2577

Complementary Roles of Research and Monitoring: Lessons From the U.S. LTER Program and Tierra Del Fuego[1]

Jerry F. Franklin[2]
Mark E. Harmon[3]
Frederick J. Swanson[4]

Abstract—Although monitoring and research often are considered distinct, they are actually closely related activities which should be tightly linked. Development and operation of meaningful monitoring programs depends upon research and scientific expertise at all stages. First, design of monitoring programs always requires scientific knowledge, and often supportive research to inform the selection of parameters and sampling design—including how, where, and when to sample. The highly idiosyncratic nature of project-based monitoring programs makes involvement of scientific experts particularly critical at the design stage. Second, scientific expertise is important in QA/QC. Third, research (often) and scientific expertise (always) are needed to interpret the results of monitoring programs—i.e., the ecological significance of a statistical change in an ecological parameter. The immense challenge of interpreting the significance of changes in ecological parameters rarely has been considered. Fourth, some types of monitoring only can be accomplished by an intensive research-quality effort indistinguishable from traditional research. For example, accurate assessments of long-term nutrient balances and soil productivity, a goal often identified in monitoring protocols (e.g., in the Santiago Accord), requires complex field and analytic capabilities.

Monitoring also can make major contributions to ecological research programs by producing research-quality data that can be used directly by scientists in their investigations. For example, repeated measures of ecosystem processes can yield new insights into factors and events that control ecosystem behavior. Monitoring also can highlight important phenomena or spatial or temporal patterns that need scientific attention, thereby defining priority research agendas. Examples in the following text are drawn from the H. J. Andrews Experimental Forest and Long-Term Ecological Research (LTER) site and a sustainable forestry project in Tierra del Fuego.

Resumen—Aunque el monitoreo y la investigación a menudo se consideran como actividades diferentes, nosotros las encontramos estrechamente relacionada, las cuales trabajan mejor cuando están ligadas. El desarrollo y conducta de los principlaes programas operativos del monitoreo son particularmente dependientes de la investigación y la especialización científica. Primero, el diseño de programas de monitoreo requiere del conocimiento científico y de investigación; problemas críticos que requieren esta entrada incluyen selección de parámetros y diseños de muestreo, incluyendo cómo, donde y cuándo muestrear segundo, científicos expertos son importantes en qa/qc. Tercero, la investigación (a menudo) y los científicos expertos (siempre) son necesarios para interpretar los resultados de programas de monitoreo; ej., La interpretación del significado ecológico de un cambio estadístico en algún parámetro. Algunos tipos de monitoreo sólo pueden ser logrados por un esfuerzo intensivo de la investigación de calidad.

Por ejemplo, la evaluación del balance de nutrientes asociados con la productividad de la tierra a largo plazo, una meta típica de los protocolos del monitoreo, únicamente puede ser realizada utilizando capacidades complejas de campo. El monitoreo también pueden hacer contribuciones mayores a los programas de la investigación ecológica; mucha investigación es, de hecho, indistinguible del monitoreo en que aquella involucra a menudo medidas cuidadosas y repetidas de organismos, procesos, o estructuras. La mayoría del monitoreo debería estar produciendo información de calidad que pueda ser usada por los científicos en sus investigaciones. Por ejemplo, medidas repetidas de procesos del ecosistema pueden producir nuevas señales en los factores y eventos que controlan el comportamiento de los ecosistemas. El monitoreo también puede resaltar fenómenos importantes de los patrones espaciales y Temporales que necesitan atención científica, ayudando a definir prioridades de investigación. Nosotros usaremos nuestras experiencias del sitio experimental de investigación ecológica a largo plazo (lter) h. J. Andrews y de un proyecto forestal sustentable en tierra del fuego para ilustrar estos conceptos.

Environmental and natural resource monitoring programs are expanding rapidly throughout the world, driven in part by the need for continuing assessments of conditions and trends in environmental and biotic variables at regional, national, and global scales. Moreover, managers and policy makers increasingly desire (and often are required legally) to quantitatively assess the effectiveness and impacts of natural resource management plans and activities. The test of sustainability hinges on monitoring the effects of selected practices; high-quality monitoring programs can provide early-warning signs of unsustainable practices. The current concepts of ecosystem and adaptive management incorporate monitoring as an essential component. Hence, major expansions in the scale, complexity, and investment in monitoring are certain, and the data generated are going to be of increasing importance.

