its source (Bilby and Ward 1991). Removal of forest overstory in these communities most often results in increased peak flows (Harr and Coffin 1992) and sedimentation (Swanson et al. 1987) in adjacent streams. Road building associated with timber management and other land uses can change watershed hydrology and effect vegetation structure (Furniss et al. 1991).

The most obvious effect of harvesting forested wetlands is vegetation removal (trees logged and shrubs and herbs cleared). Forest harvesting reduces the functional and structural diversity of forest and wetland ecosystems through the loss of either all the vegetation or select vegetation layers (Canning and Stevens 1990). Montane Coniferous Wetlands become more susceptible to wind disturbance when harvest occurs within or adjacent to these communities (Williams et al. 1995).

Canning and Stevens (1990) found several effects of harvest on forested wetlands, such as invasive species establishment that may suspend succession, especially reed canarygrass (*Phalaris arundinacea*) and Himalayan blackberry (*Rubus armenicus)*. A loss of species diversity in the wetlands and their buffers due to selective cutting is also a common result of various forest practices. Further, timber management may reduce the edge effect and decreases overall wetland/buffer species diversity. In addition to impacts on the vegetation, roads that disconnect flow as well as the practice of draining wetlands for timber production may alter the hydrologic regime, potentially changing the post-harvest plant community. Compaction of soils may reduce the reproductive ability of trees in wetlands due to stress of flooding and associated asexual reproductive strategies

### 2. Indirect Effects to the Vegetation

There are many and varied sources of indirect effects to the vegetation resulting from forest management. Timber harvest alters the rate of deposition of large woody debris, which causes changes in the hydrologic regime and shifts in vegetation (Reeves et al. 1995 and Benda and Dunne 1997). There is also a break in carbon cycling that affects nutrient cycling between the soils and trees, nutrient storage in the soils and soil structure (Costanza et al. 1997). Vegetation can also be indirectly affected by the suspension of succession by weeds (DeFerrari et al. 1994). Selective harvest of species reduces species richness and decreases gene exchange impacts genetic variability. Post-harvest wildlife populations can be overloaded by reducing their habitat and increasing localized herbivory (Canning and Stevens 1990) which in turn results in reduced diversity and increased invasive species dominance.

## *G. Effects of Forested Management on Forested Wetland Wildlife and Wildlife Habitat*

### 1. Bird Populations

The effects of timber harvest on birds are varied and depend upon species characteristics, pre-harvest vegetation, type of harvest, intensity and timing of harvest, and successional stage remaining after treatment (Hagar 1999, Manuwal 1991, O'Connell et al. 1993). Granivorous birds are likely attracted to cleared areas because of annual plants and scattered shrubs that develop (Anderson and Ohmart 1984). Species that are attracted to edge habitat tend to be seen in higher densities following timber management activities, whereas those species that are sensitive to edge would be reduced in modified habitat. Edge trees harbor more insects than those in closed forest communities and can support a greater abundance of insectivorous species (Ranney et al. 1981). As previously discussed, several bird species require and many prefer late seral habitat structure for nesting and would be displaced following timber management's removal of snags and/or mature trees. Manuwal (1991) and others suggest that in upland communities, species that are cavity nesters and those that feed on the forest floor are more dependent on old growth stands and may be dramatically impacted following intensively managed forests through fragmentation, reduced forest structure and species diversity, and other habitat components disturbed in nesting and overwintering areas.

Land uses that decrease vegetative cover are thought to increase bird susceptibility to predators by decreasing visual, auditory, and/or olfactory concealment of nests (Larison et al. 1998, Martin 1992, Murphy 1983) and by reducing the number of refuge sites to which prey can escape. Land management activities that reduce vegetation density surrounding nests may increase the predator's ability to locate previously well-concealed nests (Bowman 1980). It also increases susceptibility to predation by reducing the number of potential prey sites a predator must search (Martin 1993, 1998). In designing snag-retention areas, Lindquist and Mariani (1991) suggest that managers should provide adequate snag distribution over large areas, live-tree replacement, and patches of older stands.

A review of the literature for timber management impacts on bird species within upland and riparian communities in the PNW and other regions in the U.S. indicates that bird species diversity and abundance is affected by timber harvesting, and the effects differ depending on the intensity and frequency of harvesting. All bird species are associated with specific habitat types, forest age classes, and forest structure (Mannan and Meslow 1984). Because riparian-wetland habitat types support a disproportionate number of bird species throughout their life history, and these riparian-wetland habitat types represent a relatively small percentage of acreage, it seems reasonable that sustaining viable populations of bird species in the PNW requires the maintenance of a variety of riparian-wetland habitat types and age classes.

Avian habitat may benefit from alternative timber management practices. If harvested stands are allowed to return to mature stand levels of coarse woody debris, many habitat components are replaced. However, short rotation clearcutting depletes the residual coarse woody debris and prevents the development of old-growth structure (Hansen et al. 1991, Bunnell et al. 1997, Hall et al. 1985). Chambers and McComb (1997) tested bird richness and abundance within three timber management practices (modified clearcut, two-story, and small patch group selections) in Oregon. Species richness and abundance was highest in small-patch stands and lowest in control and clearcut stands. In a related publication, silviculture treatments imitating low-intensity disturbances were most effective in retaining nesting bird communities associated with mature forest, while two-story and clearcut treatments greatly altered bird community composition in Oregon upland forests (Chambers et al. 1999). In British Columbia, a study comparing bird abundance and diversity in clearcut, partial forest retention, and uncut mature forest indicated that bird species preferred tree-containing habitat types; retention harvesting succeeded in maintaining most of the forest bird community and increasing total avian diversity (Lance and Phinney 2001). Hansen et al. (1995) support these findings, that canopy tree retention benefits many, but not all, of the bird species they studied. In addition, review of study data sets indicated that there are distinct tree density thresholds at which bird abundance changes.

In riparian systems, streamside buffer zones greater than 40 meters wide that are adjacent to timber management activities were found to benefit forest-associated avian species when density of large trees within the buffer were not reduced by harvesting (Hagar 1999).

The following management considerations apply to riparian and wetland habitat types and to all types of birds. Disruption of natural hydrologic and disturbance processes, whether by direct impacts such as removal of habitat structure, or indirect impacts such as fragmentation and simplifying woody vegetation (Kreuper 1993), affect habitat and associated wildlife in that area. Effects can exclude species or nesting guilds by eliminating nesting substrates such as large trees required for cavity nesters and certain canopy nesters. Similarly, simplification of forest structure can negatively influence individual species, nesting guilds, or breeding assemblage by increasing nest predation.

## 2. Fish Populations

Many published studies have examined the effects of timber management on in-stream fish habitat in the PNW. However, little information specific to forested wetlands and their relationship to fish habitat outside of riparian areas has been published. Few if any studies in this region have examined how forest practices affect forested wetlands, and subsequently, fish populations using forested wetlands. However, in-stream studies examining the effect of timber management on water quality and fish populations may provide a basis for assessing the effect on forested wetlands and their connection with fish.

Loss of riparian forests negatively affects aquatic species. The loss of shade provided by riparian vegetation results in increased stream temperature, altered water quality, and a change in the composition and abundance of aquatic biota (Li et al. 1994). Loss of riparian forests can also reduce aquatic habitat structure through the removal of overhanging vegetation and root tangles.

Salmonids are widely distributed in streams, lakes, ponds, and estuaries throughout coastal areas of the PNW. Salmonids require cool, clear, relatively sediment-free water for spawning and rearing. Riparian vegetative conditions are important to salmonid habitat in regulating stream temperatures and nutrient flow, and as a source of large woody debris. Vegetation communities with low structure (herbaceous and shrub layers) provide little shading for streams and few nutrients in the form of litterfall, and reduce large woody debris input (Brown 1985). However, overhanging shrubs can provide near-shore refugia, especially if root tangles are exposed. Large woody debris is important in establishing and maintaining a diversity of habitats in stream channels.

Fish access both up- and downstream must be maintained for full utilization of available habitat. Sedimentation resulting from road construction and timber harvesting activities can severely impact spawning and rearing areas, while removal of vegetation along riparian areas may cause water temperatures to exceed optimum levels and removes the litterfall and insect rain (from overhanging vegetation) that are a source of nutrients to the stream.

The water-quality section of this report includes further discussion of forested wetlands' interaction with water quality (Section III. D.).

All wetlands provide sediment entrapment regardless of the wetland type. Wetlands provide a range of sediment reduction in overland flow, depending on the quantity and type of vegetation present and the morphology of the wetland. Pess et al. studied the distribution of coho salmon and land-use patterns in the PNW (2002). They found land use and wetland occurrence to be significantly correlated with adult coho salmon abundance and distribution. Specifically, forested areas maintained positive correlations to the abundance of spawners. In addition, wetlands and other wetland-like environments (e.g., peat) had consistent positive correlations to spawner abundance. Pess et al. suggest, based on their analysis, that priority restoration sites should include forested locations with modified wetlands, and that maintaining and restoring these sites is critical to the long-term recovery of salmonids.

### 3. Amphibian Populations

To date, literature from the PNW has not addressed how timber management within forested wetlands might affect amphibians (Hayes 2002). Furthermore, no studies were identified that characterized amphibian use of forested wetlands in this region. Therefore, the following is provided as a summary of timber management's effects on amphibians located in upland or riparian forests from research conducted within the PNW and other parts of the United States.

Research on how timber management affects amphibian species has been conducted in a range of forested habitats, including forested uplands, forested wetlands including headwater seeps, and riparian forests. Within the PNW, amphibian studies have been conducted primarily in upland forests and in riparian zones, and they have typically examined species that are considered terrestrial amphibians (Bury et al. 1991, Aubry and Hall 1991, Aubry et al. 1998, Aubry et al. 1997). Bury et al. (1991a) characterized some Oregon and Washington aquatic amphibians within stream habitats. They note that there are few data sets on the response of aquatic amphibians to timber harvest in the Cascade Range or mountainous areas of the Olympic Peninsula or British Columbia.

Research conducted in upland and riparian forests indicates some trends regarding the effect of timber management on amphibian populations. Within upland stands of the PNW, Hayes and Quinn (2001) found that older stands contained a greater diversity of amphibians than younger stands. Modification of habitat is likely a chief threat to amphibians, especially those with narrow temperature thresholds or habitat requirements (Bury et al. 1991, Campbell 1973, Stebbins and Cohen 1995). Altering essential upland habitats used during amphibians' terrestrial stages or by terrestrial species, and the fragmentation of feeding and refuge areas, may increase the risk of extinction. Habitat alteration is thought to restrict amphibian movement between upland patches and breeding sites (wetlands) and increase isolation of individuals from these environments and each other (Richter 1997).

