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A Review of Protocols for Monitoring Streams and Juvenile Fish in Forested Regions of the Pacific Northwest

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Abstract

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This document reviews existing and proposed protocols used to monitor stream ecosystem conditions and responses to land management activities in the Pacific Northwest. Because of recent work aimed at improving the utility of habitat survey and fish abundance assessment methods, this review focuses on current (since 1993) monitoring efforts that assess stream habitat conditions and juvenile fish use. It does not focus on protocols specifically intended to monitor trends in fish populations for salmon recovery efforts, other fish life-history stages (e.g., salmonid smolt monitoring or spawner surveys), or approaches designed to monitor water quality or sources of pollution. We provide an overview of agency monitoring protocols, adaptive management, and types of monitoring, and briefly review the core habitat characteristics thought to be most sensitive to forest management practices. Finally, we summarize a selection of protocols in use in the Pacific Northwest in light of those core habitat characteristics.

Keywords: Monitoring, aquatic habitat, riparian ecosystems, adaptive management, forest practices.

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Introduction

This document reviews existing and proposed protocols used to monitor stream ecosystem conditions and responses to land management activities in the Pacific Northwest. We define a monitoring protocol as a set of directions and guidelines that address specific objectives and provide methods designed to obtain data sets that can be used to detect trends or changes in habitat conditions and fish use. This review focuses on current (since 1993) monitoring efforts that assess stream habitat conditions and juvenile fish use. It does not focus on protocols specifically intended to monitor trends in fish populations for salmon recovery efforts, other fish life-history stages (e.g., salmonid smolt monitoring or spawner surveys), biotic indexes, or approaches designed to monitor water quality or sources of pollution. However, we recognize that some of these approaches may contain specific recommendations that apply to protocols for assessing stream habitat conditions and juvenile fish use (MacDonald et al. 1991).

This review consists of several sections. We begin by presenting the methods used to locate relevant stream monitoring protocols and our criteria for selecting the monitoring protocols that we evaluated as most relevant. We then provide an overview of agency monitoring protocols, adaptive management, types of monitoring, and a summary of the core habitat characteristics thought to be most sensitive to forest management practices. Finally, we provide a comparison of current protocols in light of those core habitat characteristics.

Methods

This document was compiled by conducting reviews of published and gray literature and by performing Web-based searches of protocols and databases. Databases used for the Web search included the National Technical Information Service, Cambridge Scientific Abstracts, Aquatic Sciences and Fisheries Abstracts, and Google. In addition, various agency Web sites including the U.S. Environmental Protection Agency (EPA), U.S. Department of the Interior (USDI) National Park Service, U.S. Department of Agriculture Forest Service (FS), Columbia River Inter-Tribal Fish Commission, British Columbia Ministry of Sustainable Resource Management, and state agencies from California, Oregon, Washington, and Idaho, were searched for the most recent documents and updates. Agencies, including those currently conducting protocol reviews of their own, were also contacted (e.g., Johnson et al. 2003, Lanigan 2002). References in the retrieved documents were searched for additional sources.

Because of the recent work aimed at improving the utility of habitat survey and fish abundance assessment methods (e.g., Kaufmann et al. 1999, Kurtz et al. 2001, Reeves et al. 2003, Thompson 2003), several stream monitoring protocols are currently or were recently under revision. We have focused our attention on the recently revised protocols (1993 or later) published or proposed by agencies operating in forested regions of Washington, Oregon, Idaho, California, and British Columbia.

Our criteria for screening the retrieved documents included how recently the document had been published or updated, as well as the scope, level of detail, and potential application of the protocol (or significant parts of it) for assessing influences of forest land use practices on stream habitats and juvenile salmonids.

A list of documents was compiled by using EndNote software (ISI ResearchSoft),¹ then further refined to 37 documents that we determined to be the most relevant (see appendix). Of that refined list, five of the most recent were selected for side-by-side comparison (tables 1 and 2). Where possible, URLs are provided so that readers can navigate to the documents in question and view them in detail.

Overview of Agency Monitoring Protocols

The issues involved in monitoring streams, rivers, and watersheds are not new. For aquatic ecosystems, monitoring activities commonly involve repetitive (e.g., yearly) surveys that assess changes in select physical and ecological characteristics. Regier (1976) describes monitoring processes as evolving from descriptive natural history studies to more quantitative approaches. Most monitoring of streams has involved surveys and assessments of changing environmental characteristics at the habitat scale (e.g., changes in composition of pool and riffle types, large woody debris [LWD] size and quantity), select landscape-scale characteristics (e.g., channel gradients of reaches), and use by fish (Duff and Cooper 1978; Kershner et al. 2003; Medsger et al. 1991; Platts et al. 1987; Rinne 1985; Roni, in press; USDA FS 2001). An underlying goal of these monitoring efforts is to identify and understand effects of human perturbations on ecosystems or parts of ecosystems. These effects may result from land management practices, such as timber management in forested watersheds, or from the implementation of restoration and rehabilitation

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¹ The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

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Table 1—General characteristics of five major protocols

		Protocol			
	AREMP	EPA-EMAP	USGS-NWQA	FS	EPA-RBP
Title	Aquatic and Riparian Effectiveness Monitoring Plan for the Northwest Forest Plan	Environmental Monitoring and Assessment Program—Surface Waters: Western Pilot Study Field Operations Manual for Wadeable Streams (EMAP)	Revised protocols for sampling algal, invertebrate, and fish communities as part of the National Water-Quality Assessment Program (NWQAP)	Stream Inventory Handbook, Levels 1 & 2. Region 6, Version 2.2	Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, macroinvertebrates and fish (RBP)
Author	AREMP 2003	Peck et al. 2001 (unpublished draft)	Moulton et al. 2002	USDA FS 2002	Barbour et al. 1999
Agency	Interagency	EPA	USGS	FS	EPA
Purpose	Watershed ecological conditions: status and trends	National ecological conditions: status and trends	Water quality status and trends	Stream channel, riparian, and aquatic ecosystem conditions	Water quality assessment: rapid biosurvey
Spatial scale	Regional → 6 th -field HUC subwatershed → reach	Western US → stream segment → reach	Basin → segment → reach → microhabitat	Watershed → reach	Reach
Statistical design	Random sample of HUC watersheds → random sample of reaches	Random sample of points on 1:100,000 scale “blue-line” stream network	Subjective (not defined in protocol)	Stratified random at reach level (watershed selection not defined)	“Targeted or probabilistic” (not defined in protocol)

4 Table 1—General characteristics of five major protocols (continued)

		Protocol			
	AREMP	EPA-EMAP	USGS-NWQA	FS	EPA-RBP
Features sampled (see table 2)	Physicochemical, habitat; periphyton, benthic macroinverts, and fish assemblages	Physicochemical, habitat; periphyton, benthic macroinverts, and fish assemblages; fish tissue	Periphyton, macro-invertebrates, and fish (for habitat, see Fitzpatrick et al. 1998)	Physical, fish	Physicochemical, habitat; periphyton, benthic macroinverts, and fish assemblages
Explicit QA/QC	Yes—pilot program	Yes	Recommended	Minimum standards established	Yes
Comments	Synthesis of protocols from EPA, USGS, FS, and BPA	Protocol used by many NW state and local agencies	Fixed sites; “representative” fish samples; extensive basin characterization with GIS		Multimetric assessment protocol (Index of Biotic Integrity)
URL	http://www.fs.fed.us/pnw/pubs/gtr577.pdf	http://www.epa.gov/emap/html/pubs/docs/groupdocs/surfwatr/field/ewwsm01.html	http://water.usgs.gov/nawqa/protocols/OFR02-150/OFR02-150.pdf		http://www.epa.gov/owow/monitoring/rbp/wp61pdf/rbp.pdf

Note: Features sampled are described in more detail in table 2.

Table 2—Features sampled by five core protocols

	AREMP	EAP—EMAP	USGS—NWQA	FS	EPA—RBP
Sampling strategy	Eight randomly selected reaches within each sample subwatershed. Reach length = 20X avg. bankfull width (150 m min., 500 m max.). 11 transects.	Randomly selected index site. Sample 40X avg. bankfull width (min. 150 m) from central index point. 11 transects.	Habitat and physical characteristic protocols from Fitzpatrick et al. (1988). Subjective site selection 20X avg. bankfull width (min. 150 m, max. 300 m). 11 transects.	Stream/watershed selection process not defined in this protocol. 10 percent of all fast- and slow-water units measured (minimum 10 of each type).	Not defined in protocol.
Physical habitat: Channel cross section	Nonconstrained reaches: initial cross section is monumented and an additional 10 systematic (nonmonumented) cross sections are placed at 1/10 of the reach length. Constrained reaches: Six systematic (nonmonumented) cross sections are placed at 1/5 of the reach length. Cross sections are measured with a laser range finder; 11 transects are measured in nonconstrained reaches and 6 in constrained reaches.	Wetted width measured at 21 equally spaced cross sections. Four equally spaced depth measurements taken at each transect (11 transects total).	Wetted channel width, bankfull channel width, bank height and channel features measured at each transect; bank stability index at each transect. Optional: Five transects that best represent the geomorphology are selected (one each at upstream and downstream ends of reach—one or both benchmarked).	Four equidistant bankfull depth measurements at each measured fast-water unit. Flood-prone width measured.	Estimated width, depth. EMAP protocol optional.