Traditionally monitoring has been viewed as a management or regulatory activity unrelated to scientific research.

---

[1]Paper presented at the North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources, Guadalajara, Mexico, November 1-6, 1998.

[2]Jerry F. Franklin is Professor of Ecosystem Analysis at the University of Washington Box 352100, Seattle, Washington 98195-2100 USA. e-mail: jff@u.washington.edu

[3]Mark E. Harmon is Associate Research Professor in the Department of Forest Science at Oregon State University located in Corvallis, Oregon, USA.

[4]Frederick J. Swanson is Principal Research Geologist, USDA Forest Service, Pacific Northwest Research Station, located at the Forestry Sciences Laboratory in Corvallis, Oregon, USA.

Scientists often go to great pains to distance themselves and their activities from monitoring which they typically define as the routine collection of data for nonscientific purposes. Similarly many resource managers do not consider science or scientists to be essential participants in development and operation of their monitoring programs.

To the contrary, we assert that development, operation, and interpretation of credible natural resource monitoring programs only can be achieved with extensive scientific involvement. Results of scientific research and scientific expertise are needed in at least four major aspects of monitoring: (1) Design of monitoring programs, including the selection of parameters and development of the sampling design—where, when and how to sample as well as details of the statistical design; (2) quality control; (3) interpretation of results; and (4) periodic assessments of the effectiveness of the monitoring program ("adaptive management"). In addition, some monitoring objectives only can be achieved with scientific quality research efforts; much so-called "validation monitoring" falls into this category.

In this paper, we outline some important relationships between monitoring and research based on our experiences at the H. J. Andrews Long Term Ecological Research (LTER) site and in development of a monitoring plan for a sustainable forestry project in Tierra del Fuego. Our objective is to clarify the central importance of science and scientific expertise in development and operation of environmental and natural resource monitoring programs. We note that our perspective is primarily that of scientists who have been involved with development of operational monitoring programs at local and regional levels, rather than the design of national and international assessments that are typically standardized, top-down approaches. The distinction between large-scale assessment monitoring and monitoring the effectiveness of management programs on individual properties or for individual projects is an important one. Effectiveness of monitoring at local levels involves highly individualized, as opposed to highly standardized, programs.

Study Areas

Before considering the linkages of scientific research and monitoring some background on the ecosystems and properties on which we are basing our examples may be helpful to the reader.

The H. J. Andrews Experimental Forest and LTER is located in the Cascade Range of Oregon, USA (McKee 1998, Van Cleve and Martin 1991). This mountainous site has a mesic climate with an annual precipitation of 230 cm at the headquarters site; the rugged topography is underlain by a variety of volcanic formations. The primary vegetation type is temperate coniferous forest dominated by species, such as Douglas-fir (*Pseudotsuga menziesii),* western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), and true firs (*Abies* spp.); about half is mature and old (500 years) primary forest while much of the remainder consists of young stands regenerated following timber harvest.

Research at the H. J. Andrews site began with its establishment in 1948 and includes long-term studies of hydrologic and nutrient cycling in small catchments. It was selected as a primary site for the U.S. International Biological Program's Coniferous Forest Biome project in 1968 (Edmonds 1982), and was awarded one of the first LTER grants in 1980 (Van Cleve and Martin 1991). The research program covers a broad range of topics including: structure and function of forest and associated stream ecosystems, geomorphic and other landscape-level processes, disturbance processes and ecosystem recovery, ecology of individual organisms, biodiversity, and the practical application of ecological information in resource policy development and practices.

