Establishing a Regional Monitoring Strategy: The Pacific Northwest Forest Plan[1]

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ABSTRACT / This paper identifies lessons learned and issues raised during the development of an ecosystem monitoring strategy intended to support the Northwest Forest Plan. Adaptive ecosystem management, which requires monitoring as essential feedback to management, recognizes that action is necessary or appropriate, although knowledge may be imperfect. We suggest that this principle be explicitly acknowledged in the design of monitoring programs, and we coin the term *adaptive monitoring design.* Adaptive monitoring design is an iterative process that refines the specifications for monitoring over time as a result of experience in implementing a monitoring program, assessing results, and interacting with users. An adaptive design therefore facilitates ecosystem management. We also discuss lessons of temporal and spatial scales raised by the consideration of a design for ecosystem management. Three additional issues—integration of information from different sources, institutional infrastructure, and the roles of individuals working in an interagency setting—are also identified, but not developed in detail.

The growing literature on ecosystem management describes an adaptive system in which monitoring measures progress towards goals, increases our knowledge, and improves our plans (e.g., Holling 1978, Walters 1986, Duffus 1994, Everett and others 1994, Grumbine 1994, Bormann and others 1995, Gunderson and others 1995, Interagency Ecosystem Management Task Force 1995, Montgomery and others 1995, Christensen and others 1996, Yaffee and others 1996). Adaptive management acknowledges that action is necessary or appropriate, although knowledge may be imperfect (Raiffa 1968, Holling 1978, Walters 1986, Everett and others 1994, Grumbine 1994, USFS and BLM 1994b, Gunderson and others 1995). Knowledge far from perfect 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 and three general issues that arose in the early design of an ecological

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[1]The first five authors of this paper were the core members of the Monitoring Design Group established to design a strategy for implementing ecological effectiveness monitoring under the Pacific Northwest Forest Plan. Paul Ringold led the development of this paper. Barry Mulder chaired the group from January through July of 1995, Jim Alegria led the development of the late-successional old-growth design effort, Ray Czaplewski led the development of the "survey and manage" design effort, Paul Ringold led the aquatic and riparian effort, and Kelly Burnett played an integral role in the development of the ideas in this paper and in the development of the riparian and aquatic portion of the strategy.

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monitoring strategy intended to support ecosystem management under the Northwest Forest Plan. We focus on the two lessons: (1) adaptive monitoring design and (2) scale. We also briefly describe the three other issues, generally labeled as integration, infrastructure, and individuals; these management issues are of special importance in implementing a monitoring system for ecosystem management. We believe that these five points are of general interest in ecosystem management monitoring design. It is not our purpose here to describe the details of our monitoring strategy. Other documents provide this information (Mulder and others 1995, 1997, Tolle and Czaplewski 1995).

The President's Northwest Forest Plan

Enough timber for 300,000 homes was being harvested from federal lands in the northwestern United States during an average year in the 1980s (Johnson and others 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 it is 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 19 Forest Service and 7 Bureau of Land Management resource management plans for the 100,000 km^2 within the range of the northern spotted owl (Figure 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 forest 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, 1994b, Yaffee 1994, Tuchmann and others 1996).

A key feature underlying the lawsuits was the perspective that the previous scale of management planning—at the level of 19 individual Forest Service national forests and 7 individual Bureau of Land Management districts (Figure 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 forest plan specifies a broad array of regional ecological objectives (Tables 1 and 2). Key spatial reporting or evaluation scales envisioned by the plan are regional and provincial in extent (the region is divided into 12 ecophysiographic provinces). The spatial grain of the individual features described in these objectives 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, ''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, ''to maintain and enhance the physical integrity of the aquatic ecosystem, including shorelines, banks, and bottom configurations,'' is an example of an objective with inherently local focus. This does not imply that the fine-scale feature is 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 smaller and larger scales.

Of special interest is the fact that many of the forest plan objectives apply to larger features—features not necessarily observable or manageable at the level of the 26 individual planning units that comprise the region (Figure 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 of the individual agency resource plans it amends, is intended to be a century or longer.

Monitoring Design

Background

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: monitoring to determine if the objectives of the plan are being achieved. This assignment was distinct from, and bounded by, parallel assignments to other groups focusing on implementation monitoring (to determine if the steps of the plan are being implemented), validation monitoring (to determine if the assumptions underlying the plan are correct), and nonecological monitoring.

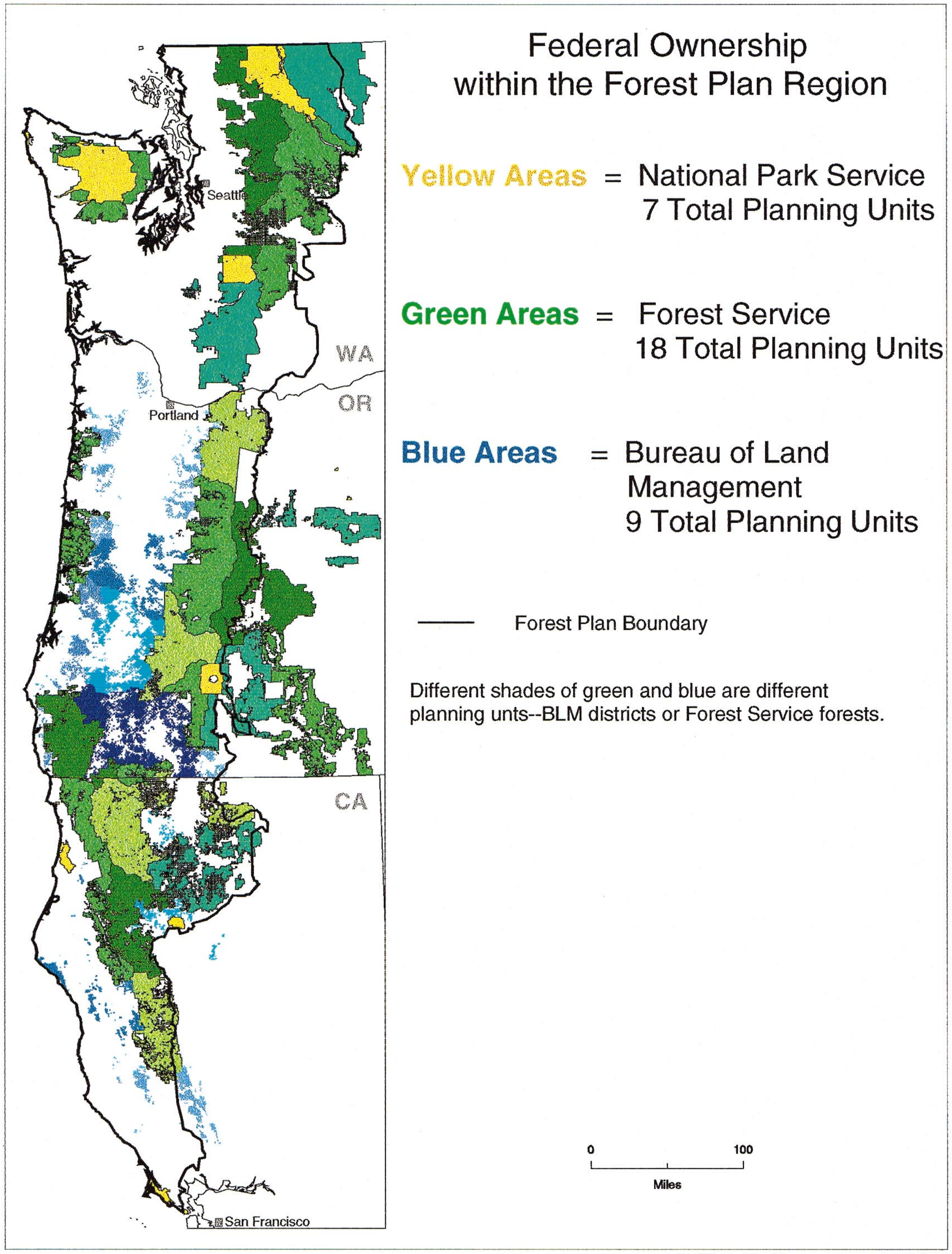

Figure 1. Map of the region.

The MDG worked collectively on a monitoring strategy that includes a general approach to ecosystem monitoring and proposals (each prepared by groups of scientists) for each of five priority elements: two threatened species, the northern spotted owl and the marbled murrelet; a large group of over 400 rare species, the "survey and manage" species; late-successional/old-growth forests; and riparian/aquatic ecosystems. The resulting strategy (Mulder and others 1995) includes the application of statistically rigorous sample surveys,

Table 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 maintans 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% accuracy) of perennial fish-bearing streams within each province and the region contain water whose temperature does not fall above 18°C and below 4 mg/liter dissolved oxygen for more than 1 h during course of the year?"

modeling, GIS analyses, remote sensing, and synthesis to address the effectiveness monitoring needs of the forest plan. The report also discusses: (1) integrating monitoring requirements for 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 produced a strategy, but also revealed two important lessons. First, we learned to view monitoring design as an adaptive process (Ringold and others 1996). The need for an adaptive process reflects a great number of uncertainties and unknowns in meeting the rigorous standards that define good monitoring practice. This proposal is consistent with notions of introducing new approaches in 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 1: Monitoring Design as an Adaptive Process

An effectiveness monitoring strategy provides the data that allow us to evaluate progress toward the goals of a plan. The goals of the forest plan are hierarchically structured, flowing from broad presidential and departmental direction (USFS and BLM 1994b), through more specific objectives for the plan, to specific monitoring questions (Table 1). The hierarchical structure ensures that high-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 its many attributes, a technically sound and usable regional monitoring strategy should have defined the questions to be addressed in rigorous quantitative terms (Green 1979, Likens 1983, Wolfe and others 1987, Hicks and Brydges 1994, Noss and Cooperrider 1994, Kondolf 1995, Larsen and others 1995). This definition includes consideration of:

1. The population to be monitored (e.g., operational definitions of intermittent streams or old growth forests).
2. The feature of that population to be measured (e.g., temperature or dissolved oxygen in a stream, temporal connectivity between watersheds, snag density or connectivity of old growth forests).
3. 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.
4. Regionally consistent measurement methods, so that measurements taken in different places or by different organizations can be combined to describe the characteristics of the region.
5. The mechanistic and conceptual linkage from the monitoring question to the broader objectives as an

Table 2. Forest plan aquatic conservation strategy (ACS) objectives[a]

	Size of indicator		
Objective	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.		X	X
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.		X	X
3. Maintain and restore the physical integrity of the aquatic system, including shorelines, banks, and bottom configurations.	X		
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.	X	X	X
5. Maintain and restore the sediment regimen under which aquatic ecosystems evolved. Elements of the sediment regime include the timing, volume, rate, and character of sediment input, storage, and transport.	X	X	
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.	X	X	
7. Maintain and restore the timing, variability, and duration of floodplain inundation and water table elevation in meadows and wetlands.	X	X	
8. Maintain and restore the species composition and structural diversity of plan 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.	X	X	
9. Maintian and restore habitat to support well-distributed populations of native plant, invertebrate, and vertebrate riparian-dependent species.	X	X	X

[a]The nine objectives are taken from USFS and BLM 1994b.

initial way to ensure that the monitoring focuses on questions of policy and ecological relevance.

These five attributes of a monitoring design have considerable merit. However, several major barriers of a technical and institutional nature limit our ability to design a program that has these attributes at the outset. As a result, if we require monitoring designs to meet these standards unequivocally, we might never initiate effectiveness monitoring.

In general, we have identified three types of barriers. The first is vague objectives. Considerable refinement (not redefinition) of the existing qualitative objectives must take place. Table 1 provides an example of this type of refinement. The three high-level objectives listed in this table reflect national policy. Refining them to result in a monitoring question (such as in level 5 of Table 1) is one of the fundamental responsibilities of monitoring design. Since such refinement reflects a translation of policy goals into technically sound questions, our view is that it requires a carefully structured, probably open and iterative, interaction between the scientific community and the public policy process. This type of 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 and others 1992, Risk Assessment Forum 1996).

An example of a quantitative question that could serve as an element in the design of a monitoring strategy is given as the fifth-level question in Table 1. Although this particular formulation may provide a technically sound foundation for a monitoring design, it may not provide the most useful information for management or for tracking elements of the objective that it falls under. Moreover, a tentative quantitative question may not be logistically parsimonious, or it may not be the formulation that is most consistent with the current state of understanding of ecosystems.

Exacerbating the issue of refining the higher level goals into specific monitoring questions and then imple-

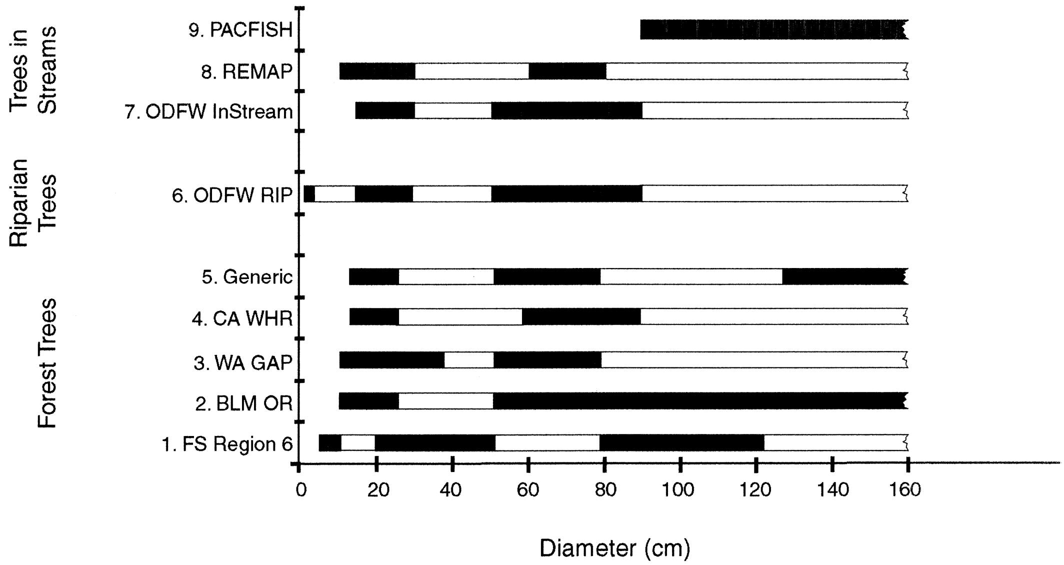

Figure 2. Tree classification schemes used by different organizations in the Pacific Northwest. Categories 1 through 5 are from John Tepley (personal communication to Tim Tolle). Categories 6 and 7 are from Oregon Department of Fish and Wildlife (1994). Category 8 is from Hayslip and others (1994) and 9 is from Haughen (1994). In all cases the upper size limit is open ended.

menting a monitoring program around that set of questions is 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 differ from institution to institution. In addition, the management actions or ecological consequences related to one set of questions may overlap with another set of questions in a manner that requires some consideration before this duplication of information can be identified and resolved. 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 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 inconsistent, changing, or nonexistent methods. 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 and others 1991) and are directly referenced in four of the nine ACS objectives (Table 2). Despite their significance, there is no operational method to characterize these systems on a consistent basis throughout the region (Mulder and others 1995, Smith and others 1997).

Inconsistent methods. The inability to combine data from different parts of the region or to compare results from one time period with those from one time period with those from another is a major barrier to a meaningful description of the status and trends of the region. Figure 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 the Forest Service datasets 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.

Changing methods. Translating the objectives of the plan into measurable indicators requires ecological understanding, which may evolve. For example, terrestrial objective 8 includes providing for "important ecological functions such as dispersal of organisms." Schumaker (1996) showed that nine common indices of habitat pattern did not correlate well 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.

The third barrier in monitoring program design is 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 requirements for status and trend information (McRoberts and others 1994, Larsen and others 1995, Stapanian and others 1997).

Exacerbating each of these three barriers is the historic reliance upon the 26 federal planning units within the region (Figure 1) to individually identify, develop, assess, and manage information.

Proposed solution. 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:

1. 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.
2. Producer needs: support monitoring system designers in revising the monitoring design by providing a tangible foundation for discussing user needs; gaining the insights necessary to minimize the most prominent technical barriers; enhancing the efficiency of the collection, analysis, and assessment systems; and refining the monitoring questions.

The difference between the traditional approach to monitoring design and an adaptive approach is that in the adaptive approach we overcome barriers to monitoring design 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 400 rare species, including 338 species of nonvascular plants and four arthropod communities. More detail describing this category can be found on page C-49 ff. in USFS and BLM (1994b). The 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 Figure 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 current knowledge was 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 Figure 3). This approach refines habitat–species models (e.g., Scott and others 1993, White and others 1997) and thereby refines 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 so that efforts improve knowledge of habitat–species relationships and support management decision making, and 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 2). Numerous protocols could be used to describe the status of the streams in this region (e.g., MacDonald and others 1991, USFS Region 6 1993, Haughen 1994, Hayslip and others 1994, Oregon Department of Fish and Wildlife 1994). Despite the availability of these protocols, we lack: (1) understanding or agreement to

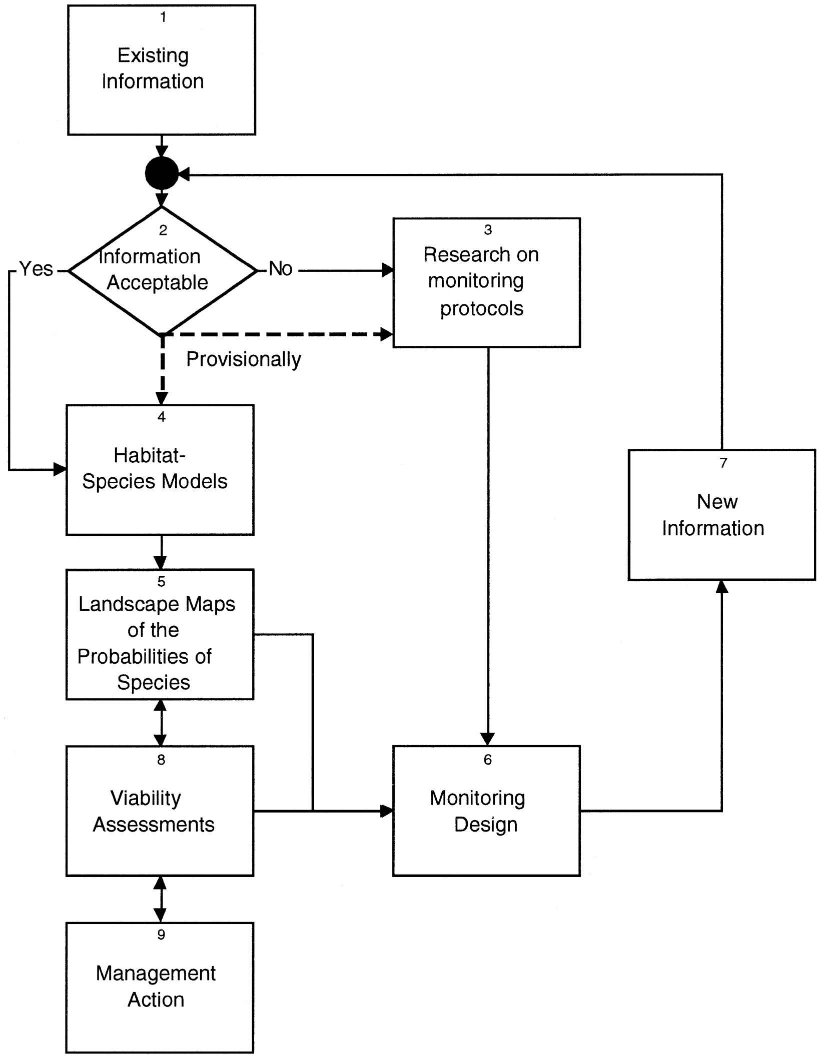

Figure 3. Adaptive monitoring design for "survey and manage" species.

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 fifth level of Table 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 the barriers, we recommend a series of modest efforts starting with an intercomparison of feasible protocols in a subcomponent of the region, for example, within one of the 12 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 implementation of this effort would also build on and supplement existing operational monitoring and research efforts. This adaptive approach is summarized in Table 3.

The adaptive approach to monitoring design described in these two examples not only addresses the obstacles identified, it 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

Table 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 scale Improved quantification of trade-offs 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 the ACS B. Proven protocols, design and reporting methodology	Description of the status and trends in select resources over time and space with known certainty	Usable information on the effectiveness of the plan

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 way 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 and others 1986, Morrison 1994, Stevens 1994, Gunderson and others 1995, Powell 1995, Steele 1995, Neave and others 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 and others (1996).

Although an adaptive approach would appear to have many advantages, it is clear there are also 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 and others 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 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 2: Need to Accommodate Multiple Spatial and Temporal Scales

Spatial scales. The forest plan centers on objectives that are regional in extent, while the features to be maintained range in size from small to very large (Table 2). 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 smaller features (MacDonald and others 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 forest 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 a region or for 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 and others 1998, Paulsen and others personal communication) or modeling approaches (Schreuder and others 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 and others 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 a particular project or management practice, is likely to lead to biased estimates (Peterson and others 1998, Paulsen and others 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 4 summarizes the differences in the design between small- and large-scale monitoring programs.

Table 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 forest plan [see especially VIII-14 (USDA and others 1993)] envisons that monitoring will provide information on the effectiveness of hundreds of management prescriptions, formally known as ''standards and guidelines'' (Alverts and others 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 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 multi-population (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 probabilistic basis. In the first case, the sample might be drawn from all 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 where there was a special concern. In both populations, the sampling 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 scales. 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 and others 1995, Powell 1995). The forest plan analyses reflect this; they evaluate alternatives with respect to their likelihood of providing desired habitat conditions and processes for 100 years and longer (USFS and BLM 1994a, Thomas and others 1993). This long temporal extent has two implications. First, we need to design a monitoring approach that will be in place for many years. This would seem to be a relatively straightforward technical task, but 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 of the long temporal character of this system is that we have a need to consider past disturbances of the landscape in the design of the monitoring program. Past 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 features 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 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 had experienced disturbance. Second, *if* space provides a reasonable surrogate for time (Pickett 1989), and *if* land-cover/land-use history can be developed, this information can provide considerable insight about the current and future status of the region in a more 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 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 takes 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 the 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 2 provides a simple example of the institutional and ecological barriers that exist in integrating information from multiple sources. That 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 forest plan amends rather than replaces 26 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 forest plan managers is allocating personnel and resources to support regional interagency analysis when such support infrastructure is not well developed even at agency and individual planning unit levels (see the 26 planning units within the region in Figure 1).

The need to develop incentives for individuals to work in an interagency setting. Implementation of the forest plan requires agencies to work together to develop common protocols, procedures, and data in pursuit of common regional objectives as specified in the plan. Individuals from those agencies therefore must work together towards the common goals of their agencies. 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 also multiple sets of agency goals that differ. 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 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 long-term financial support, technical success, and policy relevance.

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