The literature suggests that timber management in a variety of habitats affects amphibian populations; however, influence and duration of affects appear to vary with harvest type and species affected (Aubry et al. 1997, Corn and Bury 1989, 1991; deMaynadier and Hunter 1995; Johnson and O'Neil 2001; Naughton et al. 2000; Bennet et al. 1980; Welsh and Lind 1991; Bury and Corn 1988a, Grialou et al. 2000). The summation of the research indicates that based on amphibian habitat preferences and climate, response to timber management practices may be more accurately described by reduction of particular amphibian species rather then the elimination of an entire amphibian community.

While not specifically documented in forested wetlands, affects on upland or wetland communities as a result of timber management and other land use may apply to forested wetlands. These affects include alterations to vegetation structure, soil moisture, bulk density, temperature, presence of large woody debris, water quality, and microclimate. As discussed previously, amphibians possess unique life history traits and physiology that increase their sensitivity to physical changes within their home ranges. Removal of forest canopy increases solar radiation, affecting soil temperature and moisture on the forest floor. As a result, amphibians that are adapted to moist cool environments may be extirpated from the area (Johnson and O'Neil 2001). Hydrologic changes from soil compaction and rutting associated with machinery and temporary roads are shown to affect amphibian populations. Equipment may increase soil bulk density by compaction and negatively affect some amphibian populations (Aubry et al. 1997); it may also increase siltation of rock substrate breeding sites. These and other habitat changes can disrupt life history requirements for amphibian egg laying, larval development, juvenile metamorphosis, adult requirements, or overwintering (Johnson and O'Neil 2001).

Several studies report that timber harvest affects riparian herpetofauna. The probability of population fragmentation and local extinction is high, because amphibians have a limited capacity to recolonize riparian zones and headwater streams following their emigration from logged areas (Johnson and O'Neil 2001, Hawkins et al. 1988, Daugherty and Sheldon 1982, Metter 1967). However, evidence suggests that in riparian areas some amphibian species with access to undisturbed upstream habitats are able to recolonize areas that were previously logged (Corn and Bury 1989). Re-colonization of clearcut areas from adjacent areas appears to be highly species specific depending on home range and habitat requirements.

DeMaynadier and Hunter (1995) reviewed North American literature regarding the effects of timber management on amphibians. Their review of 18 research projects showed that control sites had, on average, 3.5 times as many captured amphibians than clearcut sites (clearcuts ranged from 1 to 40 years of regrowth). The review also concluded that salamanders showed greater differences between control sites and clearcut sites (mean 4.3 times) than anurans (mean 1.7 times), suggesting that anurans have a higher tolerance for warmer and drier climates, which are often the result of clearcutting.

Studies comparing amphibian abundance or species richness with forest age have shown highly variable results. Some have shown no or low correlation between stand age and species richness or diversity (Welsh and Lind 1991, Aubry and Hall 1991, Bury et al. 1991, Aubry et al. 1988, Gilbert and Allwine 1991, deMaynadier and Hunter 1995), while others have shown increases in abundance of amphibians with increasing forest age (Dupuis et al. 1995). DeMaynadier and Hunter (1995), Bury et al. (1991), Petranka et al. (1994), and others suggest that it may not be forest age per se that is important to amphibians, but the presence of certain structural components that provide the appropriate microclimate and microhabitats for amphibian species. This assumption is based on the volume of coarse woody debris associated with forest seral stage. Regenerating young stands and mature stands tend to be high in coarse woody debris, while volume of coarse woody debris in intermediate aged stands tends to be lower. Relationships between amphibian abundance and the presence of coarse woody debris (Bury et al 1991, Bury and Corn 1988, Bury et al. 1991, Aubry et al. 1988, Raphael 1988, Petranka et al. 1994, Aubry and Hall 1991, Dupuis et al. 1995) and structural components associated with older forests (Welsh and Lind 1991) have been identified by multiple research efforts. Many studies have supported what Bury et al. (1991) found: large, well decayed down wood is essential for several terrestrial salamanders, and these species may eventually be reduced in numbers or extirpated in managed forests where well decayed down wood is scarce.

Amphibian occurrence and abundance may be higher in naturally regenerated sites then in clearcut areas. Bury and Corn (1988a) used pitfall traps in five clearcut sites (all less then 10 years old) and in unlogged control sites in Oregon and Washington to study occurrence and abundance. Occurrence and abundance of the herpetofauna in clearcuts differed markedly from six comparable young stands that were naturally regenerated. In the same study, tailed frogs were absent or rare in clearcuts and appear to be sensitive to timber harvest.

Amphibian habitat may benefit from alternative timber management practices. Numerous studies (Bury and Corn 1988, Aubry et al. 1988) suggest that retaining specific habitat features may improve amphibian abundance in managed stands. Short rotation clearcutting depletes coarse woody debris and prevents the development of mature or old-growth stand characteristics (Hansen et al. 1991, Bunnell et al. 1997, Hall et al. 1985). Longer harvest rotations allow development of mature stand characteristics and restoration of coarse woody debris. Other factors correlated with amphibian abundance are litter depth (Corn and Bury 1991), large trees (Bury and Corn 1988, Welsh and Lind 1991), canopy closure (Corn and Bury 1991 Welsh 1993), and soil moisture (Petranka 1994).

### 4. Mammal Habitat

Several studies in the PNW have been conducted on the use of upland and riparian forest habitats in the PNW by mammals and timber management's effect on these species in these habitats. Generally, these studies have produced results similar to those studies of birds and amphibians in that changes in habitat structure or habitat features may shift species composition in managed areas (Corn et al. 1988). As discussed in previous sections, little information specific to PNW forested wetlands and mammal habitat associations has been published. Fewer, if any, studies have examined PNW forest practices effects on mammals in forested wetlands. As a result, the following information is provided as a summary of timber affects on mammals within a variety of habitat types (upland, riparian, and wetland communities).

Riparian areas in Oregon and Washington are used by mammals for food, shelter, a source of water, and movement (O'Connell et al. 1993). Most mammals that use riparian habitats use them for breeding and feeding. Riparian zones and similarly, forested wetlands, offer a source of water, favorable microclimates, and high plant diversity and varied and abundant forage supply (McGarigal and McComb 1992, Oakley et al. 1985).

Small mammals that are closely associated with wetter deciduous forest conditions include the white-footed vole, Pacific jumping mouse, western jumping mouse, western harvest mouse, Richard's water vole, Pacific water shrew, shrew-mole, broad-footed mole, dusky shrew, montane shrew, and bats (Cross 1988, Corn and Bury 1991, Gilbert and Allwine 1991, West 1991, McComb et al. 1992, Corn et al. 1988). These species may be more affected by harvesting in forested wetlands than species limited to drier habitats. Several bat species rely heavily on riparian habitats for foraging abundant insect prey associated with aquatic environments (O'Connell et al. 1993, Cross 1998); others are associated with dense vegetation and or downed wood (McGrigal and McComb 1993) and so would likely be affected by harvesting of a mature forested wetland area.

Little is known about the life history characteristics of most riparian habitat type obligate mammals (Johnson and O'Neil 2001). Habitat fragmentation is likely a major factor contributing to the decline of wildlife. Riparian obligate species are particularly susceptible because of the small area of the landscape occupied by riparian zones and high probability of fragmentation. Small mammals adapted to Eastside Riparian-Wetland and Herbaceous Wetland habitats may be more vulnerable to land management practices that fragment and isolate their habitats, because changes in dominant vegetation would be less suitable for movement in and out of the disturbed patches (Schroeder and Allen 1992).

## *H. Mitigating Forestry Impacts*

Two strategies currently exist that address mitigating the impacts of forest practices in wetlands, one developed by the WDNR in the Forest practices Manual, and one by the Washington Department of Ecology, in their Model Wetlands Protection Ordinance. Neither has been evaluated or tested as to the efficacy of the guidance they propose.

The Washington Forest Practices Board Manual (WDNR 2000) contains Guidelines for Wetland Replacement by Substitution or Enhancement. Applications that propose to fill more than 0.5 acre of a wetland are specially classified and require a replacement of the lost wetland functions through creation or enhancement. The Washington Forest practices Manual's guidance for wetland replacement or enhancement options includes the following information:

1. Avoid impacts by selecting the least environmentally damaging landing location, road location, and road length.
2. Minimize impacts by such measures as reducing the subgrade width, fill acreage, and spoil area.
3. Restore affected areas by removing temporary fills or road sections upon the completion of the project.
4. Reduce or eliminate impacts over time by preserving or maintaining areas.
5. Replace affected areas by creating new wetlands or enhancing existing wetlands. Replacement is required when filling or draining more than 0.5 acre of wetland. These applications will be subject to the Washington State Environmental Policy Act (SEPA), will require a Class IV special application, and will require accurate delineation of wetland boundaries.

Quantification of wetland functions is not required. No studies examining the effectiveness of these guidelines for mitigating current forest practices have been done, so it is not known if these guidelines have been effective for decreasing wetland impacts or mitigating for impacts.

Expanded information on mitigating impacts to forested wetlands is provided in the new Washington Department of Ecology Guidance on Wetland Mitigation in Washington State (WSDOE 2005). This document includes mitigation options and regulations provided by the Washington Department of Ecology as guidelines for municipalities in order to be in compliance with the Washington State 1995 Growth Management Act (Chapter 36.70A RCW). The Guidance document describes characteristics of wetlands and buffer areas as valuable and fragile natural resources and discusses how impacting wetland functions degrades many primary and secondary wetland processes that vegetation and wildlife communities rely on for a variety of functions. Wetlands are defined as 'critical areas' and are protected under GMA. Best Available Science recommended by the Guidance document is the tool used in GMA for protecting forested wetlands. The following is a summary of salient points of the Guidance document. Mitigation for wetland impacts can include avoiding, minimizing or compensating for adverse wetland impacts. Mitigation options are preferred in the following order:

Mitigation sequencing

- Avoid the impact
- Minimize the impact
- Rectify the impact through restoration
- Reduce or eliminate the impact over time through preservation and maintenance operations
- Compensate for the impact by replacing, enhancing, or substitute resources or environments
- Monitor the impact and the compensation project

Impacts to forested wetlands can be placed in four type categories:

- **Permanent impacts –** impacts resulting in permanent loss of wetlands through fill or drainage of wetland areas.
- **Temporary impacts –** short-term effects that last for a limited time and where functions can be replaced in a relatively short period of time.
- **Temporal impacts –** impacts to functions that can and will be replaced but not in a short period of time. It may take a tree canopy a minimum of 20 years to function for shade. Temporal mitigation is usually compensated at a higher replacement ratio to reflect this long-term replacement scale.
- **Indirect impacts –** impacts from activities that are adjacent or upslope from a wetland that may affect the way the wetland functions.

A mitigation/enhancement report summarizing details of the proposed project, current conditions, areas to be mitigated or improved, mitigation design, work plan with goals and objectives, performance standards, and a summary of monitoring requirements should be developed for all mitigation projects. Special attention should be placed on appropriate plant species selection determined from regional reference sites.

