CHAPTER 3

Design of an Ecological Monitoring Strategy for the Forest Plan in the Pacific Northwest

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The growing literature on ecosystem management describes an adaptive system in which monitoring measures progress toward goals, increases our knowledge, and improves our plans (e.g., Holling 1978; Walters 1986; Duffus III 1994; Everett et al. 1994; Grumbine 1994; Bormann et al. 1995; Gunderson et al. 1995; Interagency Ecosystem Management Task Force 1995; Montgomery et al. 1995; Christensen et al. 1996; Yaffee et al. 1996). Adaptive management acknowledges that action is necessary or appropriate, although knowledge may be imperfect (Raiffa 1968; Holling 1978; Walters 1986; Everett et al. 1994; Grumbine 1994; USFS and BLM 1994b; Gunderson et al. 1995). Less-than-perfect knowledge is likely to be the rule in ecosystem management, especially when the objectives include the restoration and maintenance of complex ecological patterns and processes over large areas and long periods of time.

We describe two general lessons (adaptive monitoring design, and scale) and three general issues (integration, infrastructure, and individuals) that arose in the early design of an ecological monitoring strategy intended to support ecosystem management under the Northwest Forest Plan. We primarily focus on the former (lessons), but briefly describe the latter (issues), since these management issues are of special importance to the implementation of a monitoring system for ecosystem management. It is not, however, our purpose here to describe the details of our monitoring strategy, since it is described elsewhere (Mulder et al. 1995, 1999; Tolle and Czaplewski 1995).

The Northwest Forest Plan

Enough timber for 300,000 homes was being harvested from federal land in the northwestern United States during an average year in the 1980s (Johnson et al. 1991; USFS and BLM 1994a). By 1994, sales on these lands had halted as a result of more than a dozen lawsuits. The lawsuits centered around concerns over an endangered species, the northern spotted owl, and the old-growth forest upon which is it dependent.

A presidential conference in April 1993 led to the development of the Northwest Forest Plan in 1994. The Plan is designed to provide for a "steady supply of timber sales and nontimber resources that can be sustained over the long term without degrading the health of the forest or other environmental resources" (USFS and BLM 1994b). The Plan amends the nineteen U.S. Forest Service and seven U.S. Bureau of Land Management resource management plans for the 100,000 square kilometers within the range of the northern spotted owl (fig. 3-1). It is implemented under a Memorandum of Understanding that includes the White House Office on Environmental Policy, the Department of Agriculture, five components of the Department of the Interior, the National Marine Fisheries Service, and the Environmental Protection Agency (see Appendix E of USFS and BLM 1994b). Extensive discussions on the Plan have been well developed in a number of widely available sources (Dwyer 1994; Society of American Foresters 1994; Tokar 1994; USFS and BLM 1994a,b; Yaffee 1994; Tuchmann et al. 1996).

A key feature underlying the lawsuits was the perspective that the previous scale of management planning—at the level of nineteen individual national forests and seven individual Bureau of Land Management districts (fig. 3-1)—was inadequate to respond to many ecological concerns. Specific concerns included the northern spotted owl and other species dependent upon a network of old-growth forests (Yaffee 1994) and the cumulative watershed effects on fishes and other organisms dependent upon the aquatic resources of the region.

Based on presidential direction, the Northwest Forest Plan specifies a broad array of regional ecological (table 3-1) objectives. These are divided into terrestrial objectives and Aquatic Conservation Strategy (ACS) objectives (table 3-2). Key spatial reporting or evaluation scales envisioned by the plan are regional and provincial in extent (the region is divided into