Research findings and the expertise of the scientific cadre from the H. J. Andrews site have contributed extensively to development of ecosystem management practices for federal, state, and private forest lands within the temperate forests of northwestern North America. An outstanding example is in the development and implementation of the Northwest Forest Plan (Tuchman et al. 1996) on federal lands within the range of the northern spotted owl (*Strix occidentalis caurina*), including the development of legally-mandated monitoring programs. However, H. J. Andrews science and scientists also have been involved in developing plans for management at smaller spatial scales, such as individual national forests and portions of forests (e.g., Cissell et al. in press) as well as lands belonging to corporations and to native American tribes. This has afforded H. J. Andrews scientists much practical experience in the design and implementation of monitoring programs. Some recent activities (e.g., hydrology of experimental watersheds) also are treated as monitoring programs supplying critical data to land managers. Some monitoring programs are conducted partially as graduate student projects, thus generating research findings and educational benefits.

The Trillium Forestal sustainable forestry project (known as the Rio Condor Project) involves 235,000 ha of privately owned land in the Chilean portion of Tierra del Fuego. The mountainous landscapes involved are mosaics of forest, wetland ("turba"), steppe and alpine vegetation. The forested areas are typified best as a cold temperate regions with moderate rainfall (800 to 1000 cm) and high winds. The major tree species is lenga (*Nothofagus pumilio*) which forms pure stands over much of the region; most of these are primary forests of complex structure as a result of their age (200 years or more) and frequent creation of small gaps by high winds. Coigue (*Nothofagus betuloides*) is a significant species along the west coast and nirre (*Nothofagus antarctica*) occupies forest ecotones at timberline and with turba. Extensive baseline studies on ecological conditions and biota were conducted by the Independent Science Commission (ISC) (Arroyo et al. 1996) composed of academics nominated by the Chilean Academy of Sciences. A system of biological reserves totaling 65,000 ha (including 10,000 ha of commercial forest) was selected by the ISC and permanently reserved by Trillium Forestal as part of their management plan.

Trillium Forestal intends to manage much of the forest for timber production under the terms of a permit issued by the Chilean government following preparation and review of an Environmental Impact Statement. Included are commitments to use of native species, natural regeneration, a conservative silvicultural harvest system (shelterwood with 10% permanent reserves) and harvest schedule, and protection of sensitive areas such as riparian zones, steep slopes, and wetlands (in addition to the permanent biological reserves).

An extensive monitoring program is associated with this management program to meet the requirements and needs of several interested parties including the company, a forest certifying organization, governmental organizations, and the ISC. The National Environmental Commission of Chile (CONAMA) provided extensive direction to Trillium Forestal regarding monitoring required as a condition of the project's environmental permit; many of these requirements were derived from the principals and guidelines identified in the Santiago Declaration (The Montreal Process 1995). The monitoring plan was developed primarily by members of the ISC, particularly Chairperson Mary Kalin-Arroyo, in collaboration with the senior author (Franklin). Development of the plan was challenging because it involved several major stakeholders (government, company, academic committee and potential "green" certifier), had to address numerous governmental requirements, and needed, simultaneously, to be ecologically meaningful and practical in terms of field installation, operation and cost, all of this in a very remote region of the world.

The Role of Science in the Development of Monitoring Programs

Science and scientists can play an important roles in the design of monitoring programs, including decisions about which parameters should be monitored, methods for sampling, and sampling design (spatial and temporal pattern). These are, of course, the critical elements in any design—the what, when, where, and how of the monitoring program. The possibilities are infinite—but a strong, science-based understanding of the ecosystem is the foundation for designing an effective, efficient monitoring program.

Those who suppose that these critical issues will be resolved for them, perhaps with prescriptive guidebooks, are likely to be disappointed. Standardized monitoring programs probably will be characteristic of large-scale national and multinational programs intended to continually or periodically assess environmental conditions and trends related to development of national and global policies. However, most monitoring programs will be developed as elements of smaller-scale plans or programs to assess specific accomplishments and impacts. Examples include monitoring associated with plans for individual resource management areas (e.g., national forests, national parks, Indian reservations, and privately-owned tree farms) or for regional collections of resource management units, such as the Northwest Forest Plan for federal lands within the range of the northern spotted owl.

Our experience is that such monitoring programs are highly idiosyncratic and, therefore, not amenable to design using textbook models. While the broad categories or topical areas of monitoring may be similar in many of these programs, the appropriate selection of parameters varies widely with local circumstances (ecological and social). Similarly, appropriate answers to the questions of when, where and how will often vary among projects even when the same parameter has been selected.