Mitigation acreage replacement ratios have not been evaluated in a scientific context by the Washington Forest practices Board. The Washington Department of Ecology's Guidance document contains the most recent determination of compensatory mitigation replacement acreage based on scientific literature and Best Available Science on replacement ratios . Replacement ratios apply to creation or restoration, which is in-kind, onsite, timed prior to or concurrent with alteration, and has a high probability of success. In the first table below, the first number specifies the acreage of wetlands requiring replacement and the second specifies the acreage of wetlands altered.

**Mitigation Ratios Related to Forested Wetlands and Bogs in Western Washington** (DOE Guidance, 2004)

| Category and type of wetland | Creation | Restoration | Enhancement |
|---|---|---|---|
| Category I | 6:1 for forest, not possible for a bog | 12:1 for forested<br>6:1 for a bog | 24:1 for forest<br>case by case for bog |
| Category II | 3:1 | 8:1 | 12:1 |
| Category III | 2:1 | 4:1 | 8:1 |
| Category IV | 1.5:1 | 3:1 | 6:1 |

**Mitigation Ratios Related to Forested Wetlands and Bogs in Eastern Washington** (DOE Guidance, 2004)

| Category and type of wetland | Creation | Restoration | Enhancement |
|---|---|---|---|
| Category I | 6:1 for forest, not possible for a bog | 8:1 for forested<br>6:1 for a bog | 24:1 for forest<br>case by case for bog |
| Category II | 4:1 | 8:1 | 16:1 |
| Category III | 2:1 | 4:1 | 8:1 |
| Category IV | 1.5:1 | 3:1 | 6:1 |

Regulated wetlands generally include swamps, marshes, bogs, and similar areas. Wetlands created as mitigation and wetlands modified for approved land use activities are also considered regulated wetlands. Regulated wetlands that may be potentially impacted should be classified into one of the four categories (Category I-IV) of the Wetland Rating System developed for either eastern or western Washington (Hruby 2004, Hruby 2004). A wetland is considered high quality if it is either a Category I or II under the DOE's wetland rating system; it is a rare or irreplaceable wetland type (bog, mature forest); it is habitat for threatened or endangered species; it is a mature forested wetland, it is rare regionally; it is a native habitat located in a floodway, or floodplain which is documented as a frequently-flooded area, or is providing flood retention and storage; provides biological or hydrological connectivity; has high regional or watershed importance (listed as a priority site in a watershed plan); is a large site with high species diversity and/or high abundance of native species; a site that is continuous with the headwaters of a watershed, or with a lake or pond in an upper watershed that significantly improves outflow hydrology or water quality.

Many forested wetlands in the PNW that could be impacted by timber harvest may be considered High Quality Wetlands. High Quality Wetlands are described as containing the following prior to impact:

- Minimal topographic impacts
- Minimal hydrologic impacts
- Low cover and frequency of exotic plant species
- Minimal human-related disturbances
- Native wetland plant communities
- No known water quality problems

# VI. Conclusions

This paper reviews published literature with respect to commercial forest practices and forested wetland functions in the PNW. Despite the large number of publications cited in this review and synthesis, there remains much to be understood about forested wetlands. The results from the literature search indicate that there are substantial information gaps regarding the characterization of forested wetlands, including but not limited to studies of water quality, hydrology, and fish and wildlife use. Moreover, the secondary question of how timber management affects forested wetland function in the PNW is virtually not researched. Much of the information presented within this synthesis report is drawn from studies conducted in associated communities, such as riparian areas, streams, and upland environments in the PNW, and is thus potentially applicable to forested wetlands in the PNW.

Throughout North America, forested wetlands consist of conifer trees, hardwood trees, and/or a mixture of coniferous/deciduous trees. The plant communities of forested wetlands vary from one region to another. Forested wetlands represent a smaller proportion of area in northern regions than in the southeastern U.S. In Washington State, forested wetlands, with the exception of forested bogs, may be harvested using many of the same methods as harvesting conducted in upland communities.

Hydrology is generally accepted to be the most important factor influencing wetlands, and therefore the effect of forest practices on any aspect of hydrology is of great interest. Although direct and indirect effects of forest management on forested wetland ecosystems can be surmised or intuited, little data exists regarding these potential effects. Many changes that can occur with silvicultural practices, such as rutting, soil compaction, tree and LWD removal, are commonly assumed to have hydrologic repercussions, but there is little or no peer-reviewed research to substantiate this. Studies of pre- and post-harvest forested wetlands are needed, in order to quantify the effects of forest practices on forested wetlands hydrology.

One of the more important aspects to be understood is the role that altered hydrology patterns have on productivity and regeneration patterns (Stokes and Schilling 1997). Drainage characteristics and changes in the duration and timing of flooding affect productivity and alter the course of succession, which determines the composition of the forest. There is a definite need to understand how harvest and site-preparation activities affect wetland productivity. Best management practices (BMPs) have been developed for forested wetlands in most states. As new research is completed, BMPs need to be updated and the information must be relayed to the people conducting field operations.

Tree response to environmental change often occurs over a period of years; thus, there is a need for more long-term studies in wetland forests (Stokes and Schilling 1997). Baseline (pre-harvest) ecosystem conditions in the PNW are virtually unknown, and now relatively few pristine sites remain where data could be gathered. These data should include a review of wetland functions, of hydroperiods in specific regions, and of the tolerance limits of wetlands for hydrologic changes. Forested wetland water sources include rainwater, groundwater, and surface water, all of which differ chemically (data sets do exist for each of these sources in western Washington). However, few studies have investigated water quality in the forested wetlands of the PNW. Instead, much of the knowledge on this subject stems from studies of streams and watersheds. In particular, the effects of forest practices on water quality in forested wetlands have been assessed from studies of stream and riparian areas. After such data are analyzed, a review of the effectiveness of current forest practices rules and methodologies will likely be necessary.

In general, forest practices potentially affect water quality by increasing sediment load, changing nutrient concentrations, changing pH, allowing summer temperature increases and winter temperature decreases, and adding pollutants. Some evidence exists that various forest harvest practices affect water quality parameters differently. Further research is needed to define the limits of forested wetlands' tolerance to water-quality changes and to determine which silvicultural techniques are best suited to forested wetlands.

Little research has been conducted to characterize the wildlife habitat associations in PNW forested wetlands. Moreover, studies of pre- and post-harvest forested wetlands are needed to quantify the effects of forest practices on forested wetland wildlife. Wildlife studies from upland or riparian areas within the PNW indicate that wildlife species are adapted to specific habitat features. Changes in habitat features as a result of timber management are shown to cause shifts wildlife communities within managed areas. Amphibians, birds, and mammals all exhibit this response following timber management activities. Studies from upland and riparian areas suggest that retaining specific habitat features following timber management may reduce wildlife impact within the managed area. Retaining patches of large diameter trees, snags, and large woody debris may mitigate some of the impacts to wildlife species. The literature suggests that these actions, together with retaining organic material such as brush piles, loose bark, and smaller organic litter on the forest floor, may aid wildlife in re-colonizing and may help retain species that are not highly specialized. However, no empirical evidence detailing remaining habitat features and wildlife has been published to date.

No studies characterizing fish use of forested wetlands in the PNW were found. No studies have been published examining how timber management of forested wetlands affects fish use of those wetlands. In summary, the body of literature suggests that timber management may affect many forested wetland functions. However, few if any studies have been conducted in the PNW to examine those questions within forested wetlands. Research is needed to classify forested wetland hydrology, water quality, and wildlife relationships in the PNW, and to show cause-and-effect relationships in forested wetlands following timber management.

# VII. Research Needed and Gaps Identified

## *A. Soils*

- A need for additional research in evaluating numerous soil remediation techniques for soil compaction from forest harvest activities, including tillage, woody and nutrient-rich residues, mulches, revegetation testing, and microbial additions
- More complete forested wetland inventories
- Adequacy of current wetland classification system

## *B. Water Quality*

- Short-term effects of silvicultural activities on light and air, groundwater, and soil temperature in forested wetlands and receiving streams (Gray 2000)
- Measuring and predicting fine sediment changes in wetlands resulting from different forest practices
- Tree density, buffer width, and planting treatments needed to protect hydrology and water quality
- Effects of road closure and decommissioning on water quality
- Assessing sediment routing at the drainage basin scale in order to understand and predict delivery from side scars, road surfaces, and other sources

## *C. Hydrology*

- How much hydroperiod change can a wetland withstand before experiencing permanent effects?
- How do hydrologic changes affect key functions of wetlands?
- What is the effect of loss of LWD inputs to forested wetlands? Similarly, LWD requirements of forested wetlands need to be investigated.
- What roles do forested wetlands serve on fish resources? The importance of changes in hydrologic function can be put into the perspective if their importance to fish is understood.
- What are forested wetlands' hydroperiods for specific areas? Are these hydroperiods similar to those observed in general in wetlands in the PNW (Azous and Horner 2001)
- How do roads divert flow from forested wetlands?
- How does hydroperiod alter effects of harvest?
- How does upland harvest affect basin hydrology?
- What are cumulative impacts of roads in a basin?
- What are the effects of isolation of forested wetlands from streams?

## *D. Wildlife*

- Research should be directed primarily at endemic species with small geographic ranges. Information on the geographic distribution and spatial variation in life history traits of PNW amphibians is sparse, and considerable fieldwork is needed to define limits of their distributions (Hayes 2002, Nussbaum et al. 1983, Wilkins and Peterson 2000).
- Amphibian studies focused specifically on forested wetland habitats. Most studies focus on riparian areas or upland forested areas. Thus, amphibian species richness and relative abundance among forested wetland categories is virtually unknown (Hayes 2002).
- What is the relationship between wildlife species richness and forested wetlands? We need to sample the composition and abundance of populations and communities of amphibians, birds, and mammals in forested wetlands in the PNW by ecoregion.
- Which wildlife species occur across forested wetland classes? Such work may reveal the degree of dependence of the fauna on these restricted habitats.

- What is the impact of timber harvest on the occurrence and abundance of forested wetland wildlife (amphibians, birds, mammals)?
- What is the impact of timber harvest of adjacent upland areas on the occurrence and abundance of wildlife in forested wetlands?
- What is the effect on wildlife from partial harvesting or uneven aged management?
- What are the north to south changes in amphibian species richness in forested wetland habitats and their zoogeographic implications?
- What are the competitive interactions among species of amphibians, birds, and mammals in forested wetlands?

## *E. Vegetation*

- Identify the forest practices that cause significant hydrologic changes and determine if vegetation shifts are occurring as a result of these changes.
- Compare the relative natural abundance of conifers vs. hardwoods along streams (Nierenberg 1996) to forested wetlands.
- Loss of forested wetland acreage: Little is known about losses to timber harvest, although much is known about loss to agriculture and coastal conversions (Canning and Stevens 1990).
- What is the effect of soil compaction due to forest management on the rooting zone and ultimate survival of trees?
- Are there increases in windthrow resulting from forest harvest activities of adjacent timber stands?
- What are the growth rates of wetland-associated species, and how do they differ from growth rates of the same species from upland habitats?
- How do various forestry practices affect LWD input to wetlands?
- What are the effects of conversion of hardwood stands to softwood?
- What are the timing and type of recovery after harvest?
- Is the knowledge base regarding forested wetland plant community development adequate?
- What are status and trends of forested wetlands in the PNW?