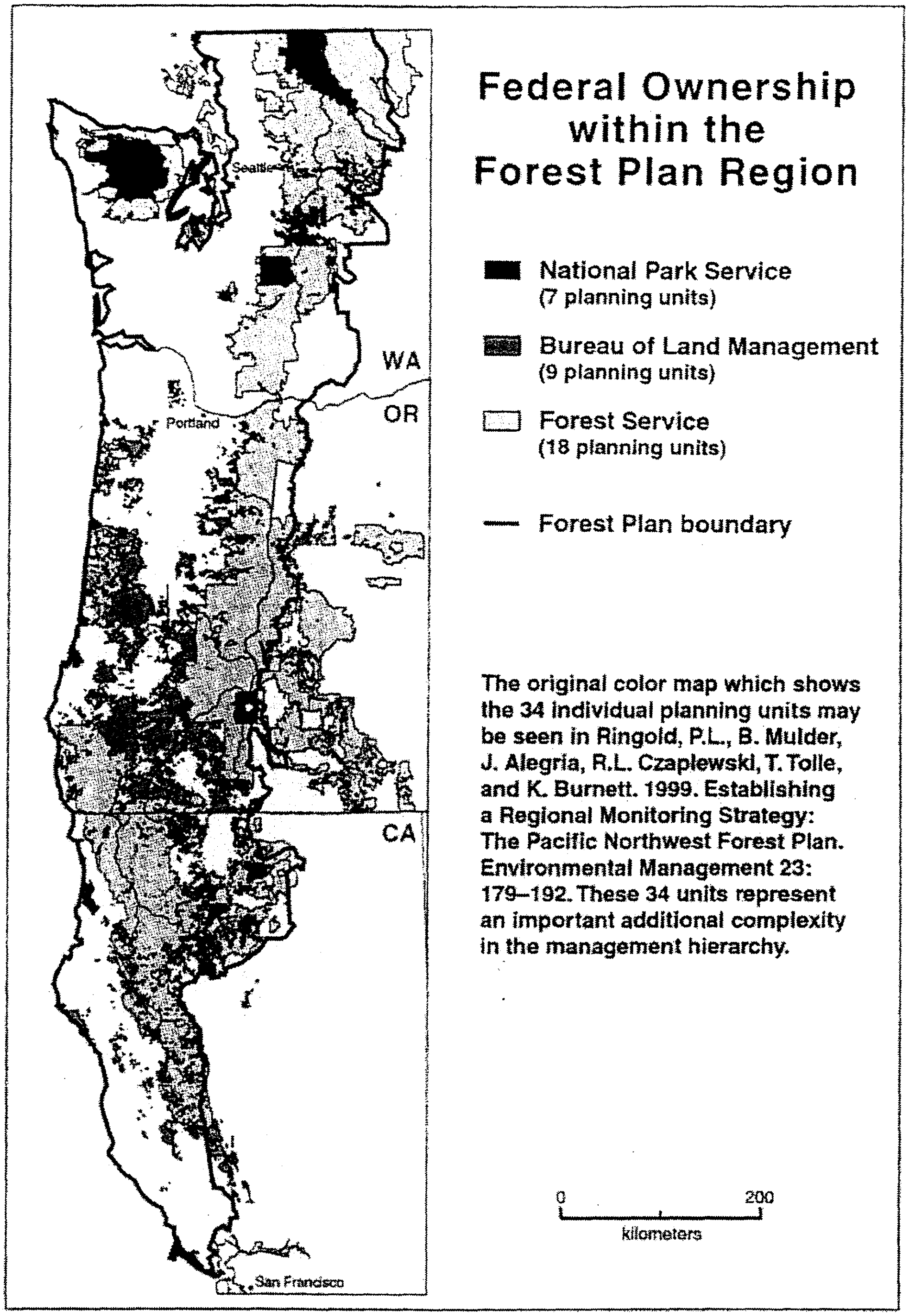

Figure 3-1. Map of the region. The region is the range of the northern spotted owl in the United States. It includes 99,000 square kilometers of federally administered land embedded in a region containing 230,000 square kilometers of total land. The region is divided into twelve physiographic provinces to allow for "differentiation between areas of common biological and physical processes." The text refers to twenty-six planning units; this figure shows twenty-seven Bureau of Land Management and Forest Service planning units, along with seven National Park Service areas. The different number of planning units reflects a change in the number from that in existence at the time of the record of decision (USFS and BLM 1994b).

Table 3-1. Hierarchy of goals and monitoring questions.

Level	*Source*	*Statement*
1	Presidential	"... protect the long-term health of our forests, our wildlife, and our waterways ..."
2	Cabinet-level goals	Includes: "restore and maintain the ecological health of watersheds and aquatic ecosystems contained within them on public lands"
3	Cabinet-level objectives	Includes nine Aquatic Conservation Strategy Objectives, including: "4. Maintain and restore water quality necessary to support healthy riparian, aquatic, and wetland ecosystems. Water quality must remain within the range that maintains the biological, physical, and chemical integrity of the system and benefits survival, growth, reproduction, and migration of individuals composing aquatic and riparian communities."
4	Interagency monitoring design group general question	Includes: "How many miles/acres of 'waterbodies' have specific chemical and biological characteristics?"
5	Interagency monitoring design group specific monitoring question	Includes: "How many miles (with 10 percent accuracy) of perennial fish-bearing streams within each province and the region contain water whose temperature does not fall above 18 degrees C and below 4 mg/l dissolved oxygen for more than one hour during course of the year?"

twelve ecophysiographic provinces). The spatial grain of the individual features described in these objective ranges from very small—site or local level—to very large—watershed and landscape level. Two examples illustrate this variability in feature size. Terrestrial objective 3 in table 3-2B, "to maintain and enhance late-successional forests as a network of existing old-growth forest ecosystems" describes an inherently large pattern to be maintained or enhanced. In contrast, aquatic conservation strategy (ACS) objective 3, which cites the need to "maintain and restore the physical integrity of the aquatic ecosystem, including shorelines, banks, and bottom configurations," is an example of an objective with inherently

Table 3-2. Forest Plan ecological objectives and their spatial grain. The Forest Plan established two sets of ecological objectives, one for aquatic systems (Table 3-2A) and one for terrestrial systems (Table 3-2B). It is the intention of the plan that these objectives be pursued on a regional and provincial extent. We have added information on the grain of the indicator associated with each objective. *Grain* is the size of the feature that would need to be described or inferred in a regional monitoring program. It reflects the sizes of features that are ecologically meaningful. The challenge here is that both fine- and coarse-grained features are to be described and managed over a large spatial extent. The Aquatic Conservation Strategy Objectives are taken directly from the Record of Decision (USFS and BLM 1994b). The Terrestrial Objectives are adapted from the same source. The information on spatial grain of the indicator was devised by the monitoring design group.

3-2A

	Spatial Grain of Indicator		
Aquatic Conservation Strategy Objectives	*Site Reach*	*Watershed*	*Landscape*
1. Maintain and restore the distribution, diversity, and complexity of watershed- and landscape-scale features to ensure protection of the aquatic systems to which species, populations, and communities are uniquely adapted.			
2. Maintain and restore spatial and temporal connectivity within and between watersheds. Lateral, longitudinal, and drainage network connections include floodplains, wetlands, upslope areas, headwater tributaries, and intact refugia. These network connections must provide chemically and physically unobstructed routes to areas critical for fulfilling life-history requirements of aquatic- and riparian-dependent species.			
3. Maintain and restore the physical integrity of the aquatic system, including shorelines, banks, and bottom configurations.			
4. Maintain and restore water quality necessary to support healthy riparian, aquatic, and wetland ecosystems. Water quality must remain within the range that maintains the biological, physical, and chemical integrity of the system and benefits survival, growth, reproduction, and migration of individuals composing aquatic and riparian communities.			

continues

Table 3-2. (*Continued*)

3-2A (continued)