Design issues are further complicated by the fact that monitoring programs are not likely to be hierarchical in structure. The notion of a neatly structured monitoring program in which sampling for various parameters is nested within a common sampling design (such as a set of forest sample plots arranged in a systematic grid) is unrealistic. In fact, operational monitoring programs are more likely to resemble "fruit salad"—they will be programs in which different parameters are monitored on contrasting temporal and spatial scales and, consequently, use different methodologies or technologies. For example, a monitoring program may incorporate a portfolio which includes population dynamics of key species, stream flow, and fire regimes.

The spatial and temporal complexity associated with different themes is illustrated by contrasts in the Rio Condor Project monitoring plan: (1) Some landscape-scale activities (e.g., miles of road, area of timber harvest) are to be monitored over the entire property at 5-year intervals using aerial photography or satellite images; (2) Riparian and stream conditions are to be monitored at 5-year intervals with ground-based, permanent sample areas placed on selected stream reaches and using a variety of sampling methodologies; and (3) Populations of high-profile (ecologically or socially sensitive) animal species, such as the red fox (*Pseudolopex culpaeus*), will be monitored over the entire property on an annual basis using techniques appropriate to the specific organisms.

Hence, challenges in design of monitoring programs include decisions about parameters (what), spatial and temporal scales of sampling for each of the parameters (where and when), issues of statistical design, and selection of sampling methods (how), such as specific instrumentation, plot design and sensors. Scientific research and expertise are key to all of these aspects of design.

Selection of Parameters

Selection of parameters is the first of the challenges. Almost any stakeholder can come up with a laundry list of "things which should be monitored." Often such lists are useful only as a starting point, and rarely reflect the realities of having to operate or finance the monitoring program!

Initially, it is important to identify which parameters are likely to be sensitive indicators of important ecological conditions—i.e., which are ecologically meaningful. There also are important practical realities. Can a candidate parameter be readily measured (or measured at all) using existing technologies? Many "parameters," which are often identified as essential parts of monitoring programs, are extremely difficult to measure and, hence impractical. For example, parameters such as annual primary productivity can be difficult to measure, whereas structural features of forest stands often are more practical to monitor. Many of the more complex parameters also may be relatively insensitive and/or slow to respond to changed environmental conditions as a result of ecosystem buffering. As a result, precise estimates of such parameters may be difficult to obtain. In addition, potential cost is an important factor—i.e., it is unrealistic to design monitoring programs that have costs which rival the value of the resource in question.

Identification of sensitive and practical (even surrogate) parameters for a monitoring program is a challenge to which science and scientists can make major contributions. Numerous examples of such contributions are found in monitoring programs developed for forest lands along the Pacific Coast of North America and in the Rio Condor monitoring proposals.

Many parameters ultimately incorporated into monitoring programs have emerged from research programs associated with the H. J. Andrews Experimental Forest and LTER program. The H. J. Andrews research program, in particular, has demonstrated the importance of coarse woody debris (CWD) in the functioning of forests and associated streams and rivers (e.g., Harmon et al. 1986, Maser et al. 1988). Coarse woody debris serves as critical habitat for many elements of biological diversity in both terrestrial and aquatic ecosystems. The link between this relatively easily measured structural element and many elements of biological diversity has made CWD an element of most monitoring programs in northwestern North America. Scientists also have contributed to the establishment of thresholds for minimum levels of CWD, and to the design of specific sampling programs such as on the Willamette National Forest, Oregon (Gregory and Ashkenar 1990).

Using gauged drainage basins (30 to 5000 ha), hydrologic research at the H. J. Andrews has provided critical information on peak streamflows associated with flood storm events. The U.S. Geological Survey has conducted basic monitoring of streamflow for many decades. Yet, these data have never been analyzed with regards to relationships among storm events, management practices, and timing and scale of peak flows. Jones and Grant (1996) developed and applied new analytical techniques to streamflow records from the gauged basins to assess the effects of land use and forest regrowth. Subsequently their conceptual framework and analytical methods provided new bases for interpreting the U.S. Geological Survey stream monitoring program, and for using it predictively.