## *F. Low-Impact Harvesting on Wet Sites*

- An examination of low-impact harvesting methods (felling and extraction) that are also cost effective.
- How do various harvest and site preparation techniques vary in effect?
- What timber harvesting techniques are currently utilized outside of the PNW that may be effective in reducing impacts to forested wetlands in the PNW.

## *G. Mitigating Forestry Impacts*

- No studies have been performed that evaluate the effectiveness of either the Washington Department of Ecology's Model Wetlands Protection Ordinance or the WDNR's Forest Practices Act guidelines for wetland mitigation or replacement.

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# Appendix A

## Breakout Session: HYDROLOGY
**November 1, 2002**

### Forested Wetland Function Research/Information Gaps

Which forest management practices are expected to have effects on functions of forested wetlands?

- Road construction/maintenance
- Clearcutting
- Harvesting – vegetation removal
- Operational actions – timber removal methods
- Site preparation/slash disposal

What is known about the effects of forest management on vegetation, hydrology/water quality, and fish and wildlife habitat functions of forested wetlands?

- Conifers – increased water consumption
- Roads can cause sediment movement
- Roads can change flows and downcutting streams can result in separation of forested wetlands from floodplain
- There is a relationship between ground/soil effects and the size of trees harvested
- Harvest/yarding causes rutting
- Harvesting makes closed systems wetter

What forested wetland functions are important? These need to be investigated.

- How much do forested wetlands contribute to flood attenuation?
- Forested wetlands slow surface (sheet) flows
- What is the relationship to upland area effects on surface flows?
- Summer base flow maintenance
- Sink or source for sediments
- Water quality functions – nutrient cycling/removal, denitrification

### Information Needs

Does hydrogeologic setting of forested wetland affect the degree of effect of different forestry techniques?

- What is effect of loss of LWD inputs to forested wetlands from harvest of adjacent uplands?
- Are upland LWD requirements sufficient for forested wetlands?
- How do roads divert flow from forested wetlands?
- What are effects of forested wetlands on fish resources?
- What are effects of conversion of hardwood to conifer stands?

- What is the timing and type of recovery after harvest?
- Is cable yarding as low impact as thought?
- Are low impact-techniques effective in minimizing soil compaction/disruption?
- What are hydrologic effects during peaks and different hydroperiods?
- How do forestry actions of non-riverine forested wetlands affect basin hydrology?
- What methods of site preparation encourage reforestation and minimize hydrologic changes?
- Is there accelerated sediment delivery to forested wetlands?
- What are cumulative impacts of roads in basin on wetland hydrology?
- What types of sediments are delivered from roads to forested wetlands?
- How do sediment inputs affect vegetative composition?
- How many miles of roads can basins have before hydrology changes?
- What are clearcutting effects on channel morphology?
- What are effects of isolation of forested wetlands from streams?
- What is the role of forested wetlands in supporting fish/wildlife use?

Data gaps (from highest to lowest priority):

- What is the threshold for hydroperiod change to still support recovery/reforestation?
- What yarding techniques and technology are least disruptive to ecosystem/wetland functions?
- Is the current classification system adequate or do we need a landscape-based “hydrogeologic” setting classification system?
- Forested wetlands hydroperiods
- Forested wetland plant community development – need to study conditions (hydrology/drought, succession/species)
- ALSO (not rated):
    - Identifying reference sites and controls for management decisions
    - Determining how precise Washington forest practices rules forested wetlands delineation methodology is

**Next Steps**

- Which questions can be answered using non-CMER research?
- Which questions can be piggybacked with non-CMER and other SAGs?
- Classification of forested wetlands
- Context – understanding composition of forested wetland resources
- What percent are of specific hydrogeomorphic (HGM) types?
- Which ones are most likely to be forested?
- Where are they, and what percentage of the forested landscape do they make up?
- What are status and trends of forested wetlands?

# Appendix B

## Breakout Session Notes: VEGETATION

**November 1, 2002**

**Which forest management practices are expected to influence forest wetland functions?**

- ALL

**Functions include**

- Special wood products, primary productivity, regional biodiversity, water quality improvements, filtration, sediment removal, flood attenuation, nutrient cycling/removal/addition, decreasing downstream erosion, temperature modification, water storage/transpiration, habitat, aesthetics, recreation, cultural resources, ethnobotanical uses, microclimate moderation, carbon storage.

**What is known about he effects of management of forested wetlands?**

- When you cut trees, sometimes they regenerate, sometimes they don't
- Tree planting affects a wide variety of functions
- Road construction and ground disturbance alter hydrologic patterns and influence vegetation
- We are able to distinguish between different categories (HGM)

**Information needs**

- What percent of the contributing basin is wetland and how much can you log before you see an affect?
- What factors influence whether or not you get trees back, and what species?
- How do different harvesting methods affect different functions?
- How much (and how often) can you harvest before functions are significantly influenced?
- How does harvesting the surrounding upland buffer affect the wetland?

**What questions will address the information needs? What is our ability to investigate priority questions? What should our priorities be?**

- Prioritized highest to lowest:
  - Harvest extent and frequency
  - Regeneration
  - Harvesting methods
  - Basin effect and adjacent harvest
- How this would be investigated:
  - Retrospective – chronological sequence
  - Well-designed study
  - Model

# Appendix C

## Breakout Session: WILDLIFE

**November 1, 2002**

### Forested Wetland Function Research/Information Gaps

Which forest management practices are expected to have effects on functions of forested wetlands?

- Removal of trees and down/standing woody material, road building, forestry – skid tracks, yarding corridors, poor/lacking delineation, herbicides/pesticides/fertilizers stand conversion (reforestation), burning, clearing, all of the above in adjacent landscapes, all forest practices activities

What is known about the effects of forest management on vegetation, hydrology/water quality, and fish and wildlife habitat functions of forested wetlands?

- It alters sediment regimes
- It alters hydrologic regimes
- Results in loss of cover (e.g., for elk)
- Heats shallow groundwater
- Clearcuts reduce/eliminate habitat
- Fewer wildlife species in monocultures
- Data exists from Breeding Bird Survey (Sauer et al, 2005)
- Duck and goose studies have been conducted
- Shade is reduced, changing soil and air temperature and humidity
- Recovery occurs to varying degrees
- Atrazine affects amphibians
- Changes in UV affects amphibians
- Downstream ameliorations
- Recruitment of LWD and litter decreases
- Primary production (algae) increases
- Vegetative succession changes
- Soil compaction effects on vegetation affects wildlife

What is known to mitigate forest management effects on forested wetland functions?

- One-end and full suspension when cable yarding
- Restricting equipment
- Limiting haul roads
- Avoidance through well-placed roads, refuse storage, staging areas
- Helicopter logging
- Leave trees/partial harvest/ selective harvest
- Directional felling
- Branches used in haul-out
- Clumping leave trees

- Diverse replants
- Pile slash over temporary roads
- Build roads on puncheon
- Sediment control BMPs
- Leaving downed wood
- Having fueling locations
- Keeping chemicals out of surface soils and wetlands
- Power-washing equipment
- Enforcing wet-weather haul requirements
- Using downed wood for conifer revegetation
- Limiting entry in wetlands
- Careful, professional delineation

**Information Needs**

Unknowns:

- What is the extent of fish/amphibian habitat use?
- What is the contribution of wetland to water quality, quantity, and structure in adjacent areas?
- What is the impact of forest practices on isolated upslope or depressional wetlands?
- What are the effects of cover removal on groundwater flow, temperature, habitats?
- What are the effects of forest chemicals on wetlands biota?
- How does tree removal affect groundwater flow and temperature in downstream fish-bearing waters?
- Do harvested wetlands regenerate?
- What is species occurrence and habitat use of different forested wetland types?

How we would go about research:

- Compare forested wetlands to adjacent uplands for species abundance and diversity and available habitat
- Conduct life history studies
- Look at marginal wetlands
- Research woody debris to set standards for maintaining functions

# Appendix D

# Background Material: Vegetation

## *Northern Puget Trough Forested Wetland Community Types (after Kunze 1994)*

Forested Bogs

- *Pinus contorta/Ledum groenlandicum/Sphagnum spp*. This community is found scattered throughout the northern Puget lowlands, but is especially common in seasonally dry basins, such as old dune troughs in coastal areas in Grays Harbor and Pacific Counties. It occurs in relatively dry areas or in areas with seasonal flooding. Where trees are tall, the substrate may be thin and trees are in contact with underlying mineral soil. Most often trees are stunted.
- *Pinus monticola/Ledum groenlandicum/Sphagnum spp*. This is a rare community type, although there is evidence that it used to be much more common. Most of these wetlands are found in Snohomish County. It occurs in relatively dry Sphagnum bogs. The substrate is composed of Sphagnum fibers, heath, and woody peat. The trees are often stunted where they grow out on the bog.
- *Tsuga heterophylla/Ledum groenlandicum/ Kalmia microphylla/Sphagnum* spp. This is a common community found throughout the northern Puget trough lowlands. It occurs both on saturated quaking bog mats and the adjacent dry portions of bogs. Substrates are predominantly Sphagnum fibers, heath, and woody peat. Trees that grow out on the mat tend to be stunted, while trees that grow on the drier portions of the mat are taller.
- *Tsuga heterophylla/Sphagnum spp*. This community is rare in the northern Puget trough lowland region. It occurs in deep Sphagnum peat where the water table is more than 30 cm below ground level. Western hemlock (*Tsuga heterophylla)* in these communities grows in dense stands with almost full canopy closure with little understory vegetation. The trees are stunted, and those with a DBH of 30 to 35 cm may be 300 or more years old.

Minerotrophic Wetlands

- *Alnus rubra/Lysichitum americanum.* This community is found throughout the northern Puget trough lowlands. It occurs near wetland margins where soils are usually saturated or seasonally flooded. These low-energy systems are usually found in floodplains of low-gradient streams. The soils are organic, and large woody debris is common. Red alder (*Alnus rubra)* forms an almost closed canopy. There is typically a species-rich understory with skunk cabbage (*Lysichitum americanum)* as a dominant species. This community is found in association with western red-cedar (*Thuja plicata)* in Oregon.
- *Alnus rubra/Rubus spectabilis.* This community is found throughout the northern Puget trough lowlands. It occurs near or along the upland margins of wetlands and on floodplains of streams and rivers. Soils vary from alluvium to alluvium with a surface horizon of muck or peat. Red alder forms a nearly closed canopy. Salmonberry (*Rubus spectabilis*)is often the only understory species.
- *Fraxinus latifolia/Carex obnupta*. This community type is most common in the southern Puget trough region (including Oregon through the Willamette Valley) but

occurs up through King County in the northern Puget trough region. It occurs both in flood plains associated with streams (riparian areas) and in kettle wetlands. Soils are typically alluvium or glacial till/outwash with a thin horizon or organic material on top. Oregon ash (*Fraxinus latifolia*) dominates the overstory and slough sedge (*Carex obnupta* )the understory. Typically, hardhack (*Spirea douglasii)* is also present, scattered in the drier edges of the habitat. The riparian communities tend to be more species rich than the kettle communities.