Aquatic Conservation Strategy Objectives	*Spatial Grain of Indicator* Site Reach	*Spatial Grain of Indicator* Watershed	*Spatial Grain of Indicator* Landscape
5. Maintain and restore the sediment regime under which aquatic ecosystems evolved. Elements of the sediment regime include the timing, volume, rate, and character of sediment input, storage, and transport.			
6. Maintain and restore in-stream flows sufficient to create and sustain riparian, aquatic, and wetland habitats and to retain patterns of sediment, nutrient, and wood routing. The timing, magnitude, duration, and spatial distribution of peak, high, and low flows must be protected.			
7. Maintain and restore the timing, variability, and duration of floodplain inundation and water table elevation in meadows and wetlands.			
8. Maintain and restore the species composition and structural diversity of plant communities in riparian areas and wetlands to provide adequate summer and winter thermal regulation, nutrient filtering, appropriate rates of surface erosion, bank erosion, and channel migration and to supply amounts and distributions of coarse woody debris sufficient to sustain physical complexity and stability.			
9. Maintain and restore habitat to support well-distributed populations of native plant, invertebrate, and vertebrate riparian-dependent species.			

The spatial grain of the indicator.

3-2B

Terrestrial Objectives	Spatial Grain of Indicator	
	Stand	Landscape
1. To maintain late-successional and old-growth species habitat and ecosystems		
2. To provide habitat for a variety of organisms associated with both late-successional and younger forests		
3. To maintain and enhance late-successional forests as a network of existing old-growth forest ecosystems		
4. To function as connectivity between late-successional reserves		
5. To perform an important role in maintaining and promoting biodiversity associated with native species		
6. To help ensure that late-successional species diversity will be conserved		
7. To maintain ecological processes, including those natural changes that are essential for the development and maintenance of late-successional and old-growth forest ecosystems		
8. To provide for important ecological functions such as dispersal of organisms, carryover of some species from one stand to the next, and maintenance of ecologically valuable structural components such as down logs, snags, and large trees		
9. To reduce risk to late-successional ecosystems resulting from large-scale disturbances and unacceptable loss of habitat due to large-scale fire, insects, and disease and major human impacts		
10. To accelerate the development of overstocked young plantations into stands with late-successional and old-growth forest characteristics		
11. To provide for desired habitat conditions for at-risk fish stocks		

The spatial grain of the indicator

local focus. This does not imply that fine-scale features are not influenced by those at broader scales, or that broad-scale patterns and processes cannot be inferred from observations of fine-scale features. In fact, many of the features have characteristics at both small and large scales.

Of special interest is the fact that many of the Plan objectives apply to larger features—features not necessarily observable or manageable at the level of the twenty-six individual planning units that comprise the region (fig. 3-1). In summary, the expectation is that both small and large features will be restored and maintained throughout the region and its component provinces. The temporal extent of the Plan, and the individual agency resource plans it amends, is intended to be a century or longer.

Monitoring Design

In the fall of 1994, an interagency monitoring design group (MDG) began to develop a strategy for forest plan monitoring. The ecological monitoring portion of the strategy was to focus on effectiveness monitoring, designed to determine if the objectives of the Plan are being achieved. This assignment was distinct from but bounded by parallel assignments to other groups focusing on implementation monitoring (determines if the steps of the Plan are being implemented), validation monitoring (determines if the assumptions underlying the Plan are correct), and nonecological monitoring.

The MDG worked collectively on a monitoring strategy that included a general approach to ecosystem monitoring and proposals (each prepared by groups of scientists) for each of five priority elements: (1) the northern spotted owl, a threatened species; (2) the marbled murrelet, also threatened; (3) "survey and manage" species—a large group of over four hundred rare species; (4) late-successional/old-growth forests; and (5) riparian/aquatic ecosystems. The resultant strategy (Mulder et al. 1995) includes the application of statistically rigorous sample surveys, modeling, GIS analyses, remote sensing, and synthesis to address the effectiveness monitoring needs of the Plan. The report also discusses (1) integrating monitoring requirements of the five specific resource elements in a cost-effective, synergistic manner, (2) establishing an institutional infrastructure, (3) developing new monitoring methodologies, and (4) establishing intra- and interdisciplinary linkages, as well as interagency linkages.

Our efforts not only resulted in a workable strategy, but also revealed two important lessons. First, we learned to view monitoring design as an adaptive process (Ringold et al. 1996) since the many uncertainties and unknowns make it difficult to adhere to the rigorous standards that define good monitoring practice. Viewing monitoring as an adaptive process is consistent with the prototyping notion of introducing new approaches to ecosystem management (Brunner and Clark 1997). Second, we identified the need to define a monitoring program in the context of the large and multiscalar spatial and temporal elements of the Plan rather than in the context of the single and smaller scales of traditional monitoring and management.

Lesson One: Monitoring Design as an Adaptive Process

An effectiveness monitoring strategy provides the data that allows us to evaluate progress toward the goals of a plan. The goals of the Northwest Forest Plan are hierarchically structured, as shown in table 3-1, to flow from broad presidential and departmental direction (USFS and BLM 1994a, b), to more specific objectives for the Plan, and finally to specific monitoring questions. The hierarchical structure ensures that higher-level goals, which are properly broad and qualitative, are clearly linked to more specific questions around which a technically sound and useful monitoring program can be designed and implemented.

Among other things, a technically sound and usable regional monitoring strategy should define the questions to be addressed in rigorous quantitative terms (Green 1979; Likens 1983; Wolfe et al. 1987; Hicks and Brydges 1994; Noss and Cooperrider 1994; Kondolf 1995; Larsen et al. 1995). Such a definition must also consider the following:

- The population to be monitored (e.g., operational definitions of intermittent streams or old-growth forests).
- The feature of that population to be measured (e.g., temperature, or dissolved oxygen in a stream, temporal connectivity between watersheds, and snag density or connectivity of old-growth forests).
- The temporal and spatial characteristics of the members of the populations, including their distribution across the region, and statistical issues, such as type I and II probabilities, (e.g., Peterman 1990), or required precision and accuracy of the results.
- Measurement methods, which must be regionally consistent so that measurements taken in different places or by different organizations can be accurately combined to describe the characteristics of the region.
- The mechanistic or conceptual linkage between the monitoring question and the broader objectives, to ensure that monitoring focuses on questions of policy and ecological relevance.

