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ADAPTIVE MONITORING DESIGN FOR ECOSYSTEM MANAGEMENT[1,2]

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Adaptive management of ecosystems (e.g., Holling 1978, Walters 1986, Everett et al. 1994, Grumbine 1994, Yaffee 1994, Gunderson et al. 1995, Frentz et al. 1995, Montgomery et al. 1995) structures a system in which monitoring iteratively improves the knowledge base and helps refine management plans. This adaptive approach acknowledges that action is necessary or appropriate with imperfect knowledge (Raiffa 1968, Walters 1986, Everett et al. 1994, USDA/FS and DOI/BLM 1994*b*) and that initial actions can be refined as more information becomes available. Imperfect knowledge is the case in ecosystem management particularly when the plan includes the management of complex ecological patterns and processes over large areas and long periods of time. In such cases, we suggest that an adaptive approach should apply not only to the management of the ecosystem, but also to the design of the monitoring program.

As the core members of an interagency Monitoring Design Group (MDG), we developed a monitoring strategy for the Northwest Forest Plan. The Northwest Forest Plan (Dwyer 1994, Society of American Foresters 1994, Tokar 1994, USDA/FS and DOI/BLM 1994*a*, *b*, Yaffee 1994) is an adaptive ecosystem management plan mandated by the President. This regional plan amends 26 local Forest Service and Bureau of Land Management plans. It applies to all 10 million hectares of Federally administered lands west of the Cascades in the Pacific Northwest. It prescribes an interagency implementation effort tied to broad ecological goals (see the goals in Appendix A in Mulder et al. 1995, and pages B1–11 in USDA/FS and DOI/BLM 1994*b*).

Our work (Mulder et al. 1995, Tolle and Czaplewski 1995) suggests that it would be appropriate to consider the monitoring plan itself as an adaptive plan. We propose that this concept be embodied in the term "adaptive monitoring design." While an incremental approach to monitoring design is not novel (e.g., Cain and Castro 1959, Gauch 1982, Strayer et al. 1986, Morrison 1994, Stevens 1994, Powell 1995, Powell and Steele 1995, Steele 1995), the approach that we offer incorporates new features to meet the needs of a new application. The new features include the iterative links

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[2] For reprints of this Forum, see footnote 1, page 692.
[3] The first five authors of this paper are the core members of the Monitoring Design Group established to design a monitoring strategy to implement ecological effectiveness monitoring under the Pacific Northwest Forest Plan. P. L. Ringold led the development of this paper. B. Mulder chaired the group from January through July 1995.
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between the presentation of information, its consideration from both a users' and a developers' perspective, and then the consideration of a refined monitoring design.

Monitoring Design as an Adaptive Process

A technically sound and usable regional monitoring strategy must have several characteristics. First, it must 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). This includes specifying the exact characteristics to be monitored (e.g., addressing questions such as, "What constitutes an intermittent stream or an old-growth forest?), the temporal and spatial characteristics of interest, and statistical issues such as Type I and II probabilities (e.g., Peterman 1990). Second, this design must account for issues of ecological and policy significance in addition to issues of statistical significance; third, it must be regionally and temporally consistent; and fourth, it must be clearly linked to specific ecosystem management needs.

Several major technical and institutional obstacles limit our ability to design and implement a monitoring program that has these characteristics:

1) Qualitative objectives. Considerable refinement (albeit within the original scope) of the existing qualitative objectives, and the specification of indicators tied to those qualitative objectives, must take place. Since these objectives reflect the outcome of policy deliberations (at the national level in the case of the Northwest Forest Plan), their refinement requires a carefully structured interaction between the scientific community and the public policy process,
2) Inconsistent, unharmonized or unavailable methods. This is not only an issue for sampling protocols, but also for other issues. We have found, for example, that attempts to use analyses based on classified rather then continuous data present significant problems. These problems reflect changes in scientific understanding or policy needs, which dictate(d) particular classifications.
3) Lack of information to estimate the characteristics of environmental features over the relevant time and space scales.
4) Limited insight on priorities. Our experience has been that priorities will not be apparent or well articulated at the outset of the design of a regional monitoring strategy, and are likely to change over time. As data sets, their analyses, and costs become available, objective foundations for setting priorities will emerge.

In recognition of these technical and organizational requirements and obstacles, we propose an adaptive approach to monitoring design. Adaptive monitoring design incrementally refines the monitoring design until these four barriers are reduced. In the course of this adaptive process, monitoring must:

1) Support natural resource managers and the public in refining the regional objectives, in revising the implementation of the Plan, in setting monitoring priorities, and most importantly in understanding the status of the resource being managed.
2) Support monitoring system designers in revising the monitoring design.

Specific examples of how an adaptive monitoring design might be implemented are provided in Mulder et al. (1995). In the case of stream monitoring the proposal would initiate monitoring as a provincial (the Northwest Forest Plan region contains 10 provinces) methods intercomparison and progressing to a fully implemented regional monitoring program. In the case of the >400 species of plants and animals whose future is not certain under the plan (the Survey and Manage species), it takes the form of the iterative improvement of a series of habitat-species models and field surveys.

While an adaptive approach to monitoring design has significant advantages, it has its own potential problems. The potential difficulties with an adaptive approach include the potential for a lack of long-term consistency especially during the most adaptive phases of the design, and the demands imposed on the time of senior science and policy personnel for a high level of continuing analysis and interaction.

An adaptive approach to monitoring design can strengthen the institutional ties that are essential for successful ecosystem management. Strong ties are important not only for ensuring that long-term monitoring enjoys the broad level of support and clarity of mission that will ensure its long-term financial support, but also for technical success. This level and type of interaction are essential for the success of the monitoring plan, and for the success of adaptive management as a whole.

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