- *Fraxinus latifolia/Symphoricarpos albus/Rubus ursinus*. This community type is most common in Oregon in the Willamette Valley, and only disturbed examples have been found in the southern Puget trough region of Washington. It occurs in riparian zones, glacial scours, and kettles. It is found on the upper margin of wetlands along the upland boundary. Soils are predominantly alluvium with some glacial till and outwash soils present. Oregon ash is the dominant tree with snowberry (*Symphoricarpos albus*) and trailing blackberry (*Rubus ursinus*) as the co-dominant species of the shrub lawyer.
- *Thuja plicata/Tsuga heterophylla/Lysichiton americanum*. This community is now relatively rare in an undisturbed form, although there is information that indicates it was once a very common community type. It occurs in low-gradient terrain, in depressions, in floodplains, and in association with small streams and seeps. Soils tend to be organic mucks or peats. Downed logs and root wads are common. The water table is at or just below the soil surface and there is often shallow inundation present somewhere in the wetland. The canopy is dominated by either or both western red-cedar and western hemlock. Tree size and age is variable. The understory density is variable from open to dense. Skunk cabbage is always present. *Sphagnum* is often present. Salal (*Gaultheria shallon)* and *Alaskan blueberry (Vaccinium alaskaense)* are common on fallen logs and mounded soil.

### *Southern Puget Trough and Lower Columbia River Lowland Forested Wetland Community Types (after Kunze 1994, Christie 1993)*

<u>Overflow Plain</u>

- *Salix lucida/Urtica dioica*. This community occurs along the main channels in the overflow plain of the Columbia River and similar habitats in the Willamette Valley in Oregon. It occurs on the flood plains behind natural levees and on low-lying islands. It is most common around the margins of shallow lakes, ponds, inlets, and lagoons. This community may be seasonally flooded or groundwater-fed and can tolerate summer drying but does not tolerate year-round flooding. The canopy is dominated by Pacific willow (*Salix lucida*) and stinging nettle (*Urtica dioica)*. Stands can be dense to open. Beaver-associated herbivory are common.
- *Fraxinus latifolia/Urtica dioica.* This plant community occurs in the overflow plain segment of the Columbia River and southern Puget trough lowlands as well as in the northern Willamette Valley in Oregon. It occurs on floodplains between natural riverside levees and overflow lakes and ponds. Commonly this community is flooded and dissected by tidal streams and sloughs. The soils remain saturated throughout the summer although surface inundation is rare. Soils are dominated by silt loams but organic-rich fine sands are also common.

- *Fraxinus latifolia/Populus trichocarpa/Cornus sericea/ Urtica dioica.* This plant community occurs in the overflow plain segment of the Columbia River, from Puget Island to the Columbia Gorge and along all major streams in the southern Puget trough region to the Willamette Valley in Oregon. It occurs on higher topographic positions on floodplain terraces and natural levees along river channels. The soils are silt-loams and some portion of the community is associated with some seasonal flooding. The canopy is dominated by both Oregon ash and black cottonwood (*Populus trichocarpa)*. The understory is dominated by red osier dogwood (*Cornus sericea)*, but red elderberry (*Sambucus racemosa)* may also be dominant. Reed canarygrass (*Phalaris arundinacea)* is a common component of this community and may have replaced the understory in some instances.
- *Fraxinus latifolia/Populus trichocarpa/Symphoricarpos albus/Urtica dioica*. This plant community occurs along the Columbia River above Longview, as well as along major streams and rivers in the southern Puget trough region and Willamette Valley in Oregon. It occupies the highest position on floodplain terraces and natural levees where wetlands still occur. The soils are silt loams and are mostly surface irrigated. Oregon ash and black cottonwood are co-dominant in the canopy. The shrub layer is dominated by snowberry with considerable amounts of stinging nettle in patches.

<u>Surge Plain Wetlands</u>

- *Populus trichocarpa/Cornus sericea/Impatiens capensis*. This community occurs in the surge plain segment of the Columbia River and has been observed upriver as far north as Longview. It is also common in Oregon down through the Willamette Valley. Soils are muck and silt that are saturated by groundwater. Stands may be inundated during winter storm surges or freshwater tides. The canopy of this wetland type is dominated by black cottonwood, the shrub layer by red osier dogwood, and the herb layer by touch-me-not (*Impatiens noli-tangere)*. Many of these communities have been degraded by grazing and forest harvest activities and the dominant understory is replaced by reed canarygrass. Some stands have been invaded by yellow flag iris (*Iris pseudocorus*) and bittersweet nightshade (*Solanum dulcamara*).

### *Native freshwater Wetlands of the Western Olympic Peninsula and southwest Washington Lowlands (after Kunze 1994, Franklin and Dyrness 1973, Christie 1993)*

<u>Low elevation Sphagnum Bog</u>

- *Pinus contorta/Ledum groenlandicum/Sphagnum* spp. This community occurs throughout the peninsula but is most common in basins containing coastal dune troughs in Grays Harbor and Pacific Counties. These habitats experience summer dry periods and winter/spring inundation or saturation. The soils are *Sphagnum* and wood peat overlaying sand and gravelly sands. The dominant vegetation varies from scattered stunted coast pines (*Pinus spp.*) in open shrublands with bog laurel (*Kalmia occidentalis)* and Labrador tea *(Ledum groenlandiucum)*to dense stands of stunted coast pine with an understory of Labrador tea and salal.
- *Pinus contorta-Thuja plicata/Myrica gale/Sphagnum* spp. This community type is found in slopes, basins, and limnogenous bogs in Grays Harbor County, western Clallam County, and western Jefferson County. The soils range from mixed sedge, heath, woody peat; and water levels vary from just below to slightly above the surface.

Some areas are groundwater fed. The canopy of this community is dominated by lodgepole pine (*Pinus contorta* var. *latifolia)* and western red-cedar with western hemlock as an occasional co-dominant. Trees tend to be stunted. The understory is dominated by sweet gale (*Myrica gale)*and *Sphagnum*. Bog laurel, salal, and skunk cabbage are usually present and are sometimes co-dominant. This community is one of the most species rich of the forested wetland types found in Washington. Decomposing large woody debris is common.

- *Thuja plicata-Tsuga heterophylla/Gaultheria shallon/Lysichiton americanum/Sphagnum* spp. This community type is common throughout the Olympic Peninsula in basins and on slopes. The dominant trees include western red-cedar and western hemlock. Trees are seldom stunted and may grow quite large, but broken tops are common. Other dominant plants include salal, deer fern (*Blechnum spicant*), Sitka spruce (*Picea sitchensis)*, and *Vaccinium* spp. Live *Sphagnum* is very common. Soils are mixed *Sphagnum*, sedge, heath, and woody peat substrates that vary from seasonally flooded to completely saturated. Downed large woody debris is common.
- *Tsuga heterophylla/Ledum groenlandicum/Sphagnum* spp. This community type is similar to one of the same name in the Puget trough region and occurs in basins and flat to rolling topography in western Clallam County within this region. The dominant vegetation is stunted western hemlock and western red-cedar in an open canopy. The shrub layer is dominated by bog laurel, Labrador tea, bracken fern, salal, and deer fern. Soils are composed of a mixture of Sphagnum, heath, and woody peat that are wet all year but may not be seasonally flooded.

<u>Low Elevation Minerotrophic Wetlands</u>

- *Picea sitchensis/Alnus rubra/Lysichitum americanum*. This community occurs throughout the peninsula on nearly flat, poorly drained ground associated with low-gradient streams and seeps. The dominant vegetation is Sitka spruce in an open canopy with western red-cedar as sub-dominant in some areas. Red alder is usually present. The shrub and herb layer are dominated by slough sedge (*Carex obnupta*) and water parsley (*Oenanthe sarmentosa*) in topographic depressions that are permanently inundated, and western crabapple (*Malus fusca)*, salmonberry, black twinberry (*Lonicera involucrata*), willows (*Salix* spp.), skunk cabbage and slough sedge in the drier portions of the habitat. Salal dominates the drier microsites. Soils are predominantly organic muck to fibrous, heath, and woody peats.
- *Pyrus fusca/Calamagrostis canadensis.* This community is rare and occurs only in western Clallam County. It occurs on low rises and is wet year round with seasonal flooding fed by both surface and groundwater. As with all western crabapple communities, it forms the drier edge of the wetland. The canopy is dominated by dense canopy of western crabapple with a dense understory of bluejoint reedgrass (*Calamagrostis canadensis*). The crabapple is maintained through beaver (*Castor canadensis)* herbivory. Soils are fibrous and woody peat overlying sand.
- *Pyrus fusca/Carex obnupta.* This community occurs all along the Olympic Peninsula coast. As with all western crabapple communities, it forms the drier edge of the wetland. This community is seasonally flooded, and then the soils are wet or saturated for the rest of the year. The canopy is dominated by a dense but open canopy of western crabapple with a dense understory of slough sedge and occasionally boykinia

(*Boykinia* spp). The crabapple is maintained through beaver herbivory. The soils are muck, and/or fibrous and woody peat.

- *Pyrus fusca/Salix hookeriana/Carex obnupta*. This community occurs along the southwest coast of Washington in Grays Harbor and Pacific Counties. It occurs in depressions and along the edges of coastal lakes and dune troughs. The canopy is dominated by a dense canopy of western crabapple and willow and an understory of slough sedge. The crabapple is maintained through beaver herbivory.
- *Thuja plicata/Tsuga heterophylla/Lysichitum americanum*. This community occurs throughout the Olympic Peninsula. It is found on flats or in depressions that are poorly drained and in which the soil is poorly aerated. The water table tends to be at or near the soil surface, where the water table is perched or is the headwater for small low-gradient streams. The canopy is dominated by western red-cedar and western hemlock and sub-dominant red alder. The understory is open and skunk cabbage is common in depressions, with salal, Alaska blueberry, mock azalea (*Menziesia ferruginea*), and salmonberry in the drier areas. The soils are organic with ample amounts of large woody debris, root wads, soil hummocks, and fallen logs.

<u>Surge Plain Wetlands</u>

- *Alnus rubra/Rubus spectabilis/Carex obnupta/Lysichitum americanum*. This community is found associated with the dry surge plain occurring on levees or other high ground. Some areas are flooded during the higher monthly tides. The canopy is dominated by red alder with an open understory of slough sedge in the depressions and salmonberry in the higher topographic areas. Soils are a mixture of clay, silt, and organic material.
- *Picea sitchensis/Alnus rubra/Rubus spectabilis/Carex obnupta*. This community is found along major rivers and slough channels of the Olympic peninsula, on natural levees and portions of surge plain terraces where surface drainage is good. Portions of this habitat may be tidally flooded. Sitka spruce is the dominant tree intermixed with red alder. Depressions in the understory are dominated by slough sedge and skunk cabbage. Salal is common on the drier, mounded ground. Soils are a mixture of clay, silt, and organic matter.

# Appendix E
# Background Material: Water Quality

## Table 1. Rainfall Data (Kulzer et al. 2001)

| Precipitation Chemistry, Western Washington area | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| National Atmospheric Deposition Program | | | | | | | | |
| | | | | | 1994-1998 | | | |
| Site | pH | conductivity | Ca | Mg | Na | K | SO4 | Cl |
| | | umho/cm | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| Olympia | | | | | | | | |
| 1995 | 5.0 | | 0.02 | 0.019 | 0.180 | 0.022 | 0.3 | 0.29 |
| 1996 | 4.9 | | 0.02 | 0.013 | 0.132 | 0.013 | 0.4 | 0.38 |
| 1997 | 4.9 | | 0.02 | 0.025 | 0.220 | 0.017 | 0.4 | 0.38 |
| 1998 | 4.9 | | 0.03 | 0.017 | 0.124 | 0.015 | 0.3 | 0.22 |
| Average | 4.9 | | 0.02 | 0.02 | 0.16 | 0.02 | 0.4 | 0.32 |
| Bellingham | | | | | | | | |
| 1994 | | | 0.07 | 0.025 | 0.172 | 0.017 | 0.3 | 0.29 |
| 1995 | 5.0 | | 0.01 | 0.012 | 0.115 | 0.005 | 0.2 | 0.19 |
| 1996 | 5.0 | | 0.02 | 0.022 | 0.215 | 0.007 | 0.2 | 0.21 |
| 1997 | 5.0 | | 0.02 | 0.018 | 0.156 | 0.009 | 0.2 | 0.27 |
| 1998 | 5.0 | | 0.02 | 0.011 | 0.084 | 0.005 | 0.2 | 0.15 |
| Average | 5.0 | | 0.03 | 0.02 | 0.15 | 0.01 | 0.2 | 0.22 |
| Annual average concentrations | | | | 1998 - 1990 | | | | |
| Site | pH | conductivity | Ca* | TP | SRP | NO3 | NH3 | TKN |
| Factoria Bellevue | | umho/cm | uS/cm | mg/L | mg/L | mg/L | mg/L | mg/L |
| Average | 4.7 | 28.2 | 21.7 | 0.069 | 0.016 | 0.245 | 0.129 | 0.579 |
| n | 11 | 12 | | 12 | 11 | 11 | 11 | 12 |
| variance(s2) | 0.4 | 499 | | 0.016 | 0.001 | 0.061 | 0.014 | 0.269 |
| s | 0.7 | 22 | | 0.128 | 0.028 | 0.247 | 0.119 | 0.518 |
| Covington Wetland | | | | | | | | |
| Average | 4.7 | 12.3 | 5.8 | 0.030 | 0.016 | 0.280 | 0.145 | 0.648 |
| n | 8 | 8 | | 9 | 8 | 8 | 8 | 9 |
| variance(s2) | 0.18 | 84.8 | | 0.001 | 0.0007 | 0.12 | 0.013 | 0.35 |
| s | 0.42 | 9.2 | | 0.034 | 0.026 | 0.348 | 0.116 | 0.589 |
| East Lake Sammamish Plateau** | | | | | | | | |
| Average | | | | 0.003 | 0.160 | | 1.062 | |
| n | | | | 6 | 6 | | 6 | |
| * If corrected for hydrogen ion concentration per Sjors (1950) | | | | | | | | |
| ** Dec 1979 - Apr 1980 | | | | | | | | |

**Table 2.  Groundwater Chemistry -Typical King County Sites (Kulzer et al. 2001)**

| Issaquah area groundwater chemistry- SUMMARY Nov. 1992 & April 1993 | | | n | Variance($s^2$) | s |
|---|---|---|---|---|---|
| pH | | 6.72 | 16 | 0.8 | 1 |
| alkalinity | mg CaCO3/L | 70.5 | 16 | 3015.5 | 55 |
| acidity | | | | | |
| hardness | mg/L | 69.1 | 16 | 1034.3 | 32 |
| conductivity | umho/cm | 115.3 | 15 | 4745.9 | 69 |
| Ca | mg/L | | | | |
| Mg | mg/L | 36.3 | 16 | 1266.6 | 36 |
| Na, dissolved | mg/L | 11.7 | 16 | 146.0 | 12 |
| K, dissolved | mg/L | 2.2 | 16 | 1.9 | 1 |
| turbidity | NTU | 1408.3 | 16 | 1498668.9 | 1224 |
| sulfate | mg/L | 5.3 | 16 | 8.3 | 3 |
| Cl | mg/L | 2.6 | 16 | 1.3 | 1 |
| TP | mg/L | 3.26 | 16 | 10.1 | 3 |
| SRP | mg/L | 0.02 | 16 | 0.0 | 0 |
| NO3 | mg/L | 1.72 | 16 | 2.4 | 2 |
| NH3 | mg/L | 0.10 | 16 | 0.0 | 0 |
| TKN | mg/L | 1.36 | 16 | 0.7 | 1 |

| Maple Valley Lower Cedar River wetland Feb-02 | | Site 1( near moat) n=1 | Site 2 (upslope, 125 m) n=1 | |
|---|---|---|---|---|
| pH | | 5.61 | 6.67 | Measured in lab |
| alkalinity | mg CaCO3/L | 5.8 | 55.3 | |
| acidity | | --- | --- | |
| hardness | mg/L | 14.3 | 78.4 | |
| conductivity | umho/cm | --- | --- | |
| Ca | mg/L | 3.15 | 6.15 | |
| Mg | mg/L | 1.56 | 15.3 | |
| Na | mg/L | 2.18 | 3.91 | |
| K | mg/L | 0.964 | 0.9 | |
| turbidity | NTU | --- | --- | |
| sulfate | mg/L | 26.3 | 5.81 | |
| Cl | mg/L | 1.9 | 3.6 | |
| TP | mg/L | 0.103 | 0.035 | |
| SRP | mg/L | 0.011 | 0.005 | Filtered |
| NO3+NO2 | mg/L | 1.9 | 0.468 | |
| NH3 | mg/L | --- | --- | |
| TKN | mg/L | --- | --- | |

## Table 3. Water Chemistry Characteristics of Western Washington Wetlands (Azous and Horner 2001)

**Vater Quality Statistics for Wetlands Not Experiencing Significant Urbanization Change (1988–1995)**

| Jrban Status | Statistic | pH | DO (mg/L) | Cond. (μ S/cm) | TSS (mg/l) | $NH_3$-N (μ g/l) | $NO_3$+$NO_2$-N (μ g/l) | SRP (μ g/l) | TP (μ g/l) | FC (CFU/100 ml) | Cu (μ g/l) | Pb (μ g/l) | Zn (μ g/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ı | Mean | 6.38 | 5.7 | 72.5 | <4.6 | <59.9 | <368.2 | <17.6 | 52.3 | >271.3 | <3.3 | <2.7 | <8.4 |
| | Maximum | 7.65 | 11.3 | 230.0 | 73.0 | 1373.0 | 3200.0 | 414.0 | 850.0 | 6240.0 | 15.0 | 21.0 | 49.0 |
| | Std. Dev. | 0.53 | 2.6 | 63.8 | >8.5 | >129.3 | >484.6 | >47.6 | 86.6 | >1000.4 | >2.7 | >2.8 | >8.3 |
| | CV | 8% | 45% | 88% | >185% | >216% | >132% | >271% | 166% | >369% | >80% | >105% | >99% |
| | Median | 6.36 | 5.9 | 46.0 | 2.0 | 21.0 | 111.5 | 6.0 | 29.0 | 9.0 | <5.0 | 1.0 | 5.0 |
| | n | 162 | 205 | 190 | 204 | 205 | 206 | 200 | 206 | 206 | 93 | 136 | 136.0 |
| ʌ | Mean | 6.54 | <5.5 | 142.4 | <9.2 | <125.7 | <598.2 | <31.5 | 92.5 | >2664.8 | <3.7 | <3.4 | <9.8 |
| | Maximum | 7.88 | 14.8 | 275.0 | 180.0 | 2270.0 | 7210.0 | 280.0 | 780.0 | 359550.0 | 7.0 | 13.0 | 33.0 |
| | Std. Dev. | 0.82 | >3.6 | 72.8 | >21.6 | >266.8 | >847.2 | >37.9 | 91.8 | >27341.7 | >1.9 | >2.7 | >7.2 |
| | CV | 13% | >66% | 51% | >235% | >212% | >142% | >120% | 99% | >1026% | >51% | >79% | >73% |
| | Median | 6.72 | 5.1 | 160.0 | 2.8 | 43.0 | 304.0 | 16.0 | 70.0 | 46.0 | <5.0 | 3.0 | 8.0 |
| | n | 132 | 173 | 161 | 175 | 177 | 177 | 172 | 177 | 173 | 78 | 122 | 122.0 |
| ɪ | Mean | 6.73 | <5.4 | 150.9 | <9.2 | <68.3 | <395.4 | 31.2 | 109.5 | >968.6 | <4.1 | <4.5 | <20.2 |
| | Maximum | 7.51 | 10.5 | 271.0 | 87.0 | 516.8 | 1100.0 | 79.0 | 1940.0 | 38000.0 | 12.0 | 22.0 | 73.0 |
| | Std. Dev. | 0.57 | >2.9 | 85.5 | >15.1 | >104.4 | >239.4 | 15.7 | 233.5 | >4752.8 | >2.5 | >4.0 | >16.7 |
| | CV | 9% | >53% | 57% | >164% | >153% | >61% | 50% | 213% | >491% | >62% | >89% | >83% |
| | Median | 6.88 | 6.3 | 132.2 | 4.0 | 32.0 | 376.0 | 28.2 | 69.0 | 61.0 | <5.0 | 5.0 | 20.0 |
| | n | 52 | 67 | 61 | 66 | 67 | 67 | 65 | 67 | 66 | 29 | 44 | 44.0 |

*Vote:* Nonurban watersheds (N) = less than 4% impervious land cover and greater than or equal to 40% forest. Highly urbanized watersheds (H) = greater than or equal o 20% impervious and less than or equal to 7% forest. Moderately urbanized watersheds (M) = wetlands not fitting either of the other categories.

## Table 4. Chemistry of Small Streams in the King County Area (Kulzer et al. 2001)

**Issaquah first-order streams**

| Column1 | Unit | Pole creek | N | Mine Creek | N2 |
|---|---|---|---|---|---|
| pH | | 7.01 | 9 | 7.17 | 8 |
| D.O. | mg/L | 10.4 | 7 | 9.18 | 6 |
| alkalinity | mg CaCO3/L | | | | |
| hardness | mg/L | 28.2 | 7 | 24.24 | 7 |
| conductivity | uS/cm | 79 | 9 | 78.5 | 8 |
| Ca | mg/L | | | | |
| Mg | mg/L | | | | |
| Na, dissolved | mg/L | | | | |
| K, dissolved | mg/L | | | | |
| turbidity | NTU | 0.67 | 9 | | |
| sulfate | mg/L | | | | |
| Cl | mg/L | | | | |
| TP | mg/L | < 0.029 | 9 | <0.074 | 8 |
| SRP | mg/L | < 0.006 | 9 | <0.007 | 8 |
| NO3 | mg/L | 1.55 | 9 | 2.21 | 8 |
| NH3 | mg/L | | | <0.012 | 2 |
| TKN | mg/L | | | | |

**Table 5. Streamwater Chemistry in Two Undisturbed Watersheds in the Cascade Mountains, Oregon (Martin and Harr 1988)**

| Water Quality Parameter | Watershed 1<br>Mean (SE) | Watershed 2<br>Mean (SE) |
|---|---|---|
| Conductance (μS) | 33 (0.8) | 41 (1.1) |
| pH | 7.3 (0.04) | 7.3 (0.04) |
| Alkalinity (mg $L^{-1}$) | 19.9 (0.60) | 23.2 (0.67) |
| $NO_3$-N (mg $L^{-1}$) | 0.003 (0.001) | 0.003 (0.001) |
| Total N (mg $L^{-1}$) | 0.042 (0.003) | 0.066 (0.003) |
| $PO_4$-P (mg $L^{-1}$) | 0.022 (0.001) | 0.022 (0.001) |
| Particulate P (mg $L^{-1}$) | 0.008 (0.001) | 0.009 (0.001) |
| Dissolved organic P (mg $L^{-1}$) | 0.018 (0.001) | 0.019 (0.001) |
| $Ca^{2+}$ (mg $L^{-1}$) | 2.91 (0.02) | 3.73 (0.19) |
| $Mg^{2+}$ (mg $L^{-1}$) | 0.58 (0.02) | 1.05 (0.03) |
| $Na^{+}$ (mg $L^{-1}$) | 2.49 (0.06) | 2.22 (0.06) |
| $K^{+}$ (mg $L^{-1}$) | 0.43 (0.03) | 0.19 (0.02) |
| Dissolved silica (mg $L^{-1}$) | 12.35 (1.01) | 14.57 (0.99) |
| Sediment (mg $L^{-1}$) | 7.05 (1.41) | 2.90 (0.71) |

# Appendix F
# Background Material: Amphibians

## Pacific Northwest Amphibians (adapted from Nussbaum et al. 1983)

| Species | Common Name | State/ Province | Distributional Status |
|---|---|---|---|
| **Order Caudata (Salamanders)** | | | |
| Ambystomatidae | Mole Salamanders | | |
| *Ambystoma gracile* | Northwestern Salamander | OR, WA, BC | typical |
| *Ambystoma macrodactylum* | Long-toed Salamander | ID, OR, WA, BC | typical |
| *Ambystoma tigrinum* | Tiger Salamander | ID, OR, WA, BC | peripheral |
| *Dicamptodon copei* | Cope's Giant Salamander | OR, WA | endemic |
| *Dicamptodon ensatus* | Pacific Giant Salamander | ID, OR, WA, BC | typical |
| *Rhyacotriton cascadae* | Cascade Torrent Salamander | WA, OR | NA |
| *Rhyacotriton. kerzeri* | Columbia Torrent Salamander | WA, OR | NA |
| *Rhyacotriton. olympicus* | Olympic Salamander | ID, OR, WA | typical |
| Plethodontidae | Lungless Salamanders | | |
| *Aneides ferreus* | Clouded Salamander | OR, BC | typical |
| *Aneides flavipunctatus* | Black Salamander | OR | peripheral |
| *Batrachoseps attenuatus* | California Slender Salamander | OR | peripheral |
| *Batrachoseps wrighti* | Oregon Slender Salamander | OR | endemic |
| *Ensatina eschscholtzi* | Ensatina | OR, WA, BC | typical |
| *Plethodon dunni* | Dunn's Salamander | OR, WA | typical |
| *Plethodon elongatus* | Del Norte Salamander | OR | typical |
| *Plethodon larselli* | Larch Mountain Salamander | OR, WA | endemic |
| *Plethodon stormi* | Siskiyou Mountains Salamander | OR | typical |
| *Plethodon vandykei* | Van Dyke's Salamander | ID, WA | typical |
| *Plethodon vehiculum* | Western Redback Salamander | OR, WA, BC | endemic |
| Salamandridae | Newts | | |
| *Taricha granulosa* | Roughskin Newt | ID, OR, WA, BC | typical |
| **Order Anura (Frogs and Toads)** | | | |
| Bufonidae | Toads | | |
| *Bufo boreas* | Western Toad | ID, OR, WA, BC | typical |
| *Bufo woodhousei* | Woodhouse's Toad | ID, OR, WA | peripheral |
| Hylidae | Treefrogs | | |
| *Hyla regilla* | Pacific Treefrog | ID, OR, WA, BC | typical |
| *Pseudacris triseriata* | Striped Chorus Frog | ID, BC | peripheral |
| Leiopelmatidae | Bell Toads | | |
| *Ascaphus montanus* | Rocky Mountain tailed frog | BC, ID, MT, WA* | endemic |
| *Ascaphus. truei* | Tailed Frog | ID, OR, WA, BC | typical |
| Pelobatidae | Spadefoot Toads | | |
| *Spea intermontana* | Great Basin Spadefoot | ID, OR, WA, BC | peripheral |
| Ranidae | True Frogs | | |

| Species | Common Name | State/ Province | Distributional Status |
|---|---|---|---|
| *Rana aurora* | Red-legged Frog | AK, OR, WA, BC | typical |
| *Rana boylei* | Foothill Yellow-legged Frog | OR | peripheral |
| *Rana cascadae* | Cascade Frog | OR, WA | typical |
| *Rana catesbeiana* | Bullfrog | ID, OR, WA, BC | introduced |
| *Rana clamitans* | Green Frog | WA, BC | introduced |
| *Rana pipiens* | Northern Leopard Frog | ID, OR, WA, BC | peripheral |
| *Rana pretiosa* | Spotted Frog | SE AK, ID, OR, WA, BC | typical |
| *Rana sylvatica* | Wood Frog | SE AK, ID, WA, BC | peripheral |

* (British Columbia Conservation Data Centre [sic] 2001, Idaho Conservation Data Center 2001, Montana Natural Heritage Program 2001, Washington Natural Heritage Program 2001)

## Tailed Frogs (*Ascaphus spp.*)

Two species of the tailed frog [Pacific tailed frog *(Ascaphus truei)* and Rocky Mountain tailed frog *(Ascaphus montanus)*], which inhabit mountainous coniferous forests, are currently under evaluation for management and conservation from British Columbia to California. Tailed frogs' reproductive process is unique among the PNW frogs in that fertilization is internal. Eggs are deposited in double strands of pea-sized eggs attached beneath rocks within stream channels (Gaige 1920, Brown 1975, Adams 1993, Capula 1989, Nussbaum et al. 1983 and others as cited in Wahbe et al. 2001).

Tailed frogs are endemic to the PNW. Their home range is generally bound by the Pacific coast and the Rocky Mountains (Corkran and Thoms 1996, Leonard et al. 1993, Nussbaum et al. 1983, and Stebbins 1985 as cited in Wahbe et al. 2001). Most of the habitat documentation for the Pacific tailed frog is from Pacific slope drainages west of the Cascade Mountains (Svihla and Svihla 1933, Visalli and Leonard 1994, Wahbe et al. 2001) and crossing onto the east side of the Cascades in Washington and north central Oregon (Smith 1997 as cited in Wahbe et al. 2001).

The Rocky Mountain tailed frog is an inland species. Its northern home range is limited to the Canada-U.S. border (Dupuis and Wilson 1999 as cited in Wahbe et al. 2001). The southern limit of this species is south-central Idaho (Stebbins 1985 as cited in Wahbe et al. 2001), the western limit is southeastern Washington (Bull 1994 as cited in Wahbe et al. 2001) and northeastern Oregon (Ferguson 1952 as cited in Wahbe et al. 2001) and its eastern limit is delineated by the Rocky Mountains in Montana (Donaldson 1934 and others as cited in Wahbe et al. 2001).

Tailed frogs commonly inhabit perennial, fast-moving, low order mountain streams ranging from sea level to above 7,000 feet in elevation (Nussbaum et al. 1983). They display a clustered distribution pattern within watersheds (Ritland et al. 2000 as cited in Wahbe et al. 2001). Mountain streams with step-pools and headwaters are the preferred breeding habitat (Dupuis 1999 as cited in Wahbe et al. 2001). At the larval stage, juvenile densities are highest in streams with boulder and cobble substrate and are most reduced in channels containing finer substrates including sand, fine gravel, and small rocks (Dupuis and Friele 1996, Wahbe 1996, Welsh and Ollivier 1998, and others as cited in Wahbe et al. 2001).

Little information has been published on adult habitat associations and the results documented in Wahbe et al. 2001 are provided as preliminary information. Coastal tailed frog species typically occur in wetter forest types with high herbaceous and fern vegetative cover (Corn and Bury 1991, Welsh 1993). In drier regions of the Cascade Mountain range, Bury et al. (1991a) found that the tailed frog populations are limited to wet forests in cool, moist habitats including steep slopes, high elevations, and talus slopes or piles (Aubry and Hall 1991). The Rocky Mountain species are restricted to high elevation spruce-fir forests (Dupuis and Wilson 1999 as cited in Wahbe et al. 2001).

Claussen 1973 (as cited in Wahbe et al. 2001) indicated that riparian buffers may provide foraging habitat for adult tailed frogs. Streams adjacent to developed under- and overstory vegetation may be important terrestrial habitat for tailed frogs. Forested riparian buffers may benefit the species by stabilizing stream channels. They may also support the species terrestrial movement, mating, egg-laying, and foraging requirements (Wahbe et al. 2001).

Foraging begins at dusk and continues throughout the night when tailed frogs emerge to feed terrestrially along stream and damp surrounding forests (Capula 1989, Leonard et al. 1993 as cited in Wahbe et al. 2001). In mesic conditions tailed frogs may forage 90 meters from stream habitat (Metter 1967, Noble and Putnam 1931 as cited in Wahbe et al. 2001).

The home range of adult tailed frogs has not been well documented. In drier inland regions most adults remain near streams (Metter 1967 as cited in Wahbe et al. 2001) or travel at a maximum distance of 12 meters (Metter 1964(a) as cited in Wahbe et al. 2001). Tailed frogs that inhabit wetter coastal regions with high humidity and extended rains are able to expand their home ranges with the ability to travel several hundred meters from a stream edge (Welsh and Reynolds 1986, Bury and Corn 1988(a), Dupuis et al. 1995, Gomez and Anthony 1996, Dupuis 1998, Wahbe et al. 2000 as cited in Wahbe et al. 2001).

### Cascade Torrent Salamander (*Rhyacotritonidae cascadae*)

The reproductive life history of this species is not well documented. Nests have not been described but may be similar to those of the Columbia torrent salamander, as the species are closely related. Clutch size, measured as number of ova in gravid females in a study in the Columbia River Gorge, averaged eight (Nussbaum and Tait 1977 in Hayes unpubl.). Data from the same study indicated a comparatively long larval stage, an estimated three to four years, for the Cascade torrent salamander. Although food and cover requirements for larvae are not documented, Nussbaum and Tait (1977 in Hayes unpubl.) found larvae to be numerous under stones in a narrow stream and fissures in the streambed. The same study found that most individuals metamorphosed in late summer and early fall, although metamorphosis in the Columbia River Gorge occurred in every season. Post-metamorphic migrations have not been documented for the genus, and neoteny has not been observed.

Little is known about the juvenile stage of the Cascade torrent salamander, and where research exists, this stage is not differentiated from adults. Data for adult stages are often pooled with other species and limited to general accounts. These accounts identify adult habitat as riffles, rock rubble, and fissures of stream banks, seeps and small streams with small rock rubble and slow water. The genus *Rhyacotriton* in general is highly intolerant to desiccation. The home range is probably small, as available data indicate that the species is sedentary (Nussbaum and Tait 1977, Nijhius and Kaplan 1998 in Hayes unpubl.). Evidence of territoriality was not found during these studies. Nussbaum and Tait (1977) in Hayes (unpubl.) estimated age at reproductive maturity to be 5.5-6 years, and length at this stage as a minimum of 41 mm for males and 44 mm for females.

Feeding behavior is largely surmised from other species of the genus. Cascade torrent salamanders likely feed on amphipods, fly larvae, springtails, and stonefly nymphs of their species semi-aquatic and aquatic habitat (Bury 1970 in Hayes unpubl.) Predators of the genus probably include giant salamanders (Welsh 1993, Welsh and Lind 1996 in Hayes pers. comm. Nov. 2002), although depredation of different life stages is unknown. One species of monogenoidean fluke is known to parasitize Cascade torrent salamanders (Kristsky et al. 1993 in Hayes unpubl.).

Cascade torrent salamanders are listed as sensitive by the states of Oregon and Washington. The species was listed in response to the concern that the conversion of old-growth forest to young stands was degrading habitat quality and causing local extinction (Corn and Bury 1989 in Hayes unpubl.). The actual status of the species in unknown, and research is needed and planned under the Washington Forest and Fish Agreement (FFA) to examine whether riparian buffers are effective in protecting the species.

### Columbia Torrent Salamander (*Rhyacotritonidae kezeri*)

Columbia torrent salamanders range from northwestern Oregon to southwestern Washington coastal and near-coastal regions, from near sea level to the highest elevations within their range. They can be found in some upper reaches of the coastal portion of the Willamette hydrographic basin, but inland distribution is poorly known. They are widespread in headwaters of managed forests; occurrence generally increases with channel gradient and decreases with basin area, and therefore tends to be more abundant closer to headwaters. Historic abundance is unknown.

Breeding is aquatic, although breeding habitats and migrations are not known. The few nests discovered were in various habitats, including headwater springs, a side-slope seep, 75 m downstream from a stream origin, under a boulder, and under thick moss. Substrates included sand, fine sediments, and gravels (Russell et al. 2002 in Hayes unpubl.). Eggs ranged in size from 3.8-4.1 mm in three nests. Clutch size is not known, but fecundity is likely low, based on research of other species in the genus (Nussbaum and Tait 1977 in Hayes unpubl.). No data exist for the larval and juvenile stages of this species. However, Columbia torrent salamander larvae constituted the majority of the individuals surveyed in pooled studies. Based on one of these studies, they likely prefer stable, low-flow streams with loose gravel and cobble substrates and little fine sediment (Welsh and Lind 1996 in Hayes unpubl.).

General descriptions of adult habitat for the genus are similar to that of the Cascade torrent salamander. In addition, Russell et al. (2002 in Hayes unpubl.) found the species in greater abundance in streams with basalt substrates than in streams with marine sedimentary substrates. Although existing studies have identified inverse relationships between abundance and gradient, results are complicated by the tendency for lower-gradient streams to be more heavily harvested for timber, possibly causing degradation of low-gradient habitats.

Home range size, territoriality, seasonal migrations, age and size at maturity, predators, and parasites are not documented for the Columbian torrent salamander, but observations of these features of other species within the genus are listed in the Cascade torrent salamander section of this report.

Columbia torrent salamanders are listed as sensitive in both Oregon and Washington, for the same reasons Cascade torrent salamanders were state listed. Actual status is unknown, but pooled data suggest that the species is sensitive to forest practices in riparian habitats, requiring a buffer of 43 m to support the numbers sustained in unlogged forest (Vesely and McComb 2002 in Hayes unpubl.). The Washington FFA research and planned studies outlined in the Cascade torrent salamander section apply to the Columbia torrent salamander as well.

### Olympic Torrent Salamander (*Rhyacotritonidae olympicus*)

The Olympic torrent salamander is restricted to the Olympic peninsula of Washington, and the species was found to be widespread within Olympic National Park (Bury and Adams 2000 in Hayes unpubl.). Most data are from the past 10 years or less. Research from Olympic National Park showed highest abundance of individuals in streams with northerly aspects and steep gradients and lower abundance in streams with fine substrates and near undercut banks (Bury and Adams 2000 in Hayes unpubl.).

Reproduction is thought to be aquatic, although breeding habitat is unknown and no egg deposition sites have been described. Low-flow sites similar to those reported for other species of *Rhyacotriton* are likely preferred by this species as well. Good and Wake (1992 in Hayes unpubl.) found low egg counts in gravid females, and fecundity is likely low. Larval and metamorphic requirements and features are unknown for this species. However, information on closely related species can be found in the discussion of Cascade torrent salamanders above. Likewise, juvenile habitat requirements are unknown but may be similar to those of adults, based on existing data on the genus.

Few accounts specific to Olympic torrent salamander habitat exist. However, Leonard et al. (1993 in Hayes unpubl.) described adult habitat as cold, clear streams, seepages, and waterfalls, usually in the splash zone, over rock substrate. Home range size, territoriality, seasonal migrations, size-age at reproductive maturity, lifespan, feeding behavior, predators, and parasites are all unknown for this species specifically.

Olympic torrent salamanders are listed as sensitive by Washington State, generally for the same reasons Cascade and Columbian torrent salamanders were state listed. The Washington FFA research and planned studies outlined in the Cascade torrent salamanders section apply to this species as well.

### Van Dyke’s salamander (*Plethodon vandykei*)

Van Dyke’s salamander is found only in Washington State and, currently, only in the Olympic Mountains, southern Cascades, and Willapa Hills. It is considered semi-aquatic because the adults are often found near streams where conditions are very moist to slightly wet (Leonard et al. 1993).

Van Dyke’s salamander is associated with seepages or streams, but may also be found far from water. It has been documented as having some life history associations with forested wetlands (Hayes 2002). Van Dyke’s salamander is suspected of utilizing forested wetlands as eggs, juveniles, adults during breeding, active season, and overwintering (Hayes 2002 pers. comm.). Typically, this species can be found in the splash zone of creeks or waterfalls under rocks or woody debris, or under logs, loose pieces of bark, and bark on logs near water. It may be common in seepages over talus or in rock faces where it hides in cracks.

Its terrestrial habitats are usually associated with north-facing slopes with a thick cover of mosses. Only two nests have been found (Leonard et al. 1993); one was under a moss-covered stone and the other was inside a large Douglas-fir log near a creek. One study showed Van Dyke's salamanders occupying habitats adjacent to streams, all of which traversed basalt lithologies on north-facing slopes (Wilkins and Peterson 2000).

### Dunn's Salamander (*Plethodon dunni*)

Dunn's salamander is one of the largest found in the PNW (Leonard et al. 1993). This relatively rare species (Leonard et al. 1993) is found in Oregon and Washington from sea level to approximately 3,500 feet in elevation. Its home range is from the Pacific coast to the Cascade crest; its southern and northern limits are in northwestern California and southern Washington, respectively (Leonard et al. 1993). Little information is available on the life cycle of this species. The habitat of the Dunn's salamander is associated with streams, seeps, and splash zones (Leonard et al. 1993). They do not live in streams but in areas of moist substrate. They are most highly associated with habitats containing rocky areas or talus adjacent to forested streams and in permanently wet or moist substrate. Juveniles and adults live in gravel or under cobbles at the edge of streams or in moist rocky areas (Leonard et al. 1993). In rainy weather, they are occasionally found in or under logs near streams or under surface debris (Corkran and Thoms 1996, Leonard et al. 1993). Only one nest site has been documented, located in a rock crevice (Corkran and Thoms 1996) adjacent to a stream (Leonard et al. 1993). Eggs were arranged in a grape-like cluster attached to the rock by a pedicel (Leonard et al. 1993).

# Appendix G
## Background Material: Fish

**Common and scientific names and origins and life histories of the salmonids of western Washington and Oregon (Everest et al. 1985)**

| Common name | Scientific name | Origin | Reproduce in | Rear in *1 |
|---|---|---|---|---|
| Pink salmon | *Oncorhynchus gorbuscha* | Native | Stream | S,E,O |
| Chum salmon | *Oncorhynchus keta* | Native | Stream | S,E,O |
| Coho salmon | *Oncorhynchus kisutch* | Native | Stream | S,E,O |
| Sockeye salmon | *Oncorhynchus nerka* | Native | Lake, Stream | L,O |
| Sockeye Kokanee | *Oncorhynchus nerka* | Native | Stream | L |
| Chinook salmon | *Oncorhynchus tshawytscha* | Native | Stream | S,E,O |
| Cutthroat trout | *Oncorhynchus clarki* | Native | Stream | L,S |
| Searun Cutthroat | *Oncorhynchus clarki* | Native | Stream | S,E,O |
| Rainbow trout | *Oncorhynchus gairdneri* | Native | Stream | L,S |
| Steelhead | *Oncorhynchus gairdneri* | Native | Stream | S,O |
| Bull trout | *Salvelinus confluentus* | Native | Stream | L,S |
| Dolly Varden | *Salvelinus malma* | Native | Stream | L,S,E,O |
| Pygmy whitefish | *Prosopium coulterii* | Native | Lake | L |
| Mountain whitefish | *Prosopium williamsoni* | Native | Stream | S |
| Brown trout | *Salmo trutta* | Introduced | Stream | L,S |
| Golden trout | *Oncorhynchus mykiss aquabonita* | Introduced | Stream | L,S |
| Brook trout | *Salvelinus fontinalis* | Introduced | Lake | L,S |
| Lake trout | *Salvelinus namaycush* | Introduced | Lake | L |
| Arctic grayling | *Thymallus arcticus* | Introduced | Stream | L,S |

*1 L= lakes, S= streams, E= estuaries, O= ocean (anadromous