Monitoring debris slides (small, rapid soil mass movement events) for 50 years on the H. J. Andrews has proven useful in evaluating the effects of roads, clearcuts, and plantation development on the response of forest watersheds to major floods (Swanson and Dyrness 1975). This research has been used to design monitoring programs for specific locations where slides are most likely to occur.

Similarly, the effects of clearcutting on forest fragmentation has been an important focus of landscape-level research at the H. J. Andrews. In a pioneering study, Franklin and Forman (1986) demonstrated the dramatic effects of dispersed patch clearcutting on various landscape parameters and processes. Significant thresholds in landscape indices such as connectivity and patch size, and in processes such as susceptibility to disturbances developed early in the harvest cycle (e.g., 25 to 30% of the landscape harvested) under a dispersed clearcut system. As a result of this project and subsequent landscape-level research, key landscape-level parameters were identified for monitoring programs on public forest lands throughout the United States and Canada.

Much research currently is focused on using remote sensing tools to assess forest structure over large areas. LIDAR imagery has helped assess forest canopy complexity, including its depth or number of layers and its horizontal variability. LIDAR is capable of distinguishing between structurally complex stands such as old-growth, and structurally simple stands such as plantations or young even-aged natural stands. As such LIDAR can be used to periodically assess the amount and distribution of old-growth forests.

These are just a few specific examples of ways in which research is providing the basis for selecting monitoring parameters. There are many others including the use of aquatic invertebrate communities as indicators of stream health (Hauer and Lamerti 1996).

Spatial and Temporal Aspects of Monitoring Protocols

Once a monitoring parameter has been selected, the next challenge is development of a sampling design—formalizing the answers to where, when, and how in a statistically robust design.

Developing sound estimates with sufficiently low error terms such that a statistically significant change might actually be identified raises immense questions. Spatial issues, for example, involve decisions about where the sampling will take place. Where are the sensitive locations in the landscape? This may not be as obvious as it appears. CONAMA directed Trillium Forestal to include aquatic monitoring as a part of the monitoring program for the Rio Condor Project. Initial direction called for physical, chemical, and biological monitoring at stations on the larger river systems. However, in the Rio Condor Project landscape the larger river systems largely are uncoupled from forested areas by extensive intervening areas of wetlands (turba or muskeg) or steppe or both; the wetlands strongly influence the chemical and sediment loads and hydrology of the major river systems. To further complicate the issue, most of these intervening lands have been heavily grazed by domestic livestock. Moreover, the streams and rivers have been grossly modified from natural conditions by introduced beaver (*Castor canadensis*) which are pervasive and abundant in all surface waters. Hence, monitoring on larger rivers is not likely to provide any insight into effects of forest management activities on aquatic organisms and processes. Ultimately, monitoring for aquatic ecosystems was focused upon "permanent reference reaches" located within or adjacent to forested portions of the landscape.

Temporal issues involve decisions about what sampling intervals will be used. Some monitoring is appropriate and technologically convenient to approach continuously (e.g., streamflow). Other ecosystem components are sampled most efficiently at regular intervals (e.g., forest stand development). Still others are efficiently sampled on an event basis (e.g., landslides and major river channel changes). The design of a monitoring program needs to reflect these differences—i.e., incorporate multiple temporal scales appropriate to the mix of parameters and objectives.

The *where* and *when* of a quantitative monitoring program ultimately must be formalized into a sampling design that will provide the basis for statistically valid measures of change. This can be difficult and may, in fact, be the decisive issue in choosing among proposed monitoring parameters. Hinds (1984) analyzed aspects of this issue and concluded that "...ecological processes that are most likely to respond to the stress of concern, so that relatively simple and well-defined measurements can be used..." are most appropriate.

As an example, Hinds found that needlefall is a useful indicator of stress conditions in coniferous forests of northwestern North America. He concluded that "...long-term trends in ecological structure or function are impossible to detect by the use of poorly-designed methods or intermittently-collected data...work must continue towards the development of long-term measurements that, in the manner of temperature in climatology, reflect widely useful and robust measurements." Confounding spatial changes with temporal changes also needs to carefully considered; the potential for this will vary widely with monitoring parameter and ecosystem type.

Monitoring changes in soil properties is an example of an area in which obtaining statistically credible estimates of change can be prohibitive in terms of cost. It is widely agreed that assessing changes in long-term site productivity is a critical element of resource-monitoring programs. For example, Criterion 4 of the Santiago Declaration includes as an indicator: "Area and percent of forest land with significantly diminished soil organic matter and/or changes in other soil chemical properties" (The Montreal Process 1995). Yet, to develop statistical estimates of many soil parameters with acceptable error terms can be difficult and expensive even for a single harvested area; estimating values for such parameters for large areas over several years or decades is simply impractical with traditional soil sampling methodology.

Scientific research and expertise is likely to be critical to developing statistically-valid sampling designs and, more fundamentally to determining whether such quantitative approaches are feasible for a specific parameter or set of parameters. Designing a monitoring program largely should be a scientific process comparable to development of a research project. It should include definition of objectives (which could, in fact, be done as a series of questions), selection of the critical response variables (monitoring parameters), and design of a sampling scheme (when, where, and how) which will fulfill the stated objectives. Science and scientists have major contributions to make in all stages of design—albeit the process must involve other considerations and participants.

Monitoring Using Traditional Scientific Approaches

Some important issues in monitoring do not lend themselves to routine monitoring efforts. Rather, they require efforts that essentially are equivalent to scientific research projects in design, implementation, and the direct involvement of scientific personnel. Some of the efforts described by the USDA Forest Service as "validation monitoring"—monitoring to examine the validity of basic management assumptions—fall into this category.

Accurate assessments of the direct impact of forest harvesting practices on organisms and ecological processes can be difficult or impossible using an extensive monitoring program which, by its nature, is of low intensity and has high levels of variability. Nevertheless quantitative information on the effects of forest management practices is ultimately essential to assess the long-term sustainability of a particular practice.

In the Rio Condor Project, two research projects have been identified as part of the monitoring program because of the complexity of the issues. These projects are designed to assess: (1) effects of forest harvest on biological diversity and important ecosystem processes (Harvesting and Biodiversity Study); and (2) effects of forest harvest on long-term site productivity and water quality (Site Productivity Study). These could be described as a very intensive component of the monitoring program or validation monitoring but, in fact, they are research projects. In both cases, they involve intensive integrated studies of ecosystem and organismal responses to forest harvesting with the objective of providing definitive tests of sustainability.

The objective of the Harvesting and Biodiversity Study is to assess the long-term effects of the primary Rio Condor harvest system (shelterwood with 10% permanent retention) on forest organisms and ecosystem processes. Are sensitive and important plant, animal, and fungal species maintained using this silvicultural approach? Response variables include: trees and vascular plants, cryptogams (mosses, lichens, liverworts), fungi, small mammals, birds (including owls, woodpeckers, and parrots), selected groups of invertebrates, and rates of litter decomposition. Specific foci are on: (1) persistence of species ("life-boating") and their role as inocula; and (2) re-establishment of species initially displaced by harvesting operations. The design of the study involves replicated comparisons of treated and control areas.

The Experimental Watershed Study is focused on: (1) long-term sustainability of forest productivity through a detailed study of nutrient and organic matter balances; and (2) effects of management on water quality and stream biota. As noted above, it is extremely difficult to assess long-term sustainability of a management program. Careful studies of nutrient and energy budgets are one way to provide definitive answers. Such studies are always technically challenging, particularly in Tierra del Fuego where atmospheric depositions of nutrients and moisture may be very important. Similarly, management impacts on hydrology, water quality, and aquatic organisms are most likely to be observed in areas where the forest and aquatic ecosystem are closely linked. The Experimental Watershed Study is based upon the model pioneered by Hubbard Brook LTER (Likens 1995) and will involve one or more sets of small catchments, each containing at least one treated watershed and a control.

The study of larger-scale hydrologic impacts of forest management is another example of research integral to monitoring programs and objectives. Researchers at H. J. Andrews LTER have used long-term data on stream flow to assess effects of land use, forest growth, natural disturbances, and climatic variability on streamflow. Streamflow properties of interest include peak (flood) flows, low flows, and seasonal and annual water yields. Potential cumulative effects of management practices is an important issue that has been essentially impossible to assess through traditional monitoring programs. At H. J. Andrews LTER, new analytical approaches have allowed scientists to refine analyses and conclude that there are major and persistent effects of roads and forest harvest on hydrologic regimes, including peak flood flows (Jones and Grant 1996). Very long-term and careful records (30 to 50 years) were needed to effectively address the issue of cumulative effects.

To summarize, it has been our goal in this section to make clear that some monitoring objectives can be achieved only with research-grade projects—whether they are described as scientific research or not. Such activities should be considered and supported as integral elements of monitoring programs.

It is equally true that monitoring programs can contribute very substantially to research programs—the same data may be used for very different purposes. In many cases, it is not possible to distinguish monitoring from long-term observations associated with experiments. Although some people have argued that all monitoring must be done with scientific rigor that effectively would make all monitoring data at least qualitatively suitable for scientific investigations, this is not likely to be achieved. However, the important point is that well-designed monitoring programs can be the source for many data sets critical to environmental science—data sets which could never be developed by traditional scientific institutions. It is important, therefore, that the potential scientific contribution of monitoring programs be kept in mind during their design and operation.

Both perspectives—science as a part of monitoring and monitoring as a contributor to science—have the additional benefit of encouraging active and continuing collaborations between the scientific and management communities with, in our opinion, net benefits to both.

The Role of Science in Quality Control

Scientists have major roles in assuring and assessing the quality of monitoring programs. This may take a highly technical form, such as in regularly assessing the quality of a program of water sampling and chemical analysis. Other quality control activities may involve periodic assessments of the technical competence of the personnel involved in monitoring and the degree to which sampling protocols are being observed.

Insuring high-quality data management is a frequently unrecognized part of the QA/QC program needed in monitoring. Scientists and scientific programs, such as the LTER program, have made major contributions to the conceptual and technical basis for management of large ecological data sets (Michener 1986, Stafford 1985, Stafford 1993, Stafford et al. 1984, Stafford et al. 1988). Scientific research programs have contributed to development of metadata standards, data formats, and on-line storage and retrieval systems. Increasingly sophisticated programs are being developed to screen data and identify outlier values and off-trend system behaviors which could be either errors or early warnings of environmental problems. The experience from ecological research programs can and should be widely applied in managing data from even modestly-sized monitoring programs.

An important part of operating a monitoring program and, specifically managing data will be making data available on a timely and comprehensive basis to a wide range of interested parties. Modern technology makes this possible. And modern societies are going to insist upon such access. This substantially elevates the importance of data management in monitoring, particularly in development of metadata and timely quality control on the data sets.

The Role of Science in Interpreting Results of Monitoring Programs

Interpreting the ecological significance of a change in a monitored parameter is not a trivial issue; it may be the most challenging element of an operational monitoring program. In a well-designed monitoring program, a statistically significant change may be observed—but is it ecologically significant?

One must have substantial knowledge to interpret the significance of observed changes in parameters. Results are rarely so straight-forward that critical values or thresholds can be easily identified. When changes are observed, many questions need to be answered before deciding upon a management or regulatory response. For example:

- Is the observed change (e.g., in soil pH) real or is it a sampling artifact?
- If the observed change is judged as "real", is this change permanent or temporary and, if temporary, what is the likely rate of recovery?
- What are the potential environmental consequences of a change of the magnitude observed?
- Were similar changes observed in undisturbed (control) environments or only in managed areas?

High natural levels of spatial and temporal variability are characteristic of forest and associated aquatic ecosystems, making it difficult to detect subtle changes in many physical and biological parameters. Such changes often can be identified only by collecting and analyzing data over very long periods (Likens 1983). Furthermore, many physical and biological responses to human manipulations, such as forest harvest, are temporary. Some parameters immediately begin to recover to pretreatment levels. As such, the rate of recovery may be more important than the initial change.

Assuming a real change in a parameter is detected, what are the potential consequences of that change? For example, what effect will a 2 percent reduction in soil organic matter or a 10% increase in the bulk density of soil have on long-term site productivity? Information that allows such interpretations is limited for many parameters and, even worse, often conflicting. Actual thresholