NORTHWEST FOREST PLAN
THE FIRST 10 YEARS (1994–2003)

Preliminary Assessment of the Condition of Watersheds

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Abstract

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We aggregated road, vegetation, and inchannel data to assess the condition of sixth-field watersheds and describe the distribution of the condition of watersheds in the Northwest Forest Plan (the Plan) area. The assessment is based on 250 watersheds selected at random within the Plan area. The distributions of conditions are presented for watersheds and for many of the attributes that contribute to the condition of watersheds by land use allocation. Under the Plan, management activities were implemented in a way to promote positive changes in the condition of watersheds. This assessment revealed that the growth rate of trees (2 to 4 percent) exceeded losses (1.6 percent owing to stand-replacing fire and harvest), and nine times more roads were decommissioned than were constructed. Fifty-seven percent of the watersheds had higher condition scores in time 2 (1998–2003) than in time 1 (1990–96) across the entire Plan area. Only 3 percent of the watersheds had lower condition scores in time 2, and the scores did not change in the remainder of the watersheds. More key watersheds, which were given the highest priority for restoration activities, increased in condition than non-key watersheds. The greatest positive change in watershed condition occurred in late-successional reserves.

Keywords: Effectiveness monitoring, aquatic ecosystems, riparian ecosystems, watersheds, decision-support models, Northwest Forest Plan, aquatic conservation strategy, Pacific Northwest.

Executive Summary

The goal of the Northwest Forest Plan's aquatic conservation strategy (strategy) is to maintain or restore the condition of watersheds. Ten years have passed since the Northwest Forest Plan (the Plan), a management strategy applied to 24 million ac of federal lands in the Pacific Northwest, was implemented. The purpose of this assessment is to describe the current status of the condition of watersheds and describe how conditions have changed since the Plan was implemented.

In this assessment, we describe the current condition and changes in condition of 250 randomly selected sixth-field watersheds in the Plan area. Watershed monitoring for the Plan has been conducted for only the last 2 years; consequently, only 55 of the 250 randomly selected watersheds have been sampled to establish baseline conditions (status). Upslope and riparian roads and vegetation data were collected by using geographic information systems in all 250 watersheds to describe the changes (trends) in these attributes since the implementation of the Plan. A decision-support model based on local expert judgment was used to aggregate upslope, riparian, and inchannel indicators of watershed condition to estimate the condition of the watershed in a repeatable and objective manner. The distribution of watershed conditions was based on these modeled condition scores in the 250 watersheds. Results of the assessment are presented for the entire Plan area according to the land use allocation categories described in the Plan.

Nearly all the changes in watershed condition scores were very small. However, it appears that effects of the strategy on the condition of watersheds have been positive based on the following evidence: (1) Fifty-seven percent of the watersheds had higher condition scores in time 2 (1998–2003) than in time 1 (1990–96) across the entire Plan area. Relatively few watersheds (3 percent) had lower condition scores in time 2, and the scores did not change in the remainder of the watersheds. (2) Over 70 percent of key watersheds, which were supposed to have the highest priority for restoration activities, increased in condition score. Less than 50 percent of the non-key watersheds increased in condition score. (3) Seven watersheds had strong positive or negative changes: those that increased in condition score were targets of road decommissioning, and those that decreased in condition experienced wildfire (and not management activity). (4) The growth rate of trees (2 to 4 percent) exceeded losses (1.6 percent owing to stand-replacing fire and harvest). Also, nine times as many roads were decommissioned as were constructed.

Currently, the watershed condition evaluations include only road construction and decommissioning and tree growth and stand-replacing loss owing to harvest or fire. Road attributes were generally weighted more heavily in the decision-support models than were the vegetation attributes. Riparian attributes carried heavier weights than upslope attributes. According to the sensitivity analysis we conducted on the decision-support models, decommissioning roads in riparian and hazard areas will have the greatest positive effects on watershed condition scores. A reduction in the number of road-stream crossings often accompanies riparian road decommissioning. Because both of these attributes are evaluated in the models, this activity will cause the greatest change in watershed condition score.

Management activities that increase the density of large (>20 in) conifers in riparian areas will also have strong positive effects on the condition of watersheds and will be a good step toward strengthening the large wood input processes in these watersheds.

Also included in this document is an evaluation of the aquatic and riparian effectiveness monitoring program, the Plan's watershed monitoring program, and a brief description of the issues that have emerged since the implementation of the Plan. The monitoring program was implemented in 2002, and an examination of the program is underway to ensure that the program is running efficiently and that the data collected are relevant and have sufficient accuracy and precision to allow tracking changes in the condition of watersheds through time. We have made considerable changes in the field sampling protocols based on the results of our quality assurance program, to increase accuracy and precision in our sampling, and to be more consistent with the PacFish/InFish monitoring program in effect on the east side of the Cascade Mountain range.

Products of the monitoring program that will be helpful to resource managers include:

- Data from all the watersheds sampled (55 as of October 2003), which have been used for projects such as watershed analysis.
- Decision-support models, which can be used to assess the condition of streams or watersheds and to prioritize for restoration.
- Data quality assurance program, which can be implemented by any aquatic sampling program.
- Protocols for invasive species, which help stop the spread of invasive aquatic species.

Several salmon species have been listed as threatened or endangered since the implementation of the Plan, and consideration of these species is one of the issues that has emerged. Research is now being conducted on the effects of fire and the effects of management in upslope and riparian areas on aquatic- and riparian-dependent species. A brief description of these and other emerging issues is presented.

Preface

This report is one of a set of reports produced on this 10-year anniversary of the Northwest Forest Plan (the Plan). The collection of reports attempts to answer questions about the effectiveness of the Plan based on new monitoring and research results. The set includes a series of status and trends reports, a synthesis of all regional monitoring and research results, a report on interagency information management, and a summary report.

The status and trends reports focus on establishing baselines of information from 1994, when the Plan was approved, and reporting change over the 10-year period. The status and trends series includes reports on late-successional and old-growth forests, northern spotted owl population and habitat, marbled murrelet population and habitat, watershed condition, government-to-government tribal relationships, socioeconomic conditions, and monitoring of project implementation under the Plan standards and guidelines.

The synthesis report addresses questions about the effectiveness of the Plan by using the status and trends results and new research. It focuses on the validity of the Plan assumptions, differences between expectations and what actually happened, the certainty of the findings, and, finally, considerations for the future. The synthesis report is organized into two parts: Part I—introduction, context, synthesis, and summary—and Part II—socioeconomic implications, older forests, species conservation, the aquatic conservation strategy, and adaptive management and monitoring.

The report on interagency information management identifies issues and recommends solutions for resolving data and mapping problems encountered during the preparation of the set of monitoring reports. Information management issues inevitably surface during analyses that require data from multiple agencies covering large geographic areas. The goal of this set of reports is to improve the integration and acquisition of interagency data for the next comprehensive report.