These attributes have considerable merit. However, three technical and institutional barriers make it difficult to design a monitoring program with such attributes. The first barrier is vaguely defined objectives. Often, designers of monitoring programs are faced with the task of translating broadly stated policy goals into technically sound, specific questions that monitoring can be used to answer. This is especially true for policy objectives at the national level (see levels 1–3 in table 3-1), which must be refined (but not *redefined*) in a carefully structured, open, and iterative interaction between the scientific community and other participants in the public policy process. This type of objective refinement is analogous to the problems and processes encountered in defining measurement and assessment end points in ecological risk assessment (e.g., Suter 1990; Norton et al. 1992; Risk Assessment Forum 1996).

An example of an appropriate quantitative question is that posed in table 3-1, level 5. Although this particular example provides a technically sound foundation for a monitoring design, the information may not necessarily be useful for management or for tracking elements of an objective. Moreover, a tentative quantitative question may not be logistically parsimonious or consistent with the current state of scientific understanding.

Exacerbating the issue of refining higher-level goals into appropriately specific monitoring questions and then implementing a monitoring program incorporating such questions is the fact that management priorities are not necessarily apparent or well articulated at the outset of the design of a regional monitoring strategy. Priorities are also likely to change over time and they often differ from institution to institution. In addition, management actions or ecological consequences related to one set of questions may overlap with another, requiring that additional effort be made to identify and resolve duplicated information. Underlying our proposal for adaptive monitoring design is the notion that as data sets and their analyses and the costs of their acquisition are made available, and as managers engage in the implementation of the Northwest Forest Plan, more tangible foundations for setting priorities will emerge.

A second barrier to designing a monitoring program that has all the desirable attributes at the outset is nonexistent, inconsistent, or changing methodology. Methods may not be available to measure some important characteristics, or one organization may measure or classify a feature differently than others. Three examples illustrate this problem.

- *Nonexistent Methods.* Riparian forests have considerable ecological importance within this region (e.g., Gregory et al. 1991) and are directly referenced in four of the nine ACS objectives (table 3-2A). Despite their significance, there is not an operational method to characterize these systems consistently throughout the region (Mulder et al. 1995; Smith et al. 1997).

- *Inconsistent Methods.* The inability to combine data from different areas within the region or to compare results from one time period with those from another is a major barrier to meaningfully describe the status and trends of the region. Figure 3-2 illustrates differences in classification schemes for tree size used by terrestrial, riparian, and aquatic resource managers within the region. When regional analyses were developed, they could not take advantage of the finer (and ecologically useful) detail of classification in the larger size classes of Forest Service data sets because the Bureau of Land Management data did not contain those classes. Similarly, because the terrestrial and aquatic classification schemes do not match, linkages between these two components are not as rigorous as would be possible with an integrated classification scheme. This figure illustrates two issues affecting the development of a regional monitoring scheme—loss of information relevant to management associated with merging differing classification schemes, and the need for broad interdisciplinary consideration in developing measurement protocols. For example, the process leading up to the development of the Northwest Forest Plan included a need to analyze vegetation patterns and amounts across the entire range of northern spotted owl. Combining data from categories led to an overly simplified set, resulting in a great loss of information. This problem occurs when one is combining data across ownerships to assess a landscape, such as was described above for the range of the northern spotted owl. It also occurs when one is combining historical records for one place. Take, for example, the case where one finds that the break between two categories is discovered to actually be 50 centimeters instead of 43 centimeters. Without continuous data, the historical record cannot be used to show trends in this size distinction. Second, this figure illustrates the need for broad interdisciplinary consideration in the collection of data. If we wish to relate this year's riparian areas to the coarse woody debris in streams in the future, our classification schemes should be compatible.
- *Changing Methods.* Translating the objectives of the Plan into measurable indicators requires ecological understanding, which may take time to evolve. For example, terrestrial objective 8, listed in table 3-2B, includes providing for "important ecological functions such as dispersal of organisms." Schumaker (1996) showed that nine common indices of habitat pattern did not correlate with mechanistic predictions of dispersal success. He identified a new pattern index, patch cohesion, which provided a better match to this process. Thus, the set of indicators useful for evaluating an objective may change over time as our understanding and capabilities change, even if the policy objectives remain constant.

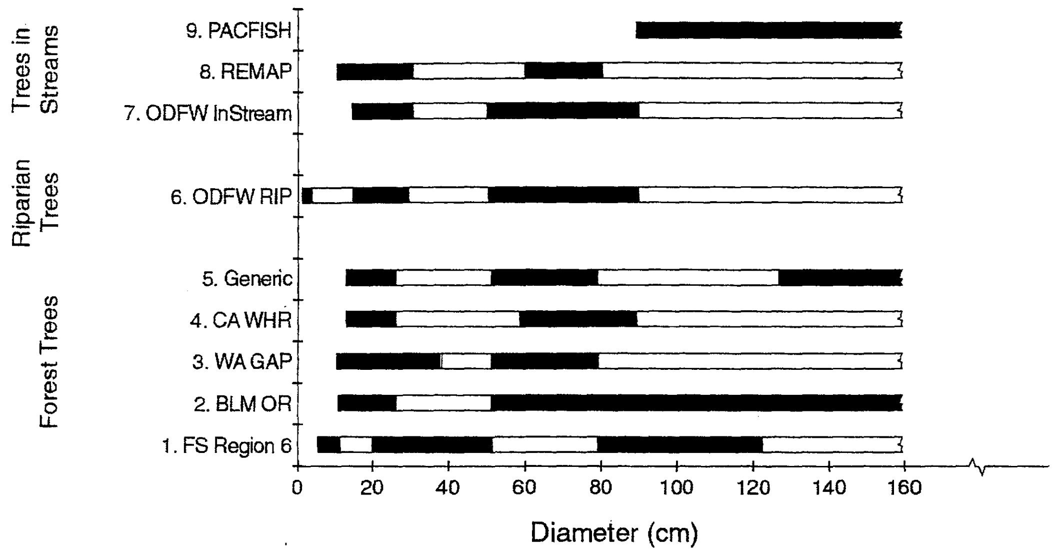

Figure 3-2. Tree classification schemes used by different organizations in the Pacific Northwest. This figure summarizes the classification schemes used to classify tree diameter by several organizations responsible for conducting surveys or inventories of resources in the region. Classification schemes 1 through 5 are for trees in forests; classification scheme 6 is for trees in a forested riparian setting; classification schemes 7 through 9 are for woody debris in streams. Forests of different size classes create habitat for different species, wood in streams forms important habitat for fishes, and wood of different sizes functions and persists differently in streams. Information for schemes 1 through 5 is from John Tepley (personal communication to Tim Tolle); information for schemes 6 and 7 is from the Oregon Department of Forestry 1994; information for scheme 8 is from Hayslip et al. 1994; and information for scheme 9 is from Haughen 1994. In all cases, the upper size class is an open-ended one; the upper limit of 200 centimeters and greater is shown here with an upper limit of 200 centimeters to allow easier graphical comparisons between classification schemes.

The third barrier in monitoring program design is a lack of information needed to estimate the variability of environmental features and measurement error over the relevant temporal and spatial scales. These estimates of variance are necessary if we are to plan the level of effort appropriate for monitoring systems to meet users' quantitative requirement for status and trend information (McRoberts et al. 1994; Larsen et al. 1995; Stapanian et al. 1997).

Exacerbating each of these three barriers is the historic reliance upon the twenty-six federal planning units within the region (fig. 3-1) to individually identify, develop, assess, and manage information.

Recognizing the pervasive nature of the foregoing obstacles, we propose an adaptive approach to monitoring design. This approach iteratively refines the monitoring design as the barriers are reduced or addressed as a result of experience in implementing the monitoring program, assessing its results, and interacting with users. In the course of this adaptive process, monitoring should meet both user and producer needs thusly:

- *User needs* support natural resource managers, regulators, policy makers, and the public in refining the monitoring questions, revising the implementation of the plan, setting monitoring priorities, and understanding the status and trends of the resource being managed.
- *Producer needs* support monitoring system designers in revising the monitoring design by providing a tangible foundation to discussing user needs; by gaining the insights necessary to minimize the most prominent technical barriers; by enhancing the efficiency of the collection, analysis and assessment systems; and by refining the monitoring questions.

The difference between the traditional approach to monitoring design and an adaptive approach is that in the latter, barriers to monitoring design are overcome by adaptively implementing monitoring rather than waiting for new information or designing a system that does not anticipate new information. Two examples from our effort illustrate this adaptive approach. In each case, aspects of all three barriers exist.

The first example addresses "survey and manage" species, the label given to over four hundred rare species, including 338 species of nonvascular plants and four arthropod communities. More detail describing this category can be found in USFS and BLM (1994b). The Northwest Forest Plan establishes four approaches for enhancing the probability of the continued viability of these species. The first approach is to manage sites where each species is known to occur; the second, third, and fourth require the collection of new information on the locations and viability of these populations. However, the distribution, abundance, life histories, and habitats of many of these rare species are poorly understood; in some cases, organisms are available for identification only for short fractions of years. In general, there is a gap between the need for information and the ability of methodologies to provide this information efficiently. In traditional monitoring design, two courses of action could be followed (depicted by "yes" and "no" choices from box 2 in fig. 3-3). First, following the "no" course, we could defer monitoring until distribution and habitat requirements were known and proven protocols existed for identifying each species; following the "yes" course, we could assume that our current knowledge is sufficient for making viability assessments and conduct no additional monitoring. In the first instance, the "no" pathway, the development of any spatially consistent, albeit imperfect, baseline information would be deferred until some future time when methods were perfected. In the second instance, imperfect monitoring would be implemented without recognizing improvements in knowledge that would be derived over time.

We propose a third course in which field sampling efforts would be deployed in an adaptive approach (the provisional paths from box 2 of fig. 3-3). This approach refines habitat-species models (e.g., Scott et al. 1993; White et al. 1997) and thereby the habitat characterization, monitoring, and management efforts as more information becomes available. A key feature of this approach is that it integrates communication, or feedback, between information producers and users, improving knowledge of habitat-species relationships and supporting management decision making; improvements to methodologies halt when the marginal return no longer improves decision making.

A second example of adaptive monitoring design relates to the implementation of a monitoring program to characterize the status of streams throughout a region or a province using site scale indicators of instream condition (see ACS objectives 3–9 in table 3-2A). Numerous protocols could be used to describe the status of the streams in this region (e.g., MacDonald et al. 1991; USFS 1993; Haughen 1994; Hayslip et al. 1994; Oregon Department of Fish and Wildlife 1994). Despite the availability of these protocols, we lack (1) understanding or agreement to determine which, if any, of the existing protocols is most appropriate for use; (2) quantification of the existing qualitative site-level monitoring objectives (i.e., producing a set of monitoring questions of the detail shown in the level 5 of table 3-1); (3) understanding of the existing temporal and spatial characteristics of the population of interest; and (4) understanding of the logistics involved in implementing a regional monitoring strategy. Traditional options are to await the outcome of research to resolve these barriers, to deploy a new monitoring program requiring extensive change in existing programs, or to utilize existing programs designed for disparate purposes as the regional program.

We propose an alternative in the form of an adaptive approach. To respond to these barriers, we recommended a series of modest efforts starting with a comparison of feasible protocols in a subcomponent of the region, for example, within one of the twelve provinces comprising the region. This effort would help to refine our collective understanding of the technical and institutional barriers involved in designing and implementing a regional monitoring program. It would also enable us to work with land managers and others to address necessary quantifications of the existing objectives. This understanding would lead to agreement on an approach for conducting monitoring throughout the region. The

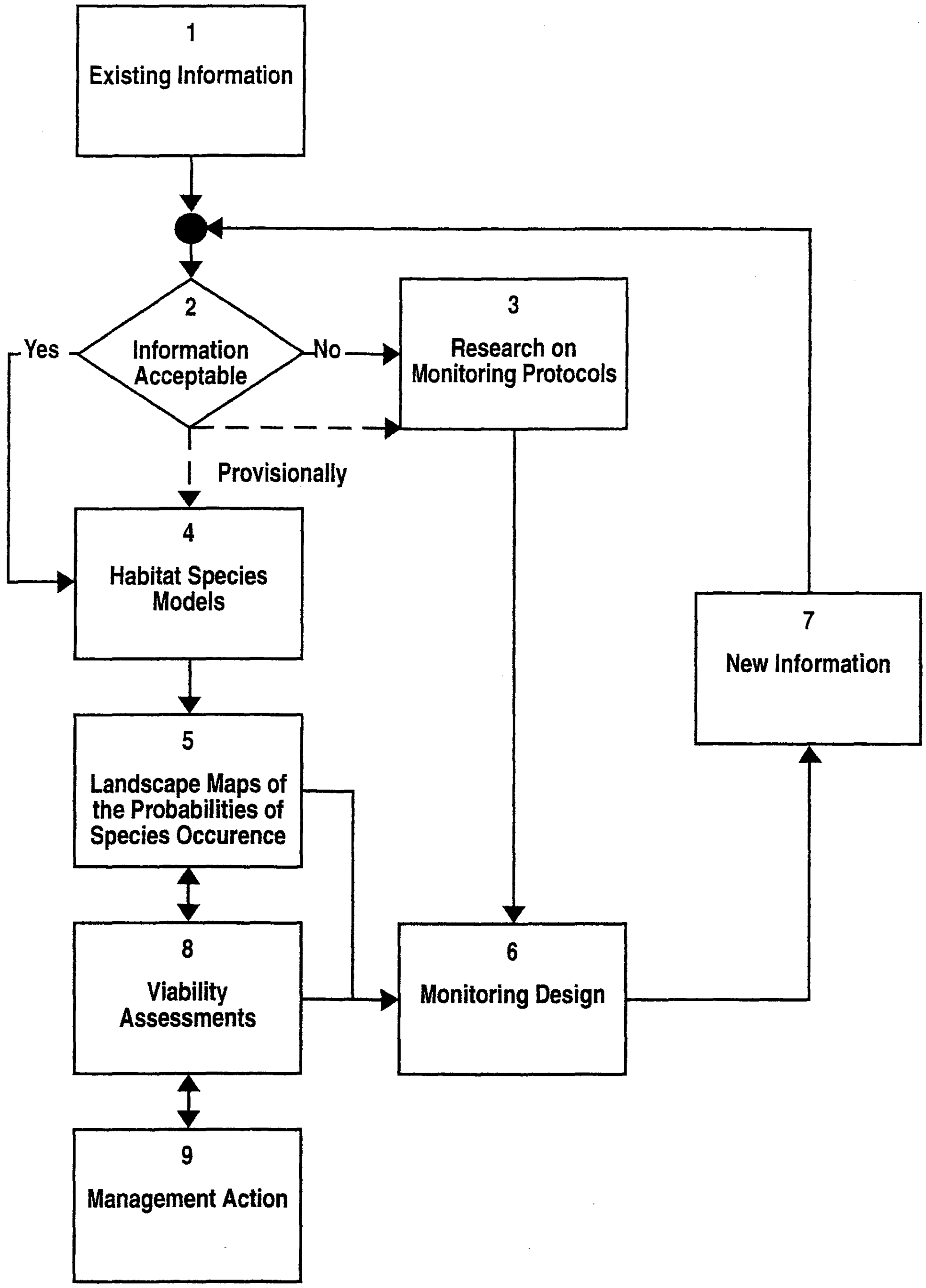

Figure 3-3. Adaptive monitoring design for survey and manage species. An adaptive design provides a mechanism to address multiple resource issues in a cost-effective way. It does this by institutionalizing an iterative feedback loop so that information is used more effectively. One way in which adaptive monitoring design differs from traditional design is by allowing for models or assessments to be provisionally acceptable. In these cases, available information is considered to be superior to no information at all and can be used to support management decision making *and* to assist in the design for collection of additional information. Once data and understanding are considered to be fully acceptable, research (step 3) and monitoring design (step 6) can be deleted, and the development of new information can proceed at an appropriate level of intensity.

implementation of this effort would also build on and supplement existing operational monitoring and research efforts. This adaptive approach is summarized in table 3-3.

The adaptive approach to monitoring design described in these two examples not only addresses the obstacles identified, but also increases the opportunity to link the development of scientific information with resource management needs. This linkage ensures that the design and implementation of the monitoring strategy is responsive to those needs so that institutions and personnel understand one another and work together toward common long-term objectives. Linkage to user needs is one of the ways to increase the probability of long-term support (Levitt 1986; Kotler and Andreason 1996).

An incremental approach to ecological monitoring design is not novel (e.g., Cain and Castro 1959; Gauch 1982; Strayer et al. 1986; Morrison 1994; Stevens 1994; Gunderson et al. 1995; Powell 1995; Steele 1995; Neave et al. 1996). However, the explicit inclusion of both information producers and information users in plan refinement is a new feature. An adaptive approach is also consistent with the notion of a practice-based approach to ecosystem management, as put forth by Brunner and Clark (1997), and with the iterative nature of problem definition in the context of solving complex ecological problems, noted in Clark et al. (1996).

Although an adaptive approach would appear to have many advantages, it is clear there are potential disadvantages. These include concerns that

- Initiating a program with goals that are neither fixed nor clear can easily contribute to the failure of those programs (e.g., Clark et al. 1996).
- The long-term organizational flexibility (in terms of dollars, personnel, or organizational infrastructure) that may be required under an adaptive approach to allow for change in design or reallocation of effort may not be feasible.
- The demands of an adaptive approach on personnel engaged in this type of structured learning process may be high (e.g., Simon 1977; Rosenberger and Lachin 1993) and may require more senior personnel than would a fixed-design monitoring program.
- The reduction of long-term comparability in the data may not be worth the improvements in the design and changes may present significant statistical challenges (Rosenberger and Lachin 1993; Overton and Stehman 1996).

Ecosystem management requires fundamental change (Grumbine 1994); the adaptive approach that we define appears an appropriate way to facilitate this change. Nonetheless, the articulation of these potential

Table 3-3. Example adaptive design for Aquatic Conservation Strategy (ACS) goals dependent upon site-level indicators.

Phase	*Input*	*Output*	*Result*
I. Provincial-scale demonstration and intercomparison	A. ACS objectives B. Multiple candidate protocols	Common understanding of the capabilities of protocols Information on resource status at provincial scale Information on statistical character of candidate indicators at a provincial scale Science/policy dialogue on utility of indicators	Agreement on Phase II protocols Preliminary information on plan effectiveness at a provincial sale Improved quantification of tradeoffs between certainty of answer and cost Improved understanding of how monitoring results will be used
II. Regional-scale demonstration	A. ACS Objectives with quantification from Phase I B. Existing protocols as refined in Phase I	Common understanding of the capabilities of protocols Information on resource status at regional scale Information on statistical character of candidate indicators at a regional scale Science/policy dialogue on utility of indicators	Agreement on operational protocols, the level of certainty they will provide, the associated cost, and how the information will be used
III. Operational monitoring program	A. Quantified monitoring objectives tightly tied to ACS B. Proven protocols, design and reporting methodology	Description of the status and trends in select resources over time and space with known certainty	Useable information on the effectiveness of the plan

pitfalls is an important element that needs to be considered in the development of a long-term plan for adaptive management and monitoring design.

Lesson Two: Accommodating Multiple Scales

Spatial Scale

The Northwest Forest Plan centers on objectives that are regional in extent, while the Aquatic Conservation Strategy calls for restoration and maintenance of features that range in size from small to large (see table 3-2A). The population viability of many species (including threatened and endangered species) is dependent upon the status of small and large features in the region as a whole. In contrast, traditional effectiveness monitoring designs (and the traditional scale of management) have been constructed around questions of smaller spatial extent and small features (MacDonald et al. 1991; Runyon 1995) such as: "Are state water quality standards being met where road prisms are contributing sediment to streams?" or "Are there measurable changes in channel erosion . . . not intended by fish habitat improvement activities?" (Siuslaw National Forest 1990). The Plan makes these questions of smaller extent no less important but adds foci on questions of larger extent and of larger features.

The challenge for monitoring system design arises from the fact that the design for a regional monitoring program is very different from a monitoring program for individual projects within the region or from individual standards and guidelines within a planning unit. The key difference is that the spatial design for a regional program must reflect sample surveys at some level (Stehman and Overton 1994; Stevens 1994; Landers et al. 1995; Paulsen et al. personal communication) or modeling approaches (Schreuder et al. 1993) that combine empirical models and stratification with rigorous sample survey methods. Sample survey techniques, in which members of a population are sampled on a probabilistic basis, have been used in a cost-effective manner to enumerate the characteristics of populations at a national level for four decades or more (Hansen et al. 1953). Inventory, the complete description of the resource, is too costly and not necessary; collection of data at sites selected on a nonprobabilistic basis, or chosen because of the presence of particular project or management practice, is likely to lead to biased estimates (Peterson et al. 1998; Paulsen et al. personal communication). Thus, the design of a regional strategy requires a commitment to sampling at locations selected at random, in a manner that permits description of features of the region with known confidence. Table 3-4 summarizes the differences in the design between small- and larger-scale monitoring programs.

Table 3-4. Different Scales of Monitoring.

Characteristic	*Local Monitoring*	*Regional Monitoring*
Purpose	Determine the effects of an individual project	Determine the aggregate effect of management activities on the region
Dominant user of information	Local managers and publics	Applicable to all managers and interests in the region
Limitations	Cannot extrapolate findings to other projects or to the region	Cannot describe the consequences of management at an individual site
Site selection	Project or activity of interest	Selected (on a probability basis) to be representative of the region

Along with the need to focus on the status of the region, there is also clearly a need to respond to questions of smaller spatial extent. The Plan (see especially VIII-14 [FEMAT 1993]) envisions that monitoring will provide information on the effectiveness of hundreds of management prescriptions, formally known as "standards and guidelines" (Alverts et al. 1996), applied to thousands of individual project decisions made every year. An example of such a question is, "What is the effect of this project on this stream?" (a project-scale question). Focusing a design around these individual projects and management decisions would be one way to address questions of smaller extent. Monitoring would, however, be prohibitively expensive and would not provide for inference on the status of the regional objectives. Thus, an important dilemma results from the demands imposed by the two types of questions as highlighted in table 3-4.

How do we reconcile the monitoring design needed to describe the status of the region with the monitoring design needed to describe the effects of a single specific management practice? We have proposed that a multipopulation (or sampling frame) approach be taken. One population would be sampled to describe the status of the region as a whole. The second population would comprise locations known to have been subject to particular types of management actions of interest. In both cases, the specific locations to be sampled would be selected on a probability basis. In the first case, the sample might be drawn from all of the stream reaches within the region. In the second case, the sample might be drawn from all stream reaches within the region on which a particular standard or guideline had been applied or in a location in which there was a special concern. In both populations the sample protocol at the site would be consistent, if not identical. Because monitoring the effectiveness of all the standards and guidelines of the Plan is not feasible, a very small subset would be selected to be the focus of sampling efforts in this second population. We have recommended that a subset be selected in response to the intersection between the standards or guidelines that have highest scientific uncertainty and those with greatest management interest.

Temporal Scale

Monitoring design must account for the temporal resolution (or grain) and extent of the features to be monitored. This discussion focuses only on temporal extent, not on temporal resolution. A regional design not only reflects large spatial extent, it also reflects long temporal frames. This linkage between broad spatial extent and long temporal periods is consistent with general ecological observations that system size and response time are directly related (e.g., Harris 1980; Forman and Godron 1986; Allen and Hoekstra 1992; Gunderson et al. 1995; Powell 1995). The Plan analyses reflect this; they evaluate alternatives with respect to their likelihood of providing desired habitat conditions and processes for one hundred years and longer (USFS and BLM 1994a; Thomas et al. 1993). This long temporal extent has two implications. The first is that we must design a monitoring approach to be in place for many years. This would seem a relatively straightforward technical task; however, the calls for long-term monitoring are legion, and the data sets are few, even for single sites. Thus, our technical and institutional experience in this area is limited. The second implication is that we have a need to consider past disturbances of the landscape in the design of the monitoring program. Disturbances arise from both natural sources, such as climate or fire (Agee 1991; Brubaker 1991), and anthropogenic sources such as forest harvesting, road building, or stream restoration. Characterization of the past disturbance of the landscape provides insight on the reference conditions that are to be maintained and restored in the ecological objectives of the Plan. It also offers insight into how rapidly those conditions can be achieved, and it supplies a key piece of information in the interpretation of existing patterns.

The ability to describe the history of management actions offers two advantages. First, it can reduce a source of variance in our analysis—the confounding effect that would be introduced by labeling a site undisturbed when it actually has experienced disturbance. Second, *if* space provides a reasonable surrogate for time (Pickett 1989), and *if* land cover or land-use history can be developed, this information can provide considerable insight about the current and future status of the region in a timely manner. We may be able to use this historical insight to make inferences about the consequences of current management actions that take a long time to manifest themselves. To the extent that this can be done successfully, the monitoring program can provide guidance on questions of smaller extent, such as the consequences of types of projects or particular standards or guidelines, in a relatively short period of time.

Other Key Points

The two lessons we have discussed are not the only points we identified in our efforts to develop an ecosystem monitoring strategy. The following three are no less important, but they are more closely related to the process of developing and implementing a strategy than to the resolution of techniques critical to the strategy. These issues reflect more the underlying or inherent lack of understanding or acceptance of monitoring among agencies and managers and what it take to successfully monitor, which may be the most critical barrier to overcome.

We do not claim to have fully identified and resolved the highest-priority issues. We also emphasize that these three issues are highly interdependent.

- *The need to integrate regional programs.* Regional analysis requires the integration of information from multiple sources to address management and science questions. For any particular question, information from multiple sources has to be integrated in a constructive and cost-effective manner, which requires compatibility among multiple sets of data. The significance of this issue with regard to even the simplest questions cannot be underestimated if we are to have regionally compatible and useful data sets for current and future questions. Figure 3-2 provides a simple example of the institutional and ecological barriers to integrating information from multiple sources. The diagram shows that classification schemes for characterizing tree size differ not only among foresters from different organizations, but also among foresters and aquatic ecologists. Thus, integration is a process that cuts across organizations, disciplines, and other boundaries.
- *The need to develop a regional reporting and decision-making capacity while maintaining similar capacities for smaller areas.* The Northwest Forest Plan amends rather than replaces twenty-six existing resource management plans. As a result, regional interagency data management and analysis is needed to support interagency decisions at the planning unit and at larger scales. The challenge for Plan managers is allocating personnel and resources to support regional interagency analysis when infrastructure is not well developed, even at agency and individual planning unit levels (see the twenty-six planning units within the region in fig. 3-1).

- *The need to develop incentives for individuals to work in an interagency setting.* Implementation of the Plan requires that agencies work together to develop common protocols, procedures, and data in pursuit of common regional objectives. Individuals from the agencies must therefore work together toward the common goals that their agencies have an interest in achieving. However, interagency organizations do not manage or supervise personnel. They do require individuals participating in their deliberations to balance the demands and interests of the interagency group against those of their home agency. The potential for conflict can create considerable tension. Although there is a single set of interagency goals, it is likely that there are multiple sets of differing agency goals. If not, an interagency organization would not be necessary. Thus, considerable thought needs to be given to providing incentives to individuals to pursue the goals of interagency organizations.

Conclusion

The design of a monitoring strategy in support of multiagency, multiscale ecosystem management poses unique technical and institutional challenges. Many of these were envisioned in the Northwest Forest Plan. Adaptive monitoring design helps to address these challenges and thus minimizes their potential for inhibiting the development of information in two ways. First, it promotes stronger links between management and monitoring; second, it minimizes risk at the outset of change, as in a prototyping approach proposed for ecosystem management (Brunner and Clark 1997). This linkage is important for ensuring that long-term monitoring enjoys the broad level of support and clarity of mission that will ensure it long-term financial support, technical success, and policy relevance.

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