6 Table 2—Features sampled by five core protocols (continued)

	AREMP	EPA—EMAP	USGS—NWQA	FS	EPA—RbP
Longitudinal profile	Longitudinal profile measured (x, y, z coordinates) by using a laser range finder and an electronic compass, following the thalweg. Shots are taken on an increment about 1/100 of the sample site length. Additional measurements taken at pool tail crests, maximum pool depth, and pool head. The same protocol is used in all sample reaches, constrained or nonconstrained.	Measured at 100 equally spaced intervals (150 in streams less than 2.5 m wide) along centerline between first and last transect.	Measured at transects.	Not collected.	Estimated reach length. EMAP protocol optional.
Pool frequency and length	Pool defined as being longer than the average wetted width. Habitat unit has to span channel.	Part of channel unit characterization; pool-forming elements noted.	Length of pools greater than 50 percent of channel width measured and mapped.	Pool defined as being longer than the average wetted width unless unit is a plunge pool. Habitat unit has to span channel.	Percentage of reach represented by stream morphology types (riffle, run, pool). EMAP protocol optional.
Pool depth	Pool tail crest, max pool depth, and pool head locations measured with laser range finder.	Part of longitudinal and cross-sectional measurements.	Part of longitudinal and cross-sectional measurements	Maximum pool tail crest and maximum pool depth.	Not measured. EMAP protocol optional.
Stream gradient	Calculated as the rise of the streambed divided by the length of the sampling segment (slope of streambed, not water surface).	Water surface slope and bearing measured along longitudinal profile.	Calculated from maps or GIS; also measured along longitudinal profile with clinometer or hand level.	Calculated from 1:24,000 maps.	High gradient (riffle/run) vs. low gradient (glide/pool). EMAP protocol optional.

Table 2—Features sampled by five core protocols (continued)

	AREMP	EPA—EMAP	USGS—NWQA	FS	EPA—RBP
Sinuosity	Calculated by using longitudinal profile data. Sum of lengths between thalweg points at each transect divided by straight-line distance.	Compass bearings along longitudinal profile.	Calculated from maps or GIS.	Calculated from 1:24,000 maps.	Scale of 0 to 20. EMAP protocol optional.
Discharge	Measured with flow meter or neutral buoyant object if stream too small. Ten cells measured for meter measurements.	Measured with flow meter (D60), neutral buoyant object, or time-filling procedure depending on depth of stream; 15 to 20 intervals for meter measurements.	Mean water-column velocity at three points along each transect.	Derived from velocity measurements; 25 velocity measurements across channel.	Surface velocity measured at thalweg. EMAP protocol optional.
Bankfull width: depth	Calculated at each transect. Eleven depth measurements between and including bankfull points at each transect to determine mean depth.	Depth of thalweg measured each 1/100 of reach; bankfull channel and incision height.	Water depth at three points along each transect.	Bankfull width and depth measured at each measured fast-water unit.	High-water mark measurement only. EMAP protocol optional.
Substrate	Similar to EMAP. Percentage of fines in pool tail areas by using Klamath grid (max. 12 pools).	Substrate size and embeddedness visually estimated at four equally spaced points along each transect.	Size and embeddedness estimated at three points along each transect.	Wolman pebble count at two points in stream reach in “normal” fast-water stream units.	Estimated composition (percentage).
			Optional: Wolman pebble count.		

∞ Table 2—Features sampled by five core protocols (continued)

	AREMP	EPA—EMAP	USGS—NWQA	FS	EPA—RbP
Large wood	Count wood if min. length ≥ 3 m and at least 0.3 m diameter at d.b.h. Length and d.b.h. estimated. Length and d.b.h. measured on first 10 pieces in reach and every 5 th piece thereafter. Note location in channel. Jams of more than 5 pieces not measured but presence documented.	Tallied between each transect. Sorted into one of 12 diameter-class categories.		Tallied for each channel unit as small, medium, or large.	Estimated area, density. EMAP protocol optional.
Other chemical and physical parameters	Total Kjeldahl N, total P, temperature, dissolved oxygen, pH, conductivity. Sampled at lowest point in subwatershed on federal land. Entrenchment ratio.	Bank angle, undercut distance at each transect. Major cations and anions, nutrients, total Fe and Mn, turbidity, color, pH, dissolved organic carbon, temp. (conductivity and dissolved oxygen optional).	Water quality.	Length of unstable banks (above bankfull stream margin), temperature, entrenchment ratio.	Temperature, conductance, dissolved oxygen, pH, turbidity.

Table 2—Features sampled by five core protocols (continued)

	AREMP	EPA—EMAP	USGS—NWQA	FS	EPA—RbP
Biological sampling:					
Periphyton/ phytoplankton	EMAP field and lab analysis protocol.	11 transects collecting substrate samples from dominant habitat type on transect. All samples collected into one composite sample. Three lab samples prepared: ID/enumeration, chlorophyll, and biomass.	Five samples from each of five locations in riffles distributed throughout reach; five macrophyte samples. Quantitative phytoplankton, microalgae; composite samples.	Not collected.	Two sampling approaches described. Representative habitats sampled. Qualitative listing of aquatic biota; composite samples collected.
Benthic macroinvertebrates	Two subsamples in each of four riffles in reach by using kick net. These eight subsamples combined into single sample for reach.	Two types of samples: “reach-wide” samples collected at each transect and combined; “targeted riffle” samples (eight) combined from separate, riffle-only samples. Modified D-frame kick net.	Qualitative and semiquantitative samples taken from each habitat type in reach and combined.	Not collected.	All riffles/runs in representative reach sampled. Samples combined.

Table 2—Features sampled by five core protocols (continued)

	AREMP	EPA—EMAP	USGS—NWQA	FS	EPA—RbP
Fish and aquatic amphibians	Single pass with electroshocker at each site between transects. Ten to twenty percent of fish measured, condition estimated by using displacement. Snout-vent lengths measured for all aquatic amphibians, Snorkeling used to determine fish/amphibians presence where threatened/endangered fish species present.	Single pass with electroshocker between transects along entire sample reach. Largest and smallest specimens measured. Voucher specimens and tissue samples collected. Seining used where electrofishing not appropriate. Jaccard coefficient used to assess sampling adequacy.	Two-pass electro-fishing and seining to determine length, weight, and abnormalities. All channel units and habitat features are sampled. Weigh and measure at least 30 individuals of each species. Voucher specimens collected.	Minimum: Sample every measured slow-water unit and every other fast-water unit. Snorkel, electroshock, hook and line, or seining. Amphibians noted.	Representative stream reach sampled with single-pass electrofishing.
Other biological parameters	Terrestrial amphibians.	Riparian canopy cover at each transect by using densiometer; vegetation structure, areal cover estimation. Instream fish cover and human influence estimates; channel constraint.	Riparian canopy cover at each transect by using densiometer; dominant riparian vegetation; instream habitat cover; bank stability index; bank angle, substrate, vegetative cover.	Avg. width of inner/outer riparian zone, successional class, overstory, understorey.	

Source: Adapted from Lanigan (2003).

programs. Common landscape approaches include watershed-scale (km²) assessments developed and implemented to evaluate environmental conditions and management actions that can influence fish habitats (Collins and Pess 1997, Morrison and Marcot 1995). They also can be used to monitor natural disturbance events (e.g., wildfires and floods). The ability to detect and explain change can be the most instructive outcome of a monitoring program (MacDonald et al. 1991).

Major issues warranting monitoring are habitat degradation, compliance with regulations related to sensitive and endangered species (e.g., the Endangered Species Act, National Environmental Policy Act), and the implementation of agency policies or management plans. In the Pacific Northwest, some pertinent examples of management plans and actions with provisions for monitoring stream ecosystems include efforts of the FS, the states of Oregon and Washington, and local watershed management councils. The FS examples include the Northwest Forest Plan (NWFP) for the Pacific Northwest (FEMAT 1993) and the Tongass Land Management Plan (USDA FS 1997) for southeast Alaska.

The FEMAT (1993) report contains interagency scientists' recommendations resulting from President William Clinton's Forest Summit in 1993. It focuses on the influences of forest and other resource management practices in the Pacific Northwest and includes an aquatic conservation strategy for restoring salmon stocks, habitats, streams, and riparian ecosystems. Recommendations include provisions for monitoring strategy objectives.

Goals of the Tongass plan include "the maintenance or restoration of the natural range and frequency of aquatic habitat and stream channel and bank conditions" in the Tongass National Forest (USDA FS 1997). A common monitoring objective for aquatic ecosystems is determining the effectiveness of fish and riparian standards and guidelines in maintaining or improving fish habitats (USDA FS 1995, 1997).

The state of Oregon is involved in several monitoring programs. Oregon's Coastal Landscape Analysis and Modeling Study (CLAMS), an interagency program, uses monitoring as one tool in a set of analyses to link ecological, economic, and social factors with forest management policies and practices in coastal Oregon watersheds.² The Oregon Plan for Salmon and Watersheds has provisions for monitoring spawning salmonids, smolt outmigration, and the effects of habitat modifications on juvenile salmonids (IMST 1999, Solazzi et al. 2003).

² Cooperative effort of Oregon State University, USDA Pacific Northwest Research Station, Oregon Department of Forestry, and the National Commission on Science for Sustainable Forestry. <http://www.fsl.orst.edu/clams/intro.html>. (January 6, 2004).

The Washington State Department of Natural Resources (WSDNR) (Grizzel et al. 2000, Pleus et al. 1999, Schuett-Hames et al. 1999) and the Skagit Watershed Council (2000) provide two examples of management strategies based on basin-wide analysis programs designed to assess influences of land uses on stream systems and fish use of habitats. For WSDNR, the monitoring of stream ecosystems is the responsibility of the Cooperative Monitoring, Evaluation, and Research Program (CMER). The CMER program is conducting a number of effectiveness studies that must incorporate some stream classification scheme (e.g., Montgomery and Buffington 1993). They are especially interested in a classification that is sensitive to watershed inputs (e.g., wood and sediment) (e.g., Grizzel et al. 2000). They are also conducting effectiveness studies for evaluating new prescriptions relating to riparian buffer zones, channel erosion problems, road runoff, and other environmental concerns. The CMER program is currently selecting monitoring sites that are representative of the range of variables of interest (e.g., stream physical processes and ecological sensitivities). A major goal of the WSDNR monitoring is to benefit that agency's ongoing adaptive management efforts.

The Skagit Watershed Council in western Washington is an example of a local watershed council that is evaluating and improving aquatic resources throughout a large river drainage. The council's strategy is designed to address stream ecosystem questions relating to flooding, sediment supply, riparian functions, floodplain functions, and habitat connectivity. Assessments have been made of habitat losses to help prioritize actions required to restore habitat-forming processes. This information was used to make decisions based on proposed project effectiveness relative to costs and likelihood of success (Skagit Watershed Council 2000). This approach allows monitoring of the amount of available habitat created by projects (e.g., removal of culvert blockages and other impediments to habitat formation and fish movement).

Adaptive Management

Adaptive management is a strategy for dealing with the risks associated with resource management decisions derived from imperfect data (Anderson et al. 2003, Holling 1978, Ralph and Pool 2003, Walters 1986). In theory, adaptive management is founded on considering land use activities as experimental manipulations implemented within the framework of a well-documented monitoring program. The intent of the concept is to gain perspectives into the response of ecosystems inhabited and used by humans.

Information obtained by the different Forest Service monitoring approaches, along with research and other new information, provides a basis for adaptive

management strategies. Adaptive management can occur when policies and management actions are changed in response to new knowledge provided by monitoring programs. Adaptive management has been adopted by many land management agencies and particularly within the FS; however, it has not been universally applied (Stankey et al. 2003). Ralph and Pool (2003), Stankey et al. (2003), and Anderson et al. (2003) discuss many of the challenges in applying adaptive management and propose some solutions. The most effective adaptive management plans include specific links with monitoring programs that can be used to evaluate management prescriptions. Ideally, provisions can be made to use data obtained through repetitive long-term monitoring as feedback information for revising management plans and actions (Wissmar 1993). In summary, adaptive management plans that include monitoring programs as integral components can provide information to managers on “what works and what does not work.”

Types of Monitoring

Many monitoring approaches have been applied to fluvial ecosystems by authors and agencies. For example, MacDonald et al. (1991) identify several monitoring approaches and define parameters that can be used to evaluate effects of forestry activities on stream chemical (e.g., water quality), physical (e.g., channel characteristics), and select biotic conditions. Examples of other historically significant approaches include (1) prescriptions designed to assess the effectiveness of best management practices in protecting water and stream quality (NCASI 1988), (2) rapid bioassessment protocols for evaluating benthic macroinvertebrates and fish populations in streams and rivers (USEPA 1989), and (3) biological criteria (USEPA 1990). These approaches range from rapid inventories (e.g., Barbour et al. 1999, Dolloff et al. 1993) to those that require extensive field surveys and statistical rigor (e.g., Peck et al. 2001, Reeves et al. 2003).

Forest management plans that include provisions for monitoring streams generally define four primary types of monitoring designed to provide information to assess if management actions meet the objectives of the prescribed standards and guidelines (USDA FS 1994, 1997; USDA and USDI 1994).

1. Baseline monitoring is analogous to an inventory. This prescription is used to establish existing conditions within a geographic area or ecosystem for planning or future comparisons. Commonly it may be applied to obtain a “natural range” of conditions for streams and watersheds to capture much of the temporal variability of the system(s) of interest.

Adaptive management plans that include monitoring programs as integral components can provide information to managers on “what works and what does not work.”

2. Implementation monitoring is designed to determine if prescribed standards and guidelines were indeed carried out. For example, when riparian buffer strips of specific widths and distances are prescribed, implementation monitoring determines if they were created and meet the given criteria.
3. Effectiveness monitoring is more complex and is applied to determine the effect of a management prescription. In the case of the buffer strip example, this includes assessing if the buffers can maintain stream temperatures within the range of natural variation expected for stream ecosystems, sustain recruitment of large wood to stream channels, or maintain windfirm characteristics of trees (i.e., trees do not blow down a few years after logging). Effectiveness monitoring may involve research to obtain additional information (USDA FS 1994, 1997; USDA and USDI 1994).
4. Validation monitoring is designed to determine if underlying assumptions are sound. Validation monitoring determines the accuracy of an assumed cause-and-effect relationship between management activities and the resource being managed (i.e., Does maintaining large woody debris actually help fish?). Validation monitoring may also require research to obtain information (USDA FS 1994, 1997; USDA and USDI 1994).

Baseline, implementation, and effectiveness monitoring have been specified in fish habitat assessments prepared for the Tongass National Forest (USDA FS 1995). The USDA Forest Service and the USDI Bureau of Land Management have developed and adopted implementation, effectiveness, and validation monitoring approaches for evaluating the Aquatic Conservation Strategy of the NWFP for federal forests in the Pacific Northwest (USDA FS 1994, 1997; USDA and USDI 1994). These monitoring approaches were designed to ensure that management actions meet the objectives of the prescribed standards and guidelines and comply with laws and management policy. General objectives of FS monitoring include (1) determining if best management practices have been implemented, (2) determining the effectiveness of management practices at multiple scales (e.g., local habitats and watersheds), and (3) validating whether ecosystem functions and processes have been maintained (USDA FS 1994, 1997; USDA and USDI 1994).

In some FS management plans, monitoring approaches are accompanied by an evaluation question and include general descriptions of standards and guidelines (key items to be monitored). For stream systems, some major items to be measured for implementation monitoring can include width and integrity of riparian reserves. Important measurements obtained through effectiveness monitoring for streams

commonly include pool frequency and quality, substrate composition, coarse woody debris frequency and quality, and water temperature (USDA FS 1994, 1997; USDA and USDI 1994).

Core Habitat and Salmon Characteristics Sensitive to Forest Practices

Hicks et al. (1991) listed a number of forest practices that have effects on salmonid abundance and habitat condition. Those practices that altered the riparian and stream habitats by removing stream canopy or large woody debris, or by adding logging slash, had potentially negative effects on salmonids, such as increasing water temperatures, lowering dissolved oxygen levels, and increasing inputs of fine sediments to channels. Large pieces of wood are essential for creating and maintaining pools for fish habitat and for storing sediment (Bilby et al. 2003, Hicks et al. 1991, Montgomery et al. 1995). Timber harvest from hillsides or road construction can accelerate erosion, alter streamflow regimes and habitats, and present physical obstructions. Increased fine sediment levels can have a detrimental effect on different salmonid life history stages (Hicks et al. 1991, Meehan 1991).

The well-documented long-term studies at Carnation Creek, British Columbia, and the Alsea watershed, Oregon, have identified a number of relationships between forest management practices and salmonid populations and habitat conditions (Hall et al. 1987, Hartman and Scrivener 1990, Meehan 1991). In the Carnation Creek monitoring studies, for instance, those practices that increased stream insolation, nutrients, and water temperature also increased the numbers and size of juvenile coho salmon (*Oncorhynchus kisutch*) (Hartman and Scrivener 1990). Increasing coho salmon size may result in early smoltification, which has been implicated in higher marine mortality (Holtby et al. 1990). Those practices that decreased streambank stability and abundance of large woody debris or changed the spawning gravel composition had negative effects (Hartman and Scrivener 1990).

Oregon's Independent Multidisciplinary Science Team (IMST 1999) listed four categories of characteristics that affect salmonids. Intact riparian forests were important in regulating stream temperature, nutrient inputs, and LWD inputs to channels. Inputs of LWD into channels from riparian areas and land failures were important for formation of stream habitats. Increased amounts of fine sediment commonly reduce salmonid habitat quality, and roads may hinder fish passage at stream-road crossings.

The number and quality of pools are also known to be important for fish (Nickelson et al. 1992, Rosenfeld et al. 2000). In a series of experimental studies in Washington, deep pools with brushy cover were found to be beneficial to juvenile salmonids (Quinn and Peterson 1994, 1996). Coho salmon abundance was positively correlated with amount of pool habitat, and fish species richness was positively correlated with habitat complexity (Quinn and Peterson 1994). Likewise, Roni and Quinn (2001) reported juvenile coho salmon densities were higher in both summer and winter in reaches treated with the addition of artificial large woody debris.

In summary, juvenile coho salmon and other fish species seem to be most sensitive to the following habitat characteristics. (See Bauer and Ralph [1999] for an annotated bibliography of 334 literature citations related to salmon habitat requirements.)

- Amount and size of large woody debris
- Number and quality of pools
- Changes in riparian vegetation
- Water temperature
- Nutrient level
- Streamflow regime
- Sediment transport regime
- Quality of spawning environment
- Road placement and structures (sediment sources, passage barriers)
- Streambank stability

Many of these habitat characteristics are interrelated, and alteration in one characteristic (e.g., LWD) can affect another (e.g., pools). Forest practices that have measurable effects on these characteristics (see references in Meehan 1991) can differ with the range of management practices imposed on the watershed (FEMAT 1993, Meehan 1991, USDA FS 1995).

Most of the affected habitat characteristics are well known and comprise “core parameters” in monitoring protocols (Bain et al. 1999, Bauer and Ralph 2001, Gregory and Bisson 1997). Some habitat features that affect distribution of juvenile coho salmon, such as stream-channel gradient, are not usually affected by forest practices. However, differences in channel gradients of reaches can be important in classification of habitats and the design of monitoring programs.

Recently Revised Monitoring Protocols

Many federal and state agencies are currently updating or developing monitoring protocols. The Washington Department of Fish and Wildlife reviewed 112 documents containing 429 salmon habitat inventory and monitoring protocols in the

Pacific Northwest (Johnson et al. 2001). Current interagency efforts include the preparation of a similar review of fish survey protocols (Johnson et al. 2003). The FS Inventory and Monitoring Institute is presently developing guidelines for and a searchable database of monitoring protocols, but none are currently available (USDA FS 2003). The Forest Service national efforts also include an aquatic ecological unit inventory protocol with a core set of sampling features and recommended protocol.³ The USDI National Park Service is developing a national framework for their inventory and monitoring efforts (National Park Service 2003). Table 1 provides a brief overview of five protocols that were considered to be the most current and applicable to this review.

Regional-scale, national water quality assessment programs that are already in place, such as the EPA's Environmental Monitoring and Assessment Program (EMAP) and the USGS National Water Quality Assessment Program (NWQAP) (Lazorchak et al. 1998, Meador et al. 1993, Moulton et al. 2002, Peck et al. 2001) have useful components for monitoring forest land use practices and regional comparisons. These documents often provide a basis for other agencies' development of monitoring programs. The EPA's revised Rapid Bioassessment Protocol (RBP) is another large-scale monitoring protocol (Barbour et al. 1999). Its features are less quantitative and thus less useful for scientifically rigorous studies.

Two monitoring plans are currently being coordinated by the FS for the Northwest Forest Plan area under the Interagency Regional Monitoring Program for the Pacific Northwest. They include the Aquatic and Riparian Effectiveness Monitoring Plan (AREMP) and the PACFISH/INFISH plan to monitor the aquatic and riparian resources related to biological opinions for bull trout, salmon, and steelhead (Kershner et al. 2003, Reeves et al. 2003). As an interagency program, the AREMP is developing a regional synthesis of protocols from the EPA, USDI Geological Survey, FS, and Bonneville Power Administration. The AREMP contains core components that are by design either directly compatible or translatable to other protocols (AREMP 2003, Reeves et al. 2003). The AREMP sampling design is directly applicable to monitoring forest land use practices and is applicable across different geographical regions. The AREMP protocol appears to be the most current synthesis of watershed monitoring that has been published to date.

The PACFISH/INFISH plan evaluates the effect of land management activities on aquatic and riparian communities at multiple scales. It was developed for Forest

The AREMP protocol appears to be the most current synthesis of watershed monitoring that has been published to date.

³ Roper, B. 2003. Personal communication. Aquatic ecologist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory, 860 North 1200 East, Logan, UT 84321.

Service Regions 1, 4, and 6 (Northern, Intermountain, and Pacific Northwest, respectively), and other federal and state agencies (Kershner et al. 2003). This protocol does not collect fish presence or abundance data. However, other methods of the PACFISH/INFISH plan are similar to the AREMP protocol, and the plans will develop compatible documents.

The FS Region 6 Stream Inventory Handbook was recently revised in parallel with the AREMP effort and contains “core data standards” developed by the NWFP interagency team mentioned earlier (USDA FS 2002). According to the document, it is the “aquatic companion” to the FS Integrated Resource Inventory and is compatible with Oregon Department of Fish and Wildlife and Washington Timber, Fish, and Wildlife aquatic inventories (USDA FS 2002).

Other watershed-specific protocols (e.g., Bain and Stevenson 1999, Dambacher et al. 2001, Moore et al. 2000) have been based on the above federal protocols and earlier approaches (Dolloff et al. 1993, Hankin and Reeves 1988). Still others, such as the Salmonid Life Cycle Monitoring Project of the Oregon Plan (Solazzi et al. 2003) and the state of Washington’s Index Watershed Monitoring Program (Seiler et al. 2002), use counts from smolt traps as an index of regional watershed conditions or salmonid abundance. Although salmon smolts can provide a useful indicator of watershed conditions (Seiler et al. 2002, Solazzi et al. 2003), monitoring protocols that use smolts were not the focus of this review.

For a comprehensive listing of habitat assessment protocols in use in the Pacific Northwest, see Johnson et al. (2001). Bain et al. (1999) summarize attributes measured in 31 stream assessment protocols in use in North America but do not list the protocols by name.

Data Quality

Some researchers have been critical of previous survey and monitoring efforts because data collected were not always quantitative or reproducible and therefore of questionable use for management purposes (Peterson and Wollrab 1999, Spence et al. 1996). Bauer and Ralph (2001) provide a thorough summary of concerns with commonly assessed habitat attributes and offer suggestions for increasing measurement precision. Roper et al. (2002) provide some tools to evaluate consistent measures of habitat. Kaufmann et al. (1999) identify several habitat variables, such as width-to-depth ratio and residual depth, that were either precise or moderately precise as described by signal-to-noise ratio (Kaufmann et al. 1999). Archer et al. (2004) found the least amount of observer variability in descriptions of stream reach, streambank, and cross-section characteristics.

Peterson and Wollrab (1999) analyzed the data collected with established FS protocols and found inconsistent and subjective procedures for sampling fish and habitat attributes, biased site-selection criteria, and problems in following established quality assurance and quality control measures. Spence et al. (1996), however, found two federal monitoring programs (EMAP and NWQAP) to be more quantifiable than other efforts. Stream surveys that require walking all reaches in the study area (e.g., Dolloff et al. 1993) can dictate efforts that result in qualitative rather than quantitative measurements (Spence et al. 1996).

Some agencies have initiated quality-assurance-and-control (QA/QC) programs to ensure that field teams can be adequately trained in the use of protocols and to assess the variability in performances of different teams' results (Gallo et al. 2003). Others recommend checks to ensure that the quality of the data remains high but provide no clear direction (Moulton et al. 2002). As QA/QC efforts continue (e.g., Gallo et al. 2003), they should lead to a refinement of field techniques and more dependable results.

Scale and Sampling Design

Regardless of their sampling intensity, strong sampling designs should account for or reduce variability among sites and increase applicability across different spatial scales (Conquest and Ralph 1998, McDonald 2002). As part of the Oregon Plan for Salmon in Watersheds, Stevens (2002) discusses characteristics of good sampling design for assessing status and trends in juvenile salmonid abundance and other factors. Likewise, in the state of Washington, the Department of Natural Resources is evaluating the use of sampling and survey protocols (modeling and statistical) developed by the USDI Fish and Wildlife Service (Thurow et al. 2004).

Two protocols considered in this review have a statistical design that allows for landscape-scale inferences (Peck et al. 2001, Reeves et al. 2003). A third, the FS Region 6 protocol, uses a stratified random sampling process at the reach level, but watershed or stream selection criteria are not discussed in the protocol document (USDA FS 2002). Two other protocols use subjective (or undocumented) site-selection criteria and, without application of statistical selection procedures, are of limited use beyond the habitat unit scale (Barbour et al. 1999, Fitzpatrick et al. 1998, Moulton et al. 2002, USDA FS 2002). Other protocols (generally intended for monitoring restoration projects) are site or reach specific. Although many subjective or site-specific protocols have elements that relate to land use practices in forested watersheds, the current, large-scale synthesis documents (e.g., Peck et al. 2001, Reeves et al. 2003) offer the benefits of widespread use, foundations based on current science, and applicability across different spatial scales.

Level of Complexity and Relevance

Rapid surveys have the benefits of speed and relative simplicity but sacrifice quantitative measurement. For example, the EPA's RBP (Barbour et al. 1999) only estimates stream channel width and depth, characterizes stream gradient as either high or low rather than measuring directly or deriving from maps, and uses qualitative measurements of aquatic biota (although more rigorous measurements are optional). The FS basinwide visual estimation technique uses visual observations with periodic measurements to calibrate for observer bias (Dolloff et al. 1993). Although this type of "calibration" seems promising, questions have been raised about the validity of underlying assumptions used to standardize the data (Thompson 2003).

At the other end of the spectrum, the USGS NWQAP and the EPA EMAP perform extensive monumented surveys of stream cross-sectional transects and longitudinal profiles, bank and channel morphology, as well as laboratory analyses of water quality, periphyton, macroinvertebrates, and fish tissue, with concomitant increase in time and expense. The AREMP protocol is similar to EMAP in its measurement of most habitat and biotic attributes.

The FS Region 6 protocol (USDA FS 2002) uses a combination of estimated and measured parameters to monitor stream habitats. Stream gradient and sinuosity are calculated from 1:24,000 maps. Maximum pool tail crest and maximum pool depth are measured directly, and large wood is estimated visually (USDA FS 2002). Large wood is counted as large, medium, or small. In contrast, EMAP uses 12 diameter-class categories for wood, and AREMP directly measures a subset of wood in the stream channel.

Comparison of Protocols

Based on our survey of the literature regarding stream monitoring protocols in use in the Pacific Northwest, we consider the following five to be the most comprehensive and widely distributed; they contain provisions for monitoring habitat and biological characteristics considered sensitive to management practices. These protocols are products of ongoing federal and state research and therefore seem to be the most up to date and useful for monitoring land use practices in forested watersheds.

- The Aquatic and Riparian Effectiveness Monitoring Plan for the Northwest Forest Plan (Reeves et al. 2003).
- The FS Region 6 Stream Inventory Handbook (USDA FS 2002).

- EPA Environmental Monitoring and Assessment Program—Surface Waters: Western Pilot Study (Peck et al. 2001).
- USGS National Water Quality Assessment Program (Moulton et al. 2002).
- EPA Rapid Bioassessment Protocol (Barbour et al. 1999).

These five protocols are listed in tables 1 and 2 to facilitate side-by-side comparison.

Conclusions

Stream monitoring programs of differing geographic scale and scientific rigor have been developed and implemented by various federal and state land management agencies. Most of the protocols reviewed contain common objectives for monitoring stream habitat conditions, fish use, and influences of land management activities. They generally rely on published research to define relationships between habitat characteristics and the presence of fish, usually salmonids. Some features may be quantified by field work in one protocol, and maps or GIS data in another. Protocols that emphasize speed and simplicity can sacrifice quantitative measurements and rely on subjective evaluations, whereas protocols that require many measurements and greater detail are more time consuming and expensive. Few protocols exist that are easy to apply, quantitatively adequate, and relatively inexpensive.

Quality-control issues, such as consistency of measurements among observers, have been addressed in some, but not all, protocols. Repeatability within a protocol should be an important consideration for all monitoring protocols. Consistency among protocols would bring added value and strength to management through a larger database and broader scope of application. Recent efforts promote compatibility among the protocols used by large-scale monitoring programs in the Pacific Northwest (Gallo et al. 2003, Lanigan 2003).

Several biological and physical characteristics of stream ecosystems seem to be sensitive to land use activities. Pool abundance and quality were two of the better documented measurements with respect to the presence of juvenile coho salmon. The amount of large woody debris in streams was sensitive to timber harvest activities and was an important habitat component related to salmonid abundance. Watershed conditions such as poor road and drainage facilities (e.g., damaged culverts), excessive erosion, and inputs of sediments to channels were common factors adversely affecting stream systems.

Clearly defined objectives are important elements in the sample design of monitoring protocols, selection of physical and biological characteristics to be

Few protocols exist that are easy to apply, quantitatively adequate, and relatively inexpensive.

measured, and intensity of sampling. Comparisons of streams in different watersheds, including those not altered by logging, would provide a baseline of the range of natural conditions and would help identify streams affected by these practices (Roni et al. 2003).

Long-term monitoring programs can be important for coordinating efforts of management organizations, decisionmakers, and researchers who intend to improve and protect natural ecosystems. The ability of management policies to change over time creates both opportunities and challenges for managing streams and can result in continued policy improvements for managing ecosystems and watersheds. Positive changes (e.g., through adaptive management) can result from new data.

English Equivalent

When you know:	Multiply by:	To find:
Meters (m)	3.28	Feet
Kilometers (km)	.6215	Miles
Square kilometers (km ²)	.386	Square miles

Literature Cited

Anderson, J.L.; Hilborn, R.W.; Lackey, R.T.; Ludwig, D. 2003. Watershed restoration-adaptive decision making in the face of uncertainty. In: Wissmar, R.C.; Bisson, P.A., eds. Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and management systems. Bethesda, MD: American Fisheries Society: 203-232.

Aquatic and Riparian Effectiveness Monitoring Program [AREMP]. 2003. Field protocol synopsis: 2003 field season. Corvallis, OR: U.S. Department of Agriculture, Forest Service. 5 p. <http://www.reo.gov/monitoring/watershed/02fieldprotocol.pdf>. (August 23, 2004).

Archer, E.K.; Roper, B.B.; Henderson, R.C. [et al.]. 2004. Testing common stream sampling methods: How useful are these techniques for broad-scale, long term monitoring? Gen. Tech. Rep. RMRS-GTR-122. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15 p.

Bain, M.B.; Hughes, T.C.; Arend, K.K. 1999. Trends in methods for assessing freshwater habitats. In: Bain, M.B.; Stevenson, N.J., eds. Aquatic habitat assessment. Bethesda, MD: American Fisheries Society: 193-200.

- Bain, M.B.; Stevenson, N.J., eds. 1999.** Aquatic habitat assessment: common methods. Bethesda, MD: American Fisheries Society. 224 p.
- Barbour, M.T.; Gerritsen, J.; Snyder, B.D.; Stribling, J.B. 1999.** Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. 2nd ed. EPA 841-B-99-002. Washington, DC: U.S. Environmental Protection Agency, Office of Water. <http://www.epa.gov/owow/monitoring/rbp/wp61pdf/rbp.pdf>. (June 30, 2004).
- Bauer, S.B.; Ralph, S.C. 1999.** Appendix D: annotated bibliography for aquatic habitat indicators and their application to water quality objectives within the Clean Water Act. EPA-910-R-99-014. Seattle, WA: U.S. Environmental Protection Agency, Region 10. 77 p. http://www.krisweb.com/biblio/gen_usepa_baueretal_1999_ahibibli.pdf. (June 30, 2004).
- Bauer, S.B.; Ralph, S.C. 2001.** Strengthening the use of aquatic habitat indicators in Clean Water Act programs. *Fisheries*. 26:14-24.
- Bilby, R.E.; Reeves, G.H.; Dolloff, C.A. 2003.** Sources of variability in aquatic ecosystems: factors controlling biotic production and diversity. In: Wissmar, R.C.; Bisson, P.A., eds. *Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and managed systems*. Bethesda, MD: American Fisheries Society: 129-146.
- Collins, B.; Pess, G.R. 1997.** Critique of Washington state's watershed analysis program. *Journal of the American Water Resources Association*. 33: 997-1010.
- Conquest, L.L.; Ralph, S.C. 1998.** Statistical design and analysis considerations for monitoring and assessment. In: Naiman, R.J.; Bilby, R.E., eds. *River ecology and management: lessons from the Pacific coastal ecoregion*. New York: Springer-Verlag: 455-475.
- Dambacher, J.M.; Jones, K.K.; Li, H.W. 2001.** The distribution and abundance of Great Basin redband trout: an application of variable probability sampling in a 1999 status review. Information Report 2001-08. Portland, OR: Oregon Department of Fish and Wildlife. 26 p. http://oregonstate.edu/Dept/ODFW/freshwater/inventory/pdffiles/Dambacher_et_al_Info_Report_2001-08.pdf. (June 30, 2004).
- Dolloff, C.A.; Hankin, D.G.; Reeves G.H. 1993.** Basinwide estimation of habitat and fish populations in streams. Gen. Tech. Rep. SE-GTR-83. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 25 p. http://www.trout.forprod.vt.edu/fishpubs/dolloff1993_01.pdf. (June 30, 2004).

- Duff, D.A.; Cooper, J.L. 1978.** Techniques for conducting stream habitat surveys on national resource land. Tech. Note. Denver, CO: U.S. Department of the Interior, Bureau of Land Management. 73 p.
- Fitzpatrick, F.A.; Waite, I.R.; D'Arconte, P.J. [et al.]. 1998.** Revised methods for characterizing stream habitat in the national water-quality assessment program. Water-Resources Investigations Report 98-4052. U.S. Department of the Interior, Geological Survey. <http://water.usgs.gov/nawqa/protocols/WRI98-4052/index.html>. (June 30, 2004).
- Forest Ecosystem Management Assessment Team [FEMAT]. 1993.** Forest ecosystem management: an ecological, economic, and social assessment. Portland, OR: U.S. Department of Agriculture; U.S. Department of the Interior [et al.]. [Irregular pagination].
- Gallo, K.; Moyer, C.; Lanigan, S. 2003.** Interagency regional monitoring: Northwest Forest Plan aquatic and riparian effectiveness monitoring program. 2002 annual report. Corvallis, OR: U.S. Department of Agriculture, Forest Service. <http://www.reo.gov/monitoring/watershed/docs/2002Report.pdf>. (June 30, 2004).
- Gregory, K.J.; Bisson, P.A. 1997.** Degradation and loss of anadromous salmonid habitat in the Pacific Northwest. In: Stouder, D.J.; Bisson, P.A.; Naiman, R.J., eds. Pacific salmon and their ecosystems. New York: Chapman and Hall: 277-314.
- Grizzel, J.; McGowan, M.; Smith, D.; Beechie, T. 2000.** Streamside buffers and large woody debris recruitment: evaluating the effectiveness of watershed analysis prescriptions in the North Cascades Region. TFW Effectiveness Monitoring Report. TFW-MAG1-00-003. Olympia, WA: Washington Department of Natural Resources. 38 p.
- Hall, J.D.; Brown, G.W.; Lantz, R.L. 1987.** The Alsea watershed study: a retrospective. In: Salo, E.O.; Cundy, T.W., eds. Streamside management: forestry and fishery interactions. Seattle, WA: University of Washington Press: 399-416.
- Hankin, D.G.; Reeves, G.H. 1988.** Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences. 45: 834-844.
- Hartman, G.F.; Scrivener, J.C. 1990.** Impacts of forestry practices on a coastal stream ecosystem: Carnation Creek, British Columbia, Canada. Canadian Bulletin of Fisheries and Aquatic Sciences. 223: 1-148.

- Hicks, B.J.; Hall, J.D.; Bisson, P.A.; Sedell, J.R. 1991.** Responses of salmonids to habitat changes. In: Meehan, W.R., ed. Influences of forest and rangeland management on salmonid fishes and their habitats. Spec. Publ. 19. Bethesda, MD: American Fisheries Society: 483-518.
- Holling, C.S., ed. 1978.** Adaptive environmental assessment and management. New York: John Wiley. 377 p.
- Holtby, B.L.; Andersen, B.C.; Kadowaki, R.K. 1990.** Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences. 47: 2181-2194.
- Independent Multidisciplinary Science Team [IMST]. 1999.** Recovery of wild salmonids in western Oregon forests: Oregon Forest Practices Act rules and the measures in the Oregon Plan for Salmon and Watersheds. Tech. Rep. 1999-1. Salem, OR: Governor's Natural Resources Office. 85 p.
- Johnson, D.H.; O'Neal, J.; Knutzen, J. [et al.]. 2003.** Protocols for counting salmonids, resident fish, and lamprey in the Pacific Northwest. Olympia, WA: Washington Department of Fish and Wildlife. 2 p.
- Johnson, D.H.; Pittman, N.; Wilder, E. [et al.]. 2001.** Inventory and monitoring of salmon habitat in the Pacific Northwest: directory and synthesis of protocols for management/research and volunteers in Washington, Oregon, Idaho, Montana, and British Columbia. Olympia, WA: Washington Department of Fish and Wildlife. 212 p.
- Kaufmann, P.R.; Levine, P.; Robinson, E.G. [et al.]. 1999.** Quantifying physical habitat in wadeable streams. EPA/620/R-99/003. Washington, DC: U.S. Environmental Protection Agency. 102 p. <http://www.epa.gov/emap/html/pubs/docs/groupdocs/surfwatr/field/phyhab.pdf>. (June 30, 2004).
- Kershner, J.L.; Coles-Ritchie, M.; Cowley, E. [et al.]. 2003.** A plan to monitor the aquatic and riparian resources in the area of PACFISH/INFISH and the biological opinions for bull trout, salmon, and steelhead. Logan, UT: U.S. Department of Agriculture, Forest Service, Fish and Aquatic Ecology Unit. http://www.fs.fed.us/biology/resources/pubs/feu/pibo_final_011003.pdf. (August 23, 2004).
- Kurtz, J.C.; Jackson, L.E.; Fisher, W.S. 2001.** Strategies for evaluating indicators based on guidelines from the EPA's Office of Research and Development. Ecological Indicators. 1: 49-60.

- Lanigan, S. 2002.** Monitoring watershed health: state-federal monitoring partnership. Sept. 2002 progress overview. Corvallis, OR: U.S. Department of Agriculture, Forest Service. http://www.reo.gov/monitoring/watershed/docs/Overview_of_efforts_.html. (August 23, 2004).
- Lanigan, S. 2003.** Monitoring protocol attributes. http://www.reo.gov/monitoring/watershed/docs/Attributesformonitoringcomparison_Master_Table.html. (November 24, 2003).
- Lazorchak, J.M.; Klemm, D.J.; Peck, D.V., eds. 1998.** Environmental monitoring and assessment program—surface waters: field operations and methods for measuring the ecological condition of wadeable streams. EPA/620/R-94/004F. Washington, DC: U.S. Environmental Protection Agency. [Pages unknown]. http://www.epa.gov/emap/html/pubs/docs/groupdocs/surfwatr/field/ws_abs.html. (June 30, 2004).
- MacDonald, L.H.; Smart, A.W.; Wissmar, R.C. 1991.** Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. Seattle, WA: Region 10, U.S. Environmental Protection Agency. 166 p.
- McDonald, T.L. 2002.** Review of environmental monitoring: survey designs. *Environmental Monitoring and Assessment*. 1: 1-16.
- Meador, M.R.; Cuffney, T.F.; Gurtz, M.E. 1993.** Methods for sampling fish communities as part of the National Water-Quality Assessment Program. Rep. 93-104. Raleigh, NC: U.S. Department of the Interior, U.S. Geological Survey. [Pages unknown]. <http://water.usgs.gov/nawqa/protocols/OFR-93-104/fish3.html>. (June 30, 2004).
- Medsser, J.J.; Linthurst, R.A.; Overton, W.S. 1991.** An EPA program for monitoring ecological status and trends. *Environmental Monitoring and Assessment*. 17: 67-78.
- Meehan, W.R., ed. 1991.** Influences of forest and rangeland management on salmonid fishes and their habitats. Spec. Publ. 19. Bethesda, MD: American Fisheries Society. 751 p.
- Montgomery, D.R.; Buffington, J.M. 1993.** Channel classification, prediction of channel response, and assessment of channel condition. Washington State Timber/Fish/Wildlife Report TFW-SH10-93-002. Olympia, WA: Washington Department of Natural Resources. 84 p.
- Montgomery, D.R.; Buffington, J.M.; Smith, R.D. [et al.]. 1995.** Pool spacing in forest channels. *Water Resources Research*. 31: 1097-1105.

- Moore, K.; Jones, K.; Dambacher, J. 2000.** Methods for stream habitat surveys, version 10.1. Corvallis, OR: Oregon Department of Fish and Wildlife, Corvallis Research Lab. [Pages unknown].
- Morrison, M.L.; Marcot, B.G. 1995.** An evaluation of resource inventory and monitoring programs used in national forest planning. *Environmental Monitoring and Assessment*. 19: 147-156.
- Moulton, S.R., II; Kennen, J.G.; Goldstein, R.M.; Hambrook, J. 2002.** Revised protocols for sampling algal, invertebrate, and fish communities as part of the National Water-Quality Assessment Program. Rep. 02-150. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. 75 p. <http://water.usgs.gov/nawqa/protocols/OFR02-150/OFR02-150.pdf>. (August 23, 2004).
- National Council for Air and Stream Improvement, Inc. [NCASI]. 1988.** Procedures for assessing the effectiveness of Best Management Practices in protecting water and stream quality associated with managed forests. Tech. Bull. No. 538. New York. 23 p.
- National Park Service. 2003.** Monitoring natural resources in our national parks. U.S. Department of the Interior. <http://science.nature.nps.gov/im/monitor/>. (November 25, 2003).
- Nickelson, T.E.; Rodgers, J.D.; Johnson, S.L.; Solazzi, M.F. 1992.** Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. *Canadian Journal of Fisheries and Aquatic Sciences*. 49: 783-789.
- Peck, D.V.; Lazorchak, J.M.; Klemm, D.J., eds. 2001.** Environmental monitoring and assessment program—surface waters: Western pilot study field operations manual for wadeable streams. Washington, DC: U.S. Environmental Protection Agency. <http://www.epa.gov/emap/html/pubs/docs/groupdocs/surfwatr/field/ewwsm01.html>. (June 30, 2004).
- Peterson, J.T.; Wollrab, S.P. 1999.** An analysis of potential stream fish and fish habitat monitoring procedures for the inland Northwest. Annual report 1999 to Bonneville Power Administration DOE/BP-25866-1. Portland, OR: Bonneville Power Administration. 52 p. <http://www.efw.bpa.gov/Environment/EW/EWP/DOCS/REPORTS/HABITAT/H25866-1.pdf>. (June 30, 2004).
- Platts, W.S.; Armour, C.; Booth, G.D. [et al.]. 1987.** Methods for evaluating riparian habitats with applications to management. Gen. Tech. Rep. INT-221. Ogden, UT: U.S. Department Of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 177 p.

- Pleus, A.E.; Schuett-Hames, D.; Bullchild, L. 1999.** TFW monitoring program method manual for the habitat unit survey. TFW-AM9-99-003. Olympia, WA: Washington Department of Natural Resources. 68 p.
- Quinn, T.P.; Peterson, N.P. 1994.** The effect of forest practices on fish populations. Final Report. TFW-F4-94-001. Seattle, WA: University of Washington, Center for Streamside Studies. 157 p. http://www.krisweb.com/krisootenai/krisdb/html/krisweb/biblio/gen_tfw_quinnetal_1994_f494001.pdf. (June 30, 2004).
- Quinn, T.P.; Peterson, N.P. 1996.** The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington. Canadian Journal of Fish and Aquatic Sciences. 53: 1555-1564.
- Ralph S.C.; Pool, G.C. 2003.** Putting monitoring first: designing accountable ecosystem restoration and management plans. In: Montgomery, D.R.; Bolton, S.; Booth, D.B.; Wall, L., eds. Restoration of Puget Sound rivers. Seattle, WA: University of Washington Press: 226–247.
- Reeves, G.H.; Hohler, D.B.; Larsen, D.P. [et al.]. 2003.** Aquatic and riparian effectiveness monitoring plan for the Northwest Forest Plan. Gen. Tech. Rep. PNW-GTR-577. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 71 p. <http://www.fs.fed.us/pnw/pubs/gtr577.pdf>. (June 30, 2004).
- Regier, H.A. 1976.** Environmental biology of fishes: emerging science. Environmental Biology of Fishes. 1: 5-11.
- Rinne, J.N. 1985.** Physical habitat evaluation of small stream fishes: point vs. transect, observation vs. capture methodologies. Journal of Freshwater Ecology. 3: 121-131.
- Roni, P., ed. [In press].** Monitoring stream and watershed restoration. Bethesda, MD: American Fisheries Society.
- Roni, P.; Liermann, M.; Steel, A. 2003.** Monitoring and evaluating fish response to instream restoration. In: Montgomery, D.R.; Bolton, S.; Booth, D.B.; Wall, L., eds. Restoration of Puget Sound rivers. Seattle, WA: University of Washington Press. 318–339.
- Roni, P.; Quinn, T. 2001.** Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Sciences. 58: 282-292.

- Roper, B.B.; Kershner, J.L.; Archer, E. [et al.]. 2002.** An evaluation of physical stream habitat attributes used to monitor streams. *Journal of American Water Resources*. 38: 1637-1646.
- Rosenfeld, J.; Porter, M.; Parkinson, E. 2000.** Habitat factors affecting the abundance and distribution of juvenile cutthroat trout (*Oncorhynchus clarki*) and coho salmon (*Oncorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Sciences*. 57: 766-774.
- Schuett-Hames, D.; Pleus, A.E.; Smith, D. 1999.** TFW Monitoring Program method manual for the salmonid spawning habitat availability survey. TFW-AM9-99-007. Olympia, WA: Washington Department of Natural Resources. 82 p.
- Seiler, D.; Volkhardt, G.; Murdoch, A. [et al.]. 2002.** 2002 index watershed salmon recovery monitoring report. Olympia, WA: Washington Department of Ecology. 48 p. <http://www.ecy.wa.gov/pubs/0203061.pdf>. (July 1, 2004).
- Skagit Watershed Council. 2000.** Application of the Skagit Watershed Council's strategy: basin analysis of the Skagit and Samish basins: tools for salmon habitat restoration and protection. Mount Vernon, WA. 80 p.
- Solazzi, M.F.; Johnson, S.L.; Miller, B. [et al.]. 2003.** Salmonid life-cycle monitoring project 2002 report. OPSW-ODFW-2003-2. Portland, OR: Oregon Department of Fish and Wildlife. 20 p. <http://oregonstate.edu/Dept/ODFW/progress-reports/annual2002ver2.pdf>. (July 1, 2004).
- Spence, B.C.; Lomnický, G.A.; Hughes, R.M.; Novitzki, R.P. 1996.** An ecosystem approach to salmonid conservation. TR-4501-96-6057. Corvallis, OR: ManTech Environmental Research Services Corp. [Not paged]. <http://www.nwr.noaa.gov/1habcon/habweb/habguide/ManTech/front.htm>. (July 1, 2004).
- Stankey, G.H.; Bormann, B.T.; Ryan, C. [et al.]. 2003.** Adaptive management and the Northwest Forest Plan: rhetoric and reality. *Journal of Forestry*. 101: 40-46.
- Stevens, D.L., Jr. 2002.** Sampling design and statistical analysis methods for the integrated biological and physical monitoring of Oregon streams. OPSW-ODFW-2002-07. Portland, OR: Oregon Department of Fish and Wildlife. 14 p. <http://oregonstate.edu/Dept/ODFW/spawn/pdf%20files/reports/DesignStevens.pdf>. (July 1, 2004).
- Thompson, W.L. 2003.** Hankin and Reeves' approach to estimating fish abundance in small streams: limitations and alternatives. *Transactions of the American Fisheries Society*. 132: 69-75.

- Thurrow, R.F.; Peterson, J.T.; Larson, C.A.; Guzevich, J.W. 2004.** Development of bull trout sampling efficiency models. Final Report to USDI Fish and Wildlife Service Aquatic Resources Division. Boise, ID: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 68 p. http://www.fs.fed.us/rm/boise/teams/fisheries/publications/Thurrow%20et%20al.%20Final%20Report%202004_2%20.pdf. (August 23, 2004).
- U.S. Department of Agriculture, Forest Service [USDA FS]. 1994.** Section 7, fish habitat monitoring protocol for the upper Columbia River basin. Portland, OR: Pacific Northwest Region, Intermountain Region, Northern Region. On file with: Forestry Sciences Laboratory, 2770 Sherwood Lane, Suite 2A, Juneau, AK 99802-1628. 61 p.
- U.S. Department of Agriculture, Forest Service [USDA FS]. 1995.** Report to Congress: anadromous fish habitat assessment. R10-MB-279. Juneau, AK: Alaska Region and Pacific Northwest Research Station. [Pages unknown].
- U.S. Department of Agriculture, Forest Service [USDA FS]. 1997.** Tongass Land Management Plan Revision. Final Environmental Impact Statement. Juneau, AK: Region 10 [Alaska]. <http://www.tongass-seis.net/seis/index.html>. (August 23, 2004).
- U.S. Department of Agriculture, Forest Service [USDA FS]. 2001.** Fish and aquatic stream habitat assessment. Chapter 20 FSH 2090-Aquatic Ecosystem Management Handbook, R-10 amendment 2090-2001-1. Juneau, AK: Region 10 [Alaska]. [Not paged].
- U.S. Department of Agriculture, Forest Service [USDA FS]. 2002.** Stream inventory handbook: levels 1 and 2. Region 6 version 2.2. Portland, OR: Pacific Northwest Region. [Pages unknown].
- U.S. Department of Agriculture, Forest Service [USDA FS]. 2003.** Inventory and Monitoring Institute. <http://www.fs.fed.us/institute/>. (November 25, 2003).
- U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management [USDA and USDI]. 1994.** Record of Decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl. [Place of publication unknown]. 74 p. [Plus attachment A: standards and guidelines].

- U.S. Environmental Protection Agency [USEPA]. 1989.** Rapid bio-assessment protocols for use in streams and rivers: benthic macro-invertebrates and fish. EPA/444/4-89-001. Washington, DC: Office of Water. [Pages unknown]. <http://www.epa.gov/owowwtr1/monitoring/rbp/index.html>. (August 23, 2004).
- U.S. Environmental Protection Agency [USEPA]. 1990.** Biological criteria. EPA/440/5-90-004, Washington, DC. [Pages unknown]. <http://www.epa.gov/bioindicators/html/biolcont.html>. (August 23, 2004).
- Walters, C.J. 1986.** Adaptive management of renewable resources. New York: Macmillan. 374 p.
- Wissmar, R.C. 1993.** The need for long-term monitoring programs in forest ecosystems of the Pacific Northwest. *Environmental Monitoring and Assessment*. 26: 219-234.

Appendix: Literature Identified as Most Relevant to Protocols for Monitoring Streams and Juvenile Fish

- Andersen, T. 2001.** Kalispel resident fish project. Annual Report, Project No. 1995-00100 DOE/BP-37227-5. Portland, OR: Bonneville Power Administration. 75 p. <http://www.efw.bpa.gov/Environment/EW/EWP/DOCS/REPORTS/RESIDENT/R37227-5.pdf>. (July 1, 2004).
- Aquatic and Riparian Effectiveness Monitoring Program [AREMP]. 2003.** Field protocol synopsis: 2003 field season. Corvallis, OR: U.S. Department of Agriculture, Forest Service. 5 p. <http://www.reo.gov/monitoring/watershed/02fieldprotocol.pdf>. (August 23, 2004).
- Armour, C.L.; Burnham, K.P.; Platt, W.S. 1983.** Field methods and statistical analyses for monitoring small salmonid streams. FWS/OBS-83/33. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Western Energy and Land Use Team, Division of Biological Services, Research and Development. 200 p.
- Bain, M.B.; Stevenson, N.J., eds. 1999.** Aquatic habitat assessment: common methods. Bethesda, MD: American Fisheries Society. 224 p.
- Barbour, M.T.; Gerritsen, J.; Snyder, B.D.; Stribling, J.B. 1999.** Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. 2nd ed. EPA 841-B-99-002. Washington, DC: U.S. Environmental Protection Agency, Office of Water. <http://www.epa.gov/owow/monitoring/rbp/wp61pdf/rbp.pdf>. (June 30, 2004).
- British Columbia Ministry of Fisheries. 1999.** Overview fish and fish habitat inventory, methodology version 1.0. <http://srmwww.gov.bc.ca/risc/pubs/aquatic/overview/assets/overview.pdf>. (October 31, 2003).
- British Columbia Ministry of Fisheries. 2001.** Reconnaissance (1:20,000) fish and fish habitat inventory: standards and procedures, version 2.0. <http://srmwww.gov.bc.ca/risc/pubs/aquatic/recon/recce2c.pdf>. (October 31, 2003).
- California Department of Fish and Game. 2003.** California coastal salmonid restoration monitoring and evaluation program: interim restoration effectiveness and validation monitoring protocols (draft). Fortuna, CA: California Department of Fish and Game. 359 p. http://www.dfg.ca.gov/nafwb/pubs/2003/200303_Interim_Protocol_Manual.pdf. (March 2003).
- Coyle, T.; Karl, D.; Mendel, G. 2001.** Assessment of salmonids and their habitat conditions in the Walla Walla River basin. Annual report. BPA Report DOE/BP-00000485-1. 108 p. <http://www.efw.bpa.gov/Environment/EW/EWP/DOCS/REPORTS/RESIDENT/R00000485-1.pdf>. (July 1, 2004).

- Dambacher, J.M.; Jones, K.K.; Li, H.W. 2001.** The distribution and abundance of Great Basin redband trout: an application of variable probability sampling in a 1999 status review. Information Report 2001-08. Portland, OR: Oregon Department of Fish and Wildlife. 26 p. http://oregonstate.edu/Dept/ODFW/freshwater/inventory/pdffiles/Dambacher_et_al_Info_Report_2001-08.pdf. (June 30, 2004).
- Dolloff, C.A.; Hankin, D.G.; Reeves G.H. 1993.** Basinwide estimation of habitat and fish populations in streams. Gen. Tech. Rep. SE-GTR-83. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 25 p. http://www.trout.forprod.vt.edu/fishpubs/dolloff1993_01.pdf. (June 30, 2004).
- Dunham, J. 2000.** Sampling protocol: bull trout habitat study (DRAFT). Boise, ID: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 23 p.
- Fitzpatrick, F.A.; Waite, I.R.; D'Arconte, P.J. [et al.]. 1998.** Revised methods for characterizing stream habitat in the national water-quality assessment program. Water-Resources Investigations Report 98-4052. U.S. Department of the Interior, Geological Survey. <http://water.usgs.gov/nawqa/protocols/WRI98-4052/index.html>. (June 30, 2004).
- Hankin, D.G. 1984.** Multistage sampling designs in fisheries research applications in small streams. *Canadian Journal of Fisheries and Aquatic Sciences*. 41: 1575-1591.
- Hankin, D.G.; Reeves, G.H. 1988.** Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. *Canadian Journal of Fisheries and Aquatic Sciences*. 45: 834-844.
- Jones, M.L.; Stockwell, J.D. 1995.** A rapid assessment procedure for the enumeration of salmonine populations in streams. *North American Journal of Fisheries Management*. 15: 551-562.
- Kershner, J.L.; Coles-Ritchie, M.; Cowley, E. [et al.]. 2003.** A plan to monitor the aquatic and riparian resources in the area of PACFISH/INFISH and the biological opinions for bull trout, salmon, and steelhead. Logan, UT: U.S. Department of Agriculture, Forest Service, Fish and Aquatic Ecology Unit. [Pages unknown]. http://www.fs.fed.us/biology/resources/pubs/feu/pibo_final_011003.pdf. (August 23, 2004).

- Lazorchak, J.M.; Klemm, D.J.; Peck, D.V., eds. 1998.** Environmental monitoring and assessment program—surface waters: field operations and methods for measuring the ecological condition of wadeable streams. EPA/620/R-94/004F. Washington, DC: U.S. Environmental Protection Agency. [Pages unknown]. http://www.epa.gov/emap/html/pubs/docs/groupdocs/surfwatr/field/ws_abs.html. (June 30, 2004).
- McCullough, D.A.; Espinosa, F.A. 1996.** A monitoring strategy for application to salmon-bearing watersheds. Tech. Rep. 96-5. Portland, OR: Columbia River Inter-Tribal Fish Commission. 169 p. [plus appendices]. <http://www.critfc.org/tech/96-5report.pdf>. (August 24, 2004).
- Meador, M.R.; Cuffney, T.F.; Gurtz, M.E. 1993.** Methods for sampling fish communities as part of the national water-quality assessment program. Rep. 93-104. Raleigh, NC: U.S. Department of the Interior, U.S. Geological Survey. [Pages unknown]. <http://water.usgs.gov/nawqa/protocols/OFR-93-104/fish3.html>. (June 30, 2004).
- Moore, K.; Jones, K.; Dambacher, J. 2000.** Methods for stream habitat surveys, version 10.1. Corvallis, OR: Oregon Department of Fish and Wildlife, Corvallis Research Lab. [Pages unknown].
- Moulton, S.R., II; Kennen, J.G.; Goldstein, R.M.; Hambrook, J. 2002.** Revised protocols for sampling algal, invertebrate, and fish communities as part of the national water-quality assessment program. Rep. 02-150. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. 75 p. <http://water.usgs.gov/nawqa/protocols/OFR02-150/OFR02-150.pdf>. (August 23, 2004).
- Murphy, P.; Huntington, C.W. 1995.** Updated stream survey methodology for the Clearwater National Forest. Orofino, ID: Clearwater National Forest. [Pages unknown].
- Neilson, L.A.; Johnson, D.L., eds. 1983.** Fisheries techniques. Bethesda, MD: American Fisheries Society. 468 p.
- Niemelae, E.; Julkunen, M.; Erkinaro, J. 1999.** Revealing trends in densities of juvenile Atlantic salmon, *Salmo salar* L., in the subarctic River Teno using cluster analysis on long-term sampling data. Fisheries Management and Ecology. 6: 207-220.
- Oregon Coastal Salmon Restoration Initiative. 1997.** OCSRI Conservation Plan. Final plan. Salem, OR: Oregon Coastal Salmon Restoration Initiative. Chapter 16. On file with: Forestry Sciences Laboratory, 2770 Sherwood Lane, Suite 2A, Juneau, AK 99802-1628.

- Overton, S.W.; McDonald, T.L. 1998.** Regional estimation of juvenile coho abundance in streams. West Technical Report 98-5. Cheyenne, WY: Western EcoSystems Technology, Inc. On file with: Forestry Sciences Laboratory, 2770 Sherwood Lane, Suite 2A, Juneau, AK 99802-1628.
- Peck, D.V.; Lazorchak, J.M.; Klemm, D.J., eds. 2001.** Environmental monitoring and assessment program—surface waters: Western pilot study field operations manual for wadeable streams. Washington, DC: U.S. Environmental Protection Agency. <http://www.epa.gov/emap/html/pubs/docs/groupdocs/surfwatr/field/ewwsm01.html>. (June 30, 2004).
- Peterson, J.T.; Wollrab, S.P. 1999.** An analysis of potential stream fish and fish habitat monitoring procedures for the inland Northwest. Annual report 1999 to Bonneville Power Administration DOE/BP-25866-1. Portland, OR: Bonneville Power Administration. 52 p. <http://www.efw.bpa.gov/Environment/EW/EWP/DOCS/REPORTS/HABITAT/H25866-1.pdf>. (June 30, 2004).
- Pleus, A.E.; Schuett-Hames, D.; Bullchild, L. 1999.** TFW monitoring program method manual for the habitat unit survey. TFW-AM9-99-003. Olympia, WA: Washington Department of Natural Resources. 68 p.
- Reeves, G.H.; Hohler, D.B.; Larsen, D.P. [et al.]. 2003.** Aquatic and riparian effectiveness monitoring plan for the Northwest Forest Plan. Gen. Tech. Rep. PNW-GTR-577. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 71 p. <http://www.fs.fed.us/pnw/pubs/gtr577.pdf>. (June 30, 2004).
- Seiler, D.; Volkhardt, G.; Murdoch, A. [et al.]. 2002.** 2002 index watershed salmon recovery monitoring report. Olympia, WA: Washington Department of Ecology. 48 p. <http://www.ecy.wa.gov/pubs/0203061.pdf>. (July 1, 2004).
- Solazzi, M.F.; Johnson, S.L.; Miller, B. [et al.]. 2003.** Salmonid life-cycle monitoring project 2002 report. OPSW-ODFW-2003-2. Portland, OR: Oregon Department of Fish and Wildlife. 20 p. <http://oregonstate.edu/Dept/ODFW/progress-reports/annual2002ver2.pdf>. (July 1, 2004).
- Spence, B.C.; Lomnický, G.A.; Hughes, R.M.; Novitzki, R.P. 1996.** An ecosystem approach to salmonid conservation. TR-4501-96-6057. Corvallis, OR: ManTech Environmental Research Services Corp. [Not paged]. <http://www.nwr.noaa.gov/1habcon/habweb/habguide/ManTech/front.htm>. (July 1, 2004).

- Stevens, D.L., Jr. 2002.** Sampling design and statistical analysis methods for the integrated biological and physical monitoring of Oregon streams. OPSW-ODFW-2002-07. Portland, OR: Oregon Department of Fish and Wildlife. 14 p. <http://oregonstate.edu/Dept/ODFW/spawn/pdf%20files/reports/DesignStevens.pdf>. (July 1, 2004).
- U.S. Department of Agriculture, Forest Service. 1993.** Stream inventory handbook: level 1 & 2. Version 7.0. Portland, OR: Pacific Northwest Region. [Pages unknown].
- U.S. Department of Agriculture, Forest Service. 2002.** Stream inventory handbook: levels 1 and 2. Region 6 version 2.2. Portland, OR: Pacific Northwest Region. [Pages unknown].

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