Contents

1 **Chapter 1: Introduction**

3 **Overview of the Aquatic Conservation Strategy**

4 **Overview of the Aquatic and Riparian Effectiveness Monitoring Program**

4 **Monitoring Questions**

4 **Assumptions of the Monitoring Program**

5 **Study Area**

7 **Chapter 2: Methods**

7 **Study Design**

7 **Definition of Watershed Condition**

9 **Assessment of Watershed Condition**

11 **Attributes**

12 **Data Collection and Sources**

12 Upslope and Riparian Attributes

14 Inchannel Attributes

14 **Statistical Analysis**

17 **Chapter 3: Results**

17 **Plan Area**

17 Current Status

27 Changes Since the Implementation of the Plan

32 **Key Watersheds**

32 Current Status

36 Changes Since the Implementation of the Plan

42 **Adaptive Management Areas**

42 Current Status

42 Changes Since the Implementation of the Plan

43 **Congressional Reserves**

43 Current Status

47 Changes Since the Implementation of the Plan

49 **Late-Successional Reserves**

49 Current Status

49 Changes Since the Implementation of the Plan

51 **Matrix**

51 Current Status

52 Changes Since the Implementation of the Plan

52 **Nonfederal Lands**
53 Current Status
53 Changes Since the Implementation of the Plan
55 **Chapter 4: Discussion**
61 **Chapter 5: Evaluation of the Aquatic and Riparian Effectiveness Monitoring Program**
61 **Lessons Learned While Implementing the Effectiveness Monitoring Component of the Plan**
61 Probabilistic Survey Design
61 Field Survey Protocols
61 Decision-Support Models
61 **Products Produced by the Monitoring Program**
61 Data Summaries for Local Units
62 Annual Technical Reports
62 Quality Assessment Program
62 Field Maps
62 Protocols to Prevent the Spread of Invasive Species
62 Complete Coverage of Sixth-Field Watershed Boundaries
63 **Cooperative State, Federal, and Tribal Monitoring Efforts**
63 Sample Design
63 Common Protocols
64 Assessing Watershed Condition for All Watersheds
65 **Meeting Future Data Needs**
65 Better Tracking of Road Improvements
65 Landslide Assessments
65 Using Biological Data to Assess Watershed Condition
65 Exploring New Cost-Effective Technologies
67 **Reconciling Sample Design with Funding Limitations**
71 **Chapter 6: Emerging Issues**
73 **Chapter 7: Summary**
73 **Introduction**
73 **Study Design**
73 Assessment of Watershed Conditions
74 **Methods**
74 Upslope and Riparian Attributes

75 Inchannel Attributes

75 Statistical Analysis

75 **Results**

75 Plan Area

77 Key Watersheds

77 Land Use Allocations

79 **Discussion**

81 **Acknowledgments**

82 **Metric Equivalents**

82 **Literature Cited**

86 **Appendix 1: Objectives of the Aquatic Conservation Strategy**

87 **Appendix 2: Description of Physiographic Provinces**

90 **Appendix 3: The 250 Randomly Selected Watersheds**

95 **Appendix 4: Model Structure and Evaluation Criteria for Each of the Provincial Decision-Support Models**

111 **Appendix 5: Sensitivity Analysis of the Decision-Support Models**

120 **Appendix 6: Road and Vegetation Analyses Conducted by Province**

125 **Appendix 7: Synopsis of Field Protocols Used by the Monitoring Program**

127 **Appendix 8: Quality Assurance Assessment of Geographic Information System and Inchannel Data**

Chapter 1: Introduction

In the early 1990s, controversy over harvest in old-growth forests led to sweeping changes in management of federal forests in western Washington, Oregon, and northwest California. These changes were prompted by a series of lawsuits in the late 1980s and early 1990s, which effectively shut down federal timber harvest in the Pacific Northwest. In response, President Clinton convened a summit in Portland, Oregon, in 1993, where he issued a mandate for federal land management and regulatory agencies to work together to develop a plan to resolve the conflict. The President's guiding principles followed shortly after the summit in his *Forest Plan for a Sustainable Economy and a Sustainable Environment* (Tuchmann et al. 1996)—otherwise known as the Northwest Forest Plan (the Plan).

Immediately after the summit, a team of scientists and technical experts were convened to conduct an assessment of options (FEMAT 1993). This assessment provided the scientific basis for the environmental impact statement and record of decision (ROD) (USDA and USDI 1994) to amend Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl (*Strix occidentalis caurina*).

The ROD, covering 24 million federal ac, put in place a new approach to federal land management. Key components of the ROD included a new set of land use allocations—late-successional reserves, matrix lands, riparian reserves, adaptive management areas, and key watersheds. Northwest Forest Plan (the Plan) standards and guidelines provided direction regarding how these land use allocations were to be managed. In addition, the Plan put in place a variety of strategies and processes to be implemented. These included adaptive management, an aquatic conservation strategy, late-successional reserve and watershed assessments, a survey and manage program, an interagency organization, social and economic mitigation initiatives, and monitoring.

Monitoring provides a means to address the uncertainty of our predictions and compliance with forest management laws and policy. The ROD stated that monitoring is essential and required (USDA and USDI 1994):

> Monitoring is an essential component of the selected alternative. It ensures that management actions meet the prescribed standards and guidelines and that they comply with applicable laws and policies. Monitoring will provide information to determine if the standards and guidelines are being followed, verify if they are achieving the desired results, and determine if underlying assumptions are sound.

Judge Dwyer reinforced the importance of monitoring in his 1994 decision declaring the Plan legally acceptable: "Monitoring is central to the [Northwest Forest Plan's] validity. If it is not funded, or done for any reason, the plan will have to be reconsidered."

The ROD monitoring plan provided a general framework to begin development of an interagency monitoring program. It identified key areas to monitor, initial sets of questions, types and scope of monitoring, the need for common protocols and quality assurance, and the need to develop a common design framework. In 1995, the effectiveness monitoring program plan (Mulder et al. 1995) and initial protocols for implementation monitoring (Alegria et al. 1995) were approved by the Regional Interagency Executive Committee. Approval of the effectiveness monitoring plan led to the formation of technical teams to develop the overall program strategy and design (Mulder et al. 1999) and monitoring protocols for late-successional and old-growth forests (termed older forests) (Hemstrom et al. 1998), northern spotted owls (Lint et al. 1999), marbled murrelets (*Brachyramphus marmoratus*) (Madsen et al. 1999), tribal relations (USDA and USDI 2002), and watershed condition (Reeves et al. 2004). Socioeconomic monitoring protocols continue to be tested (Charnley et al., in press).

Periodic analysis and interpretation of monitoring data is essential to completing the monitoring task critical to completing the adaptive management cycle. This important step was described in the overall monitoring strategy (Mulder et al. 1999) and approved by the Regional Interagency Executive Committee. This 10-year report is the first comprehensive analysis and interpretation of monitoring data since the ROD.

The primary objectives of this report are to describe the status of aquatic and riparian resources and changes in their condition under the Plan's aquatic conservation strategy. The document is one in a series of assessments describing current status and trends of northern spotted owls (Lint

2005), older forests (Moeur et al. 2005), marbled murrelets (Huff, in press), socioeconomic conditions (Charnley et al., in press), tribal relations (Crespin et al., in press), and implementation or compliance monitoring (Baker et al., in press). This series of reports is accompanied by a synthesis report by a panel of scientists and managers that integrates and interprets the findings from the status and trends reports and offers alternatives to policymakers (Haynes et al., in press).

Because the monitoring program was not implemented until 2002, we have yet to collect much of the data required to conduct a 10-year assessment of the Plan (fig. 1). We present a preliminary assessment of the condition of watersheds in the Plan area—the first quantitative assessment conducted since the Plan was implemented in 1994. Perhaps more importantly, we present the analytical approach used to assess the condition of watersheds in the Plan area. We used data from upslope, riparian, and inchannel attributes to estimate status and trend in watersheds by documenting the distribution of watershed conditions in the 24 million ac of federal land encompassed by the Plan. Standard procedures have yet to be established for determining the condition of watersheds or for conducting watershed monitoring at the large spatial and temporal scales encompassed by the Plan. Numerous approaches could be taken to determine the condition of watersheds. The approach presented here is based on a statistically valid sampling design that enables us to make inferences about watersheds in the Plan area, combined with a decision-support model that incorporates indicators of watershed condition in a way that is consistent and repeatable across time and space (Reeves et al. 2004).

Evaluating the effectiveness of the strategy is based on measuring changes in the distribution of watershed condition scores through time. Few details on the changes in individual watersheds are provided. The strategy does not describe the baseline condition of watersheds, nor does it define a desired distribution. We infer that if the strategy has been effective in maintaining or improving the condition of watersheds, then the distribution of watershed condition scores should either stay the same through time, or it should shift in a direction that indicates improvement. The primary objectives of the Plan's watershed monitoring include determining the baseline distribution of the condition of watersheds and tracking changes in the distribution through time. To spotlight some of the success local units have achieved with project-scale restoration, we describe several case studies in sidebars throughout the report. Some of the projects may have had immediate effects, such as opening up habitat to fish by replacing poorly designed culverts that previously blocked fish passage. But most restoration projects should be viewed as a critical first step in restoring natural watershed processes.

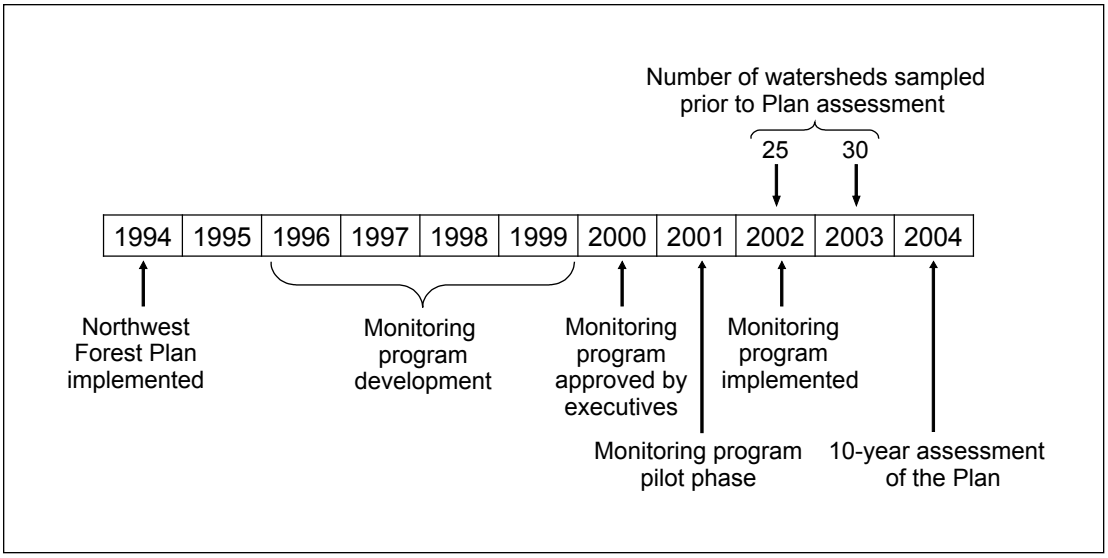


Figure 1—Timeline of the monitoring program development and implementation.

Expectations of the Aquatic Conservation Strategy

The strategy was designed to maintain or improve the ecological health of watersheds. The strategy is based on preserving natural disturbances in watersheds; therefore, not all watersheds are expected to be in good condition at any particular time. Nor is any particular watershed expected to be in a certain (or the same) condition through time. Thus, we examine the distribution of watershed condition through time. The strategy does not identify goals of a specific number or percentage of watersheds that should be in good condition. Nor does the strategy identify a desirable distribution of the condition of watersheds. The strategy does state that because it is based on natural disturbance processes, it will take time–on the scale of decades to perhaps more than a century–for watersheds to respond to the changes in management that resulted from the implementation of the strategy (FEMAT 1993). Consequently, we do not expect to see major changes in the condition of watersheds in a single decade. To examine the effectiveness of the strategy, we compare the distribution of the condition of watersheds in 2003 with the distribution from 1994. If the strategy has been effective, then the distribution of watershed condition scores in 2003 will either be the same as in 1994 or the condition scores of many of the watersheds will be higher in 2003 than they were in 1994.

Overview of the Aquatic Conservation Strategy

The aquatic conservation strategy is a comprehensive, regionwide strategy designed to maintain, restore, and protect those processes and landforms that create good ecological conditions in watersheds, such as providing high-quality habitat for aquatic and riparian organisms and good water quality (FEMAT 1993). The strategy contains nine objectives that describe general characteristics of functional aquatic and riparian ecosystems that are intended to maintain and restore good habitat in the context of ecological disturbance (see app. 1). This approach was intended to prevent further degradation and restore habitat over broad landscapes, as opposed to focusing on individual projects or species (USDA and USDI 1994). Aquatic and riparian organisms evolved in a dynamic environment influenced by natural disturbance. The authors of the strategy believed that stewardship of aquatic resources is most likely to protect biological diversity and productivity when land use activities do not substantially alter the natural disturbance regime to which organisms are adapted (FEMAT 1993). Therefore, the strategy used several tactics to try to maintain the natural disturbance regime in watersheds. The four components of the strategy were intended to work in concert to maintain and restore the health of aquatic and riparian ecosystems:

1. Watershed analysis—used to characterize watersheds and provide a basis (context) for making management decisions.
2. Riparian reserves—used to enhance habitat for riparian-dependent organisms, to provide good water quality, to provide dispersal corridors for terrestrial species, and to provide connectivity within watersheds.
3. Key watersheds—provide high-quality habitat or refugia for aquatic- and riparian-dependent species or would be able to after restoration.
4. Watershed restoration—designed to recover degraded habitat and maintain existing good conditions.

The strategy also includes standards and guidelines that apply to management activities in riparian reserves and key watersheds.

Although late-successional reserves are not listed among the components of the strategy, they provide increased protection for aquatic and riparian ecosystems. Late-successional reserves contain areas of high-quality

stream habitat that serve as refuge for aquatic and riparian organisms and as source areas from which organisms may move to recolonize formerly degraded areas (USDA and USDI 1994).

Monitoring was included in the strategy to achieve three goals: ensure that management actions follow the standards and guidelines and comply with applicable laws and policies (implementation monitoring), determine the effectiveness of management practices at multiple spatial scales ranging from individual watersheds to the entire Plan area (effectiveness monitoring), and determine whether the assumptions underlying the strategy are sound (validation monitoring). The first goal was accomplished through the implementation monitoring program (Baker et al., in press). The aquatic and riparian effectiveness monitoring program (monitoring program) was developed to reach the remaining goals.

Overview of the Aquatic and Riparian Effectiveness Monitoring Program

The monitoring program is responsible for the effectiveness monitoring component of the strategy. Procedures for monitoring the effectiveness of a management strategy at such large spatial and temporal scales are not well established. The program is one attempt to characterize the ecological condition of watersheds. Its purpose is to assess current watershed condition, track trends in watershed condition through time, and report on the Plan's effectiveness across the region by integrating information from a set of biological and physical indicators measured in the watersheds (Reeves et al. 2004). The focus is not on the condition of individual watersheds; rather, the results are presented in the form of a distribution of the condition of watersheds across the Plan area. If the Plan is effective, the condition of watersheds should either stay the same or improve over time (Reeves et al. 2004). Note that the Forest Ecosystem Management Assessment Team (FEMAT) scientists did not intend for each of the strategy's objectives to be monitored individually, nor did they expect that the objectives would be met across the Plan landscape at all times.

The monitoring program was pilot tested in 2000 and 2001 to evaluate sampling protocols and determine the funding and crew structure needed to implement the monitoring program (fig. 1). Monitoring officially began in 2002, although funding was about half the amount identified as being needed to fully implement the program. As of fall 2003, 55 of an expected 100 watersheds were sampled.

Monitoring Questions

The monitoring program is charged with answering questions related to evaluating the effectiveness of the aquatic conservation strategy in achieving its goal of maintaining and improving the condition of watersheds in the Plan area (Reeves et al. 2004). The primary question being asked is: what is the status and trend of watershed conditions in the Plan area? Additional questions, whose answers provide insight for evaluating the success of the aquatic conservation strategy, include:

- Are the key processes that create and maintain habitat conditions in aquatic and riparian systems intact?
  - What is the status of upslope processes as indicated by vegetation and roads?
  - What is the status of riparian processes as indicated by vegetation and road-stream crossings?
  - What is the status of inchannel processes as indicated by pools, substrate, water temperatures, large structure in the channel, and rates of channel movement?
- Has the distribution of key indicators shifted in a direction that indicates improved or degraded habitat and biotic condition?
- How does the aggregate quality of the key indicators used to evaluate watershed condition (i.e., the distribution of watershed condition scores) change through time under the Plan?

Assumptions of the Monitoring Program

The Plan was designed to account for the complex and dynamic nature of aquatic ecosystems resulting from the wide range of physical characteristics, natural disturbance events, and climatic features of the region (Benda et al. 1998, Naiman et al. 1992). Consequently, one of the assumptions

underlying the monitoring program is that watersheds are dynamic systems, and we do not expect all watersheds to be in good condition at any one time (Naiman et al. 1992, Reeves et al. 1995). Nor do we assume that individual watersheds will remain in a static condition indefinitely. Therefore, the primary product of the monitoring program is a distribution that describes the range of conditions of watersheds in the Plan area. Implementing the strategy should result in a range of watershed conditions across the landscape that represents the natural range of conditions expected in a well-functioning aquatic network.

Study Area

The Plan encompasses more than 24 million ac of federal lands in western Washington, western Oregon, and northwestern California (fig. 2). The Plan area includes the entire geographic range of the northern spotted owl. Stream and riparian habitat conditions differ greatly across the Plan area because of natural and management-related factors. Geologic and climatic history influence topographic relief, landforms and channel patterns, and the dominant erosion processes. Precipitation ranges from more than 200 in per year in some areas near the coast to less than 20 in on the east side of the Cascade Range. Riparian vegetation communities are structured by climate and the disturbance regime of the area, including hydrologic processes and disturbance such as forest fires. Many of these critical components of landscape form and function are in distinctive combinations characteristic of each physiographic province in the region. Physiographic provinces incorporate physical, biological, and environmental factors that shape broad-scale landscapes and therefore reflect differences in responses such as soil development and plant community structure.

The Plan area contains eight aquatic physiographic provinces (fig. 2) including the Olympic Peninsula, North Cascades, Willamette/Puget Trough, West Cascades, Washington/Oregon Coast, High Cascades, Klamath/Siskiyou, and Franciscan. Land ownership in the Willamette/Puget Trough is predominantly private, and none of the watersheds in this province met the minimum federal land ownership criteria for the monitoring program. Consequently, this province is not included in the analysis. Descriptions of the provinces based largely on those presented in FEMAT (1993) are provided in appendix 2.

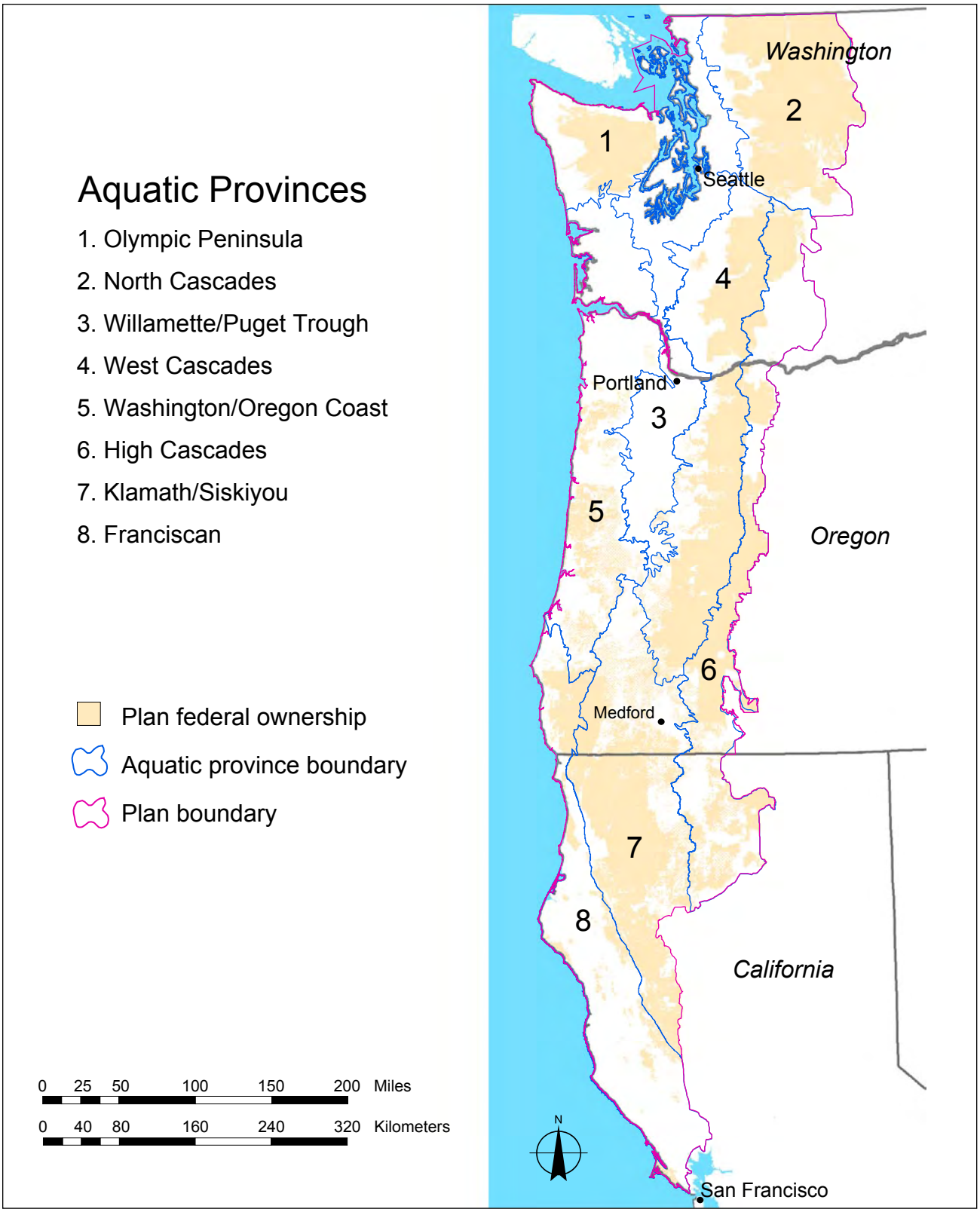


Figure 2—Physiographic provinces in the Plan area. The Plan area extends from the U.S.-Canada border to Point Reyes, California, and includes the eastern flank of the Cascade Mountain range and encompasses the range of the northern spotted owl.

Chapter 2: Methods

Study Design

The subwatershed (sixth-field hydrological unit, hereafter called watershed) formed the basic geographic unit for monitoring. These watersheds are 10,000 to 40,000 ac, and include both complete (contains all headwaters for a main stream) and composite (contains only part of the source waters) watersheds. Because the Northwest Forest Plan (the Plan) applies only to federally managed lands, watersheds must contain a minimum of 25 percent federal ownership (USDA Forest Service, USDI Bureau of Land Management [BLM], or USDI National Park Service) along the total length of the stream (1:100,000 National Hydrography Dataset stream layer) to be considered for sampling in the monitoring program. The ownership criterion was recommended by Reeves et al. (2004) to gauge the influence of the strategy by sampling watersheds in which the strategy was implemented to varying degrees while avoiding sampling watersheds in which the contribution of federal lands to the condition of the watershed was insignificant. The Plan area contains 2,631 watersheds, of which 1,912 contain some land that is federally owned and 1,372 have at least 25 percent federal ownership. The ownership criterion excludes about 10 percent of the federal lands in the Plan area from this analysis.

To assess the effectiveness of the Plan, 250 sixth-field watersheds (app. 3) were randomly selected from the 1,372 watersheds that meet the ownership criterion by using generalized random stratified tessellation survey, a process that guarantees a spatially balanced sample (Stevens and Olsen 2003, 2004). The sixth-field watershed coverage (version 1.1, dated 2002) for the Plan area was used to select watersheds. According to Reeves et al. (2004), 50 watersheds should be sampled each year for 5 years. On year 6, the watersheds sampled the first year will be revisited. Because of funding limitations, we were only able to sample inchannel attributes in a combined total of 55 watersheds in 2002 and 2003, rather than the 100 watersheds as recommended by Reeves et al. (2004). Because of this limitation, we have data from only 22 percent of the watersheds needed to build a baseline distribution for use in evaluating the effectiveness of the strategy. Also, none of the watersheds was sampled more than once; therefore, we have no inchannel data to support the trend analysis.

Inchannel data were collected at multiple sites in each watershed (fig. 3). These sites were selected by using generalized random stratified tessellation survey (Stevens and Olsen 2003, 2004), the same procedure used to select watersheds. The 1:100,000 National Hydrography Dataset stream layer was clipped to the boundary of each watershed. Sample points were placed on the stream layer within the watershed boundary at random. These points represented the downstream starting point for the inchannel surveys.

Because inchannel data were available for only 55 of 250 watersheds, and these data are from only one time period, the data required for the analysis were incomplete. The watershed condition scores (based on road, vegetation, and inchannel data) were used solely to begin building the baseline distribution of watershed condition scores in the Plan area. In describing the current status of the different attributes, we relied on road and vegetation data from the 250 watersheds and inchannel data from the 55 watersheds that have been sampled. For the trend analysis, we relied only on the road and vegetation data in the 250 randomly selected watersheds from two periods.

Definition of Watershed Condition

The definition of watershed condition developed by the monitoring program was based on the goals of the strategy and on guidance provided by Reeves et al. (2004). The condition of a watershed was defined as "good" if the physical attributes were adequate to maintain or improve biological integrity, including diversity and abundance of species—particularly, native or desired fish species. Specific physical attributes included intact upslope and riparian habitats that were biologically and structurally diverse and functioning properly—i.e., banks were stable, large wood was present in the stream channel, and sediment and nutrient inputs were similar to natural levels. Flows should have been adequate to maintain or improve riparian and inchannel habitat. Chemical characteristics and water temperature must have been in a range that maintained biological integrity. Further, the system should have been able to recover to desired conditions when disturbed by large natural events or by

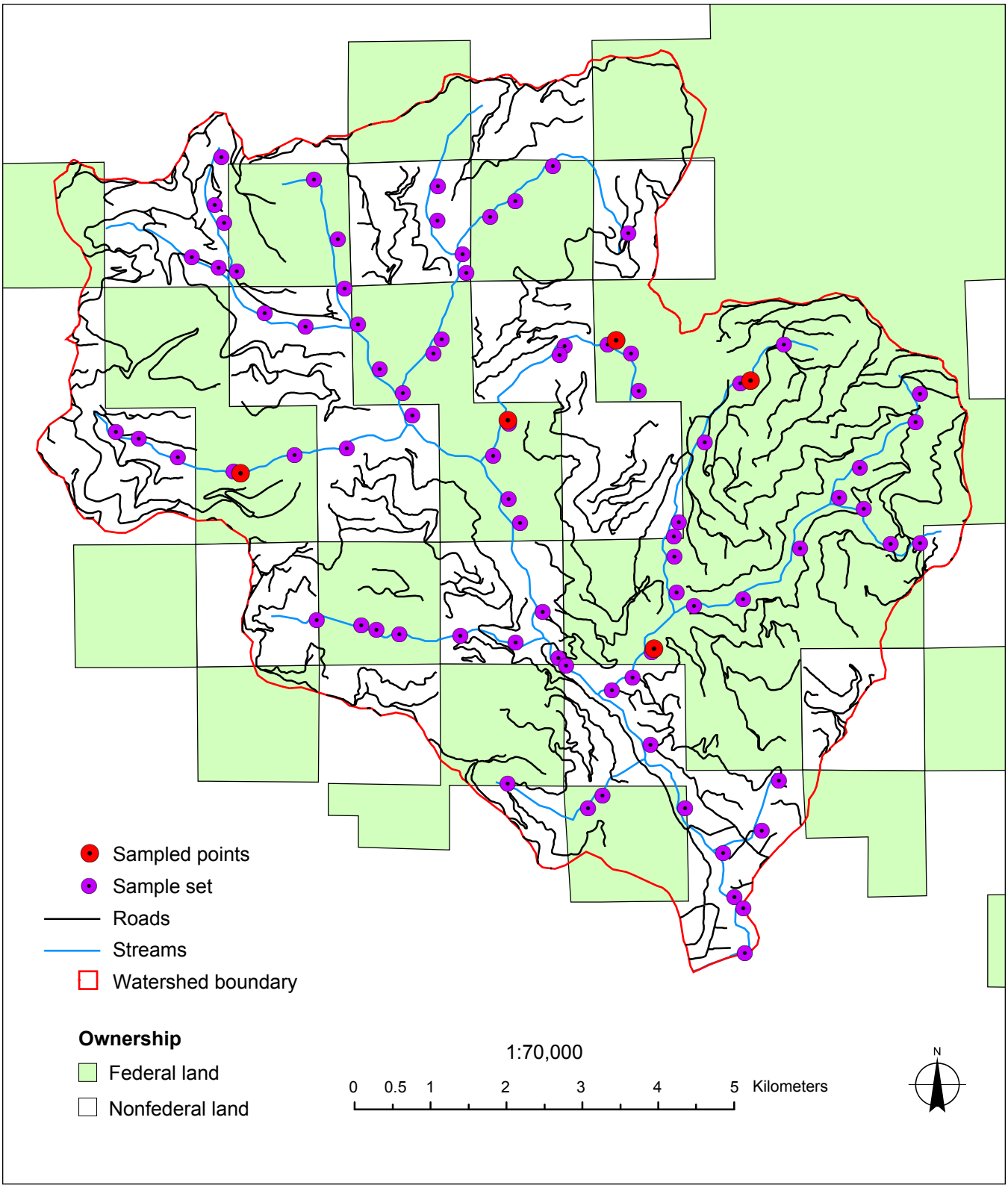


Figure 3—Example of randomly selected sample sites in a sixth-field watershed. The sampled stream reaches (red dots) were selected from 1:100,000 stream layers by using a generalized random stratified tessellation survey, a process that guarantees a spatially balanced sample (Stevens and Olsen 2004).

land management activities. Appendix 4 contains specific criteria used to evaluate the condition of watersheds in each province.

The definition is fish (salmon)-centric, in other words, we define good condition as ability to provide high-quality fish habitat. A watershed with intact processes may not be in good condition in terms of providing quality fish habitat. Watersheds naturally differ in their condition, and they periodically experience natural disturbance. For this reason, we need to recognize that unmanaged watersheds are not necessarily in good condition. Although condition may be improving in a recently disturbed watershed, no watershed is in good condition all the time, regardless of its management history. Further, we expect that the probability that all watersheds would be in good condition at any one time is very low.

Assessment of Watershed Condition

Decision-support models were used to assess the condition of individual watersheds by using locally relevant evaluation criteria. These models are computer-based models that capture evaluation procedures and apply a consistent decision or evaluation process across time and space. Reeves et al. (2004) recommended using these models because they are easy to understand and to replicate.

Decision-support models use data to evaluate a premise. For the analysis described in this report, we evaluated the premise that watersheds are in good condition. Data used in the assessment lend varying levels of support to that premise, ranging from full support to no support. We developed criteria to evaluate each attribute based on available data and expert judgment. Data on individual attributes were compared to these criteria and given an evaluation score that ranged between +1 and –1, where +1 indicates full support and –1 indicates no support for the premise. The evaluation score is positively related to the condition of watersheds, such that the attributes (or watersheds) in good condition should receive an evaluation score of (or near) +1. Evaluation scores for the attributes were aggregated into an overall assessment of watershed condition. Evaluation scores were typically aggregated by using either a weighted or unweighted average. Weights were assigned based on the experts' opinions of the relative importance of an attribute in contributing to the condition of watersheds. In a few cases, an aggregated score weighted toward the lowest evaluation score was used to allow a single variable to override other variables.

A decision-support model was built, refined, and peer-reviewed for each province (n = 7) during workshops attended by local agency professionals (fig. 4). Models were built at the provincial scale to account for the ecological differences that exist between provinces. For example, precipitation and the availability of water in the creeks is an important consideration on the east side of the Cascade crest and in many parts of California and southern Oregon. However, water is rarely a limiting factor in coastal watersheds.

The workshops consisted of an informal group process through which participants came to consensus on the model structure and evaluation criteria. After the workshops, models were built and run and the results returned to the workshop participants. Participants compared the results of the model to their knowledge of the condition of the watersheds and suggested refinements to the model as necessary. Changes were made to the model and the results were reevaluated.

The models differ across provinces in the specific attributes evaluated, the weights assigned to individual attributes, and the evaluation criteria used (app. 4). Although the attributes available for use in the evaluation models were specified by Reeves et al. (2004), workshop participants determined how individual attributes were used in each model. For example, an evaluation of road-stream crossings was included in each of the provincial models, but the specific attribute evaluated differed across provinces (frequency of road crossings was sometimes expressed as number per mile of road and at other times as number per mile of stream). The width of the riparian buffers used also differed across provinces. The models were based on local data and knowledge. Most of the differences between models reflect ecological differences across provinces, but some reflect availability of data used as a basis for the evaluation criteria. We view the modeling effort as an iterative process. In the future, we will work toward making the models more

All photos on this page by Steve Lanigan

Figure 4—Nearly 50 participants provided technical expertise and local knowledge for decision-support model construction and refinement during a series of aquatic province workshops.

similar to the extent possible, given ecological differences between provinces. Advantages and disadvantages of using multiple models in the analysis are discussed in chapter 4. The sensitivity of each of the models to change is presented in appendix 5.

Attributes

The attributes used in this analysis describe existing inchannel conditions and watershed processes. The information and analytical tools necessary to quantify and comprehensively assess watershed processes are currently lacking. Thus, the monitoring program must rely on physical and biological attributes that act as surrogates or indicators of specific watershed processes. Reeves et al. (2004) initially identified 90 potential attributes that represent key functions and processes in watersheds. This number of attributes was reduced based on criteria established by Noon et al. (1999). The remaining attributes represent upslope, riparian, and inchannel processes (table 1).

In individual watersheds, roads and vegetation data in upslope and riparian areas were collected across the entire watershed by using geographic information systems (GIS) data sets. Riparian reserve boundaries have yet to be delineated; therefore, we were not able to include riparian reserves in the analysis. Riparian area for road and vegetation assessment was based on fixed-width buffers that were placed on the stream layer (see following section for details).

Inchannel data (physical and water chemistry attributes) were collected at several sample sites randomly selected in the watershed (fig. 3). Sites are sections of the stream channel that differ in length from 175 to 525 yd, depending on the width of the channel. Crews sampled individual sites until an 8-day sampling period expired. In each watershed, sites were sampled in the order they were selected. Sites located in unwadeable water or private land were not sampled. The number of sites sampled was typically a function of access (i.e., more sites were sampled in

Table 1—Attributes included in the watershed condition assessments listed by ecologic process[a]

General process	Key process	Attribute
Upslope subsystem:		
Vegetative succession, growth, and mortality	Wood production and transport	Vegetation seral stage
Soil cycle	Sediment production and transport	Road density
Soil cycle	Sediment production and transport	Landslides
Riparian flood-plain subsystem:		
Vegetative succession, growth, and mortality	Wood delivery, community structural development	Vegetation seral stage and association
Soil cycle	Sediment production and transport	Stream-crossing density
Soil cycle	Sediment production and transport	Road density
Soil cycle	Sediment production and transport	Landslides
Hydrologic cycle	Water storage and yield	Channel connectivity with flood plain
Inchannel subsystem:		
Channel structural dynamics	Sediment and wood delivery	Channel cross section
Channel structural dynamics	Sediment and wood delivery	Channel sinuosity and gradient
Channel structural dynamics	Sediment and wood delivery	Channel pools
Channel structural dynamics	Sediment and wood delivery	Channel wood
Channel structural dynamics	Sediment and wood delivery	Substrate composition
Channel structural dynamics	Flood-plain connectivity	Off-channel habitat
Energy exchange	Heat delivery	Water temperature
Chemical and nutrient turnover	Chemical and nutrient delivery	Water quality
Hydrologic cycle	Water delivery	Water quantity

[a] Data on these attributes were evaluated in the decision-support models and aggregated to determine the watershed condition score. Source: Adapted from Reeves et al. 2004.

areas that were easily accessed). On average, six sites were sampled in each watershed, with a range from three to eight.

Data Collection and Sources

The evaluation of upslope and riparian conditions in watersheds was tailored to specific physiographic provinces. Although physiographic provinces are useful in describing both terrestrial and aquatic ecosystems, different processes dominate the functioning of these ecosystems. Consequently, the Forest Ecosystem Management Assessment Team (FEMAT 1993) used different physiographic province boundaries for aquatic and terrestrial ecosystems. The physiographic boundaries used in this analysis were developed from those used in the aquatic ecosystem assessment, which were based on broadly drawn precipitation and geologic areas (FEMAT 1993). These province boundaries differ from those used by the other effectiveness monitoring components (e.g., the late-successional old-growth and the northern spotted owl (*Strix occidentalis caurina*)), which were delineated primarily by vegetation type and political boundaries (state lines). The aquatic province boundaries used in FEMAT were not available in a digital format, so the province boundary lines used in FEMAT were refined by using level 4 lines described by Omernik in Oregon and Washington (Bryce et al. 1999), Bailey ecological subsections lines in California (Bailey et al. 1994), and the Cascade crest derived from the Forest Service Pacific Northwest Region sixth-field watershed layer.

The GIS coverages used in the analyses were collected from various sources, including the USDA Forest Service, USDI Bureau of Land Management, USDI National Park Service, and other state and federal agencies. Details on the coverages used in the analyses are provided in appendix 6.

Upslope and Riparian Attributes

Roads—

In each of the 250 watersheds, road density in upslope and riparian areas and the frequency of road-stream crossings were determined. Data were based exclusively on the GIS layers, with no field verification. For these analyses, road and 1:24,000 stream layers were clipped to watershed boundaries. A fixed buffer was placed over streams in the watershed to determine riparian area. These riparian areas used do not represent riparian reserves. The width of the buffer differed across the provinces, and generally was 164 ft on the west side of the Cascade Range and 100 ft on the east side (app. 4). The width of the riparian buffer was determined during the decision-support model workshops. The buffer widths were based on what the participants believed was the relevant area for the riparian process of interest. For example, a narrow buffer was used in evaluating the extent that stream channels were constricted by the presence of a road. Wider buffers were used for evaluating wood and sediment input into streams. Upslope area was defined as the area outside the riparian boundary. For riparian road density analyses, the road layer was laid over the riparian buffer and miles of road inside the buffer were counted. Miles of road outside the buffer were used to determine upslope road density. To estimate the number of road-stream crossings, we counted road and stream intersections. Forty-eight sample watersheds spread across the Plan area were inspected for potential erroneous crossings from digitizing errors. The percentage of suspected false crossings was less than 2 percent for the total sample.

Information on road building and decommissioning conducted (fig. 5) since the Plan was implemented was spotty and incomplete. Although most of the federal road coverages contain attributes that describe whether specific road segments were decommissioned, dates of decommissioning and information on road building on Forest Service land were not available. Historical roads coverages (e.g., from 1994 when the Plan was implemented) were also not available. Therefore, to obtain road data from 1994 (time 1) and the present (time 2) (table 2) to analyze change, we used total road miles (existing + decommissioned) as the time 1 data point and the existing roads as the time 2 data point. We assumed that all the roads were decommissioned later than 1994. The Forest Service and the BLM rarely decommissioned roads before 1990.[1] Although analyzing just the miles of roads that have been decommissioned may seem more straightforward than looking at miles of roads in

[1] Erkert, T. 2003. Personal communication. Road engineer, USDA Forest Service, Pacific Northwest Region, 333 SW First Ave., Portland, OR 97204.

Bengt Coffin

Figure 5—Decommissioned roads are stabilized and disconnected from natural surface hydrological features.

time 1 and time 2, this approach would not allow us to use the decision-support model and determine the distribution of watershed conditions across the Plan area in the two periods.

Vegetation—

The analysis used GIS layers developed by the Interagency Vegetation Mapping Project (IVMP) in Oregon and Washington and by CalVeg in California to assess vegetation characteristics. Both layers were built by using Landsat Thematic Mapper remote sensing data (Moeur et al. 2005). In each of the 250 watersheds, the vegetation layer and the 1:24,000 stream layer were clipped to the watershed boundary. A fixed-width buffer was generated from the stream layer to designate the riparian area (app. 6). The area outside the buffer was defined as upslope.

For change analyses, data from the IVMP or CalVeg layer were used as the time 1 (around 1996) data point (table 2). For the time 2 (2002) data, the vegetation change layer developed for the older forest vegetation monitoring program (Moeur et al. 2005) was used in concert with the IVMP or CalVeg layer. This change layer was built by using data that were independent of the original IVMP and CalVeg data, and

Table 2—Dates of geographic information system layers used to determine the condition of watersheds in time 1 and time 2[a]

	Time 1	Time 2
Forest Service roads	Later than 1990	2002
Bureau of Land Management roads	1994	1998
Other roads	Later than 1990	1998
IVMP	1993–96	2002
CalVeg	1994	2003

[a] Interagency Vegetation Mapping Project (IVMP) and CalVeg are the vegetation layers used in this analysis.

was used to update the original baseline layers. The change layers were laid over the IVMP or CalVeg layer, and the vegetation inside polygons that indicated post-1994 disturbance was classified as early seral. We then repeated the analyses conducted for the time 1 assessment. These change layers describe stand-replacing events resulting from harvest and fire (fig. 6), but they do not capture partial losses owing to thinning or surface fire, nor do the layers show tree growth.

To account for tree growth, we used data from about 40,000 plots measured twice since 1994 by the Forest Inventory Analysis (administered by the Forest Service in California) and the Current Vegetation Survey (administered by the Forest Service and BLM in Oregon and Washington).

Mark Isley

Figure 6—The vegetation layers used to identify stand-replacing events, such as this clearcut on nonfederal land were constructed by using satellite imagery.

Moeur et al. (2005) provided the details on the plot data used. We calculated the average percentage of area with trees in one size class in time 1 (e.g., <20 in) that transitioned to the next size class in time 2 (>20 in) since the Plan was implemented. We calculated this percentage for each vegetation type (e.g., pinion-juniper, Douglas-fir forest) in each province. This change rate was used to calculate change factors for each watershed by using the change rate for each of the vegetation types in the watershed, weighted according to the area of the watershed covered by the vegetation type. The change rate reflects the net change in vegetation owing to growth, recruitment, natural mortality, fire, and management activities. By using the change layer (which accounts for stand-replacing harvest and fire) and also applying change rates calculated from the plot data (which accounts for harvest and fire as well as thinning, growth, and natural mortality), we double counted stand-replacing events. According to Moeur et al. (2005), about 1.6 percent of the older forest trees (>20 in) were disturbed by stand-replacing harvest and fire. Thus, we assume that our analysis overestimates the amount of land disturbed by that amount, on average, across the 250 watersheds.

Plot data were not available for the national parks or for BLM lands in California because plots were not installed in these areas in 1994 when the Plan was implemented. We therefore assumed that the transition probabilities calculated in individual provinces applied to parks and California BLM lands in that province. For example, the transition probability calculated from plots on the Olympic National Forest and other areas on the peninsula were applied to the Olympic National Park. Because national parks are not managed for timber production, we likely overestimated stand-replacing disturbance in the national parks.

Inchannel Attributes

Physical and chemical inchannel data were combined with roads and vegetation data from the current period (time 2) for assessing watershed condition in the 55 watersheds that have been sampled as of fall 2003. Information on physical, biological, and chemical characteristics of the reach were obtained from field data. Biological data were not used in this assessment because time was insufficient to build it into the decision-support models. The length of the sample reach was determined as 20 times the average bankfull width, with minimum and maximum reach lengths of 175 and 525 yd, respectively (app. 7). Physical habitat indicators include:

- Bankfull width-to-depth ratio and entrenchment ratio, calculated from cross-sectional profiles (Peck et al. 1999; fig. 7).
- Pool frequency, sinuosity, and gradient, calculated from longitudinal profiles (Peck et al. 1999).
- Wood frequency, by using the protocol developed by the Oregon Department of Fish and Wildlife (Moore et al. 1999; fig. 8).
- Percentage of fine sediments, by using a protocol developed by USDA Forest Service, Pacific Southwest Region (1998; fig. 9) and substrate D_{50} (median particle size), by using a modification of Peck et al. (1999).

Chemical data were collected for total Kjeldahl nitrogen and total phosphorus and analyzed in the laboratory. Additional data were collected for dissolved oxygen, conductivity, pH, and water temperature by using a meter. These data were used to describe water quality in the watersheds.

Statistical Analysis

To test for the direction of change between the time 1 and time 2 distributions, we used a one-tailed Wilcoxon signed rank test. This test examines the differences between the time 1 and time 2 condition scores for individual watersheds and determines whether more watersheds increased or decreased in condition than would be expected by chance. The Wilcoxon test is a nonparametric that does not assume a normal distribution of the data. To avoid type II error, we set $\alpha = 0.10$ in all the analyses conducted.

Wald's F-test was used to test for differences between the distributions for key and non-key watersheds (psurvey.analysis library, v. 2.2; http://epa.gov/nheerl/arm/analysispages/techinfoanalysis.htm) as described at the U.S. Environmental Protection Agency Aquatic Resource Monitoring-Analysis Web site (http://epa.gov/nheerl/arm/analysispages/monitanalysisinfo.htm) and by Diaz-Ramos et al. (1996).

Linear regression was used to examine the relationship between condition scores and federal ownership in watersheds. For the regression analysis, condition score was the dependent factor, and percentage of federal ownership was the independent factor. Land use allocation was included as a covariate. All analyses were conducted by using S-Plus statistical software, version 6.1 (Insightful Corp. 2002).

Steve Lanigan

Figure 7—A laser level was used to measure cross-sectional profiles at transects placed throughout each stream reach. This information was then used to determine bankfull width-to-depth ratios and entrenchment ratios.

Molly Glynn

Figure 8—Each piece of wood must meet the following criteria to be counted: (1) be longer than 3 m (9.8 ft) and (2) at least 30 cm (11.8 in) in diameter one-third of the way up from the base or largest end.

Steve Lanigan

Figure 9—A sediment grid was used to quantify the percentage of fine sediments on the surface of pool tail substrate.

Overview of the Decision-Support Model

Decision-support models can be used to conduct objective ecological assessments by integrating diverse kinds of data, such as vegetation, roads, and inchannel habitat indicators. These models are not mathematical or statistical models, they simply apply a decision process consistently across time and space. Advantages of using decision-support models include:

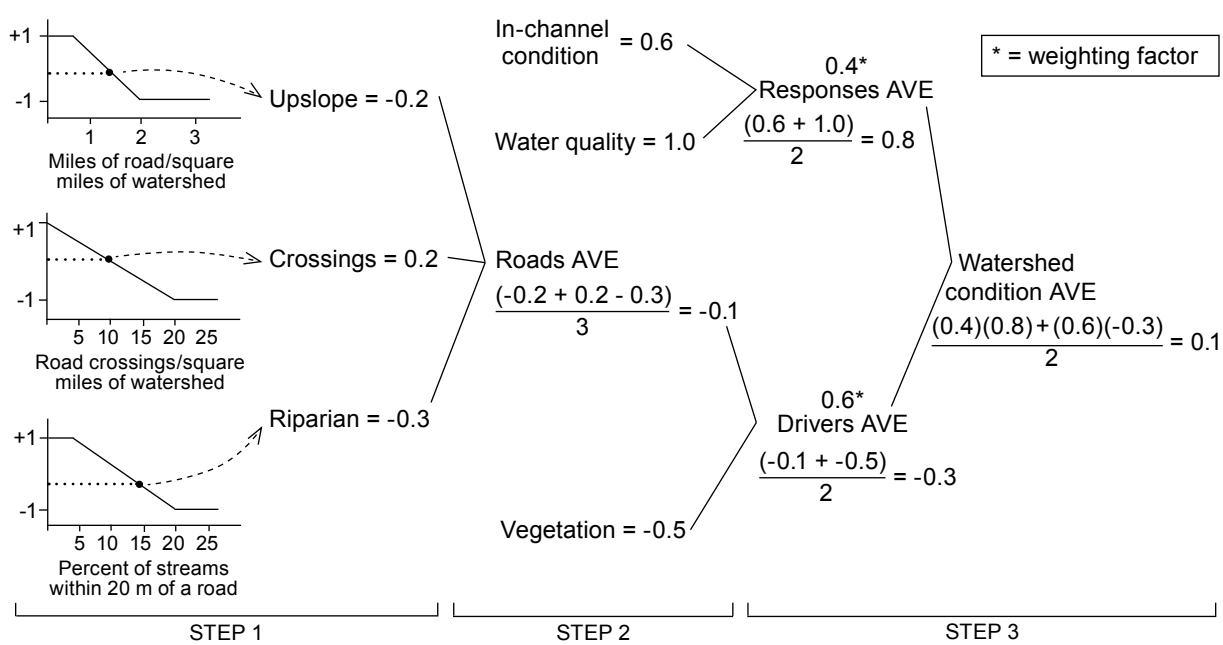
- All aspects of the analysis process are shown; therefore, it is easy to explain to customers.
- Models can be developed to assess ecological condition at any spatial or temporal scale.
- As we learn more about how watersheds function, models can be refined and rerun on data from earlier periods to correct deficiencies.

The following simplified model structure illustrates a decision-support model process for determining watershed condition. The actual model structures we used are presented in appendix 4.

Step 1: Evaluation criteria are determined for each model attribute. The evaluation curves are used to score each attribute between +1.0 ("good") and -1.0 ("poor"). The curves are based on published literature, field data, and professional judgment. Evaluation curve examples are shown for the road components.

Step 2: The evaluation scores for each of the attributes are aggregated together for each general model component by using user-defined rules. Selection of the rules is based on experts' knowledge of the system and ecological processes. Rules can produce an aggregated score weighted toward the resource with either the highest or lowest evaluation score, or use the average of scores (as shown in this example). A score can also be based on the weighted or unweighted average of the indicator evaluation scores, e.g., as shown in step 3.

Step 3: The evaluation scores are aggregated based on the model structure. In this model structure, the watershed condition is determined by using the weighted average of drivers (60 percent) and response (40 percent) scores. For the models presented in appendix 4, drivers scores are determined for the entire watershed by using geographic information systems data, whereas the response scores are based on inchannel data. The watershed condition score will always range from -1.0 to +1.0.



Example of a simplified decision-support model. In step 1, individual attributes are evaluated by using evaluation criteria. In steps 2 and 3, the evaluation scores of the attributes are aggregated to determine the overall watershed condition score.

Continue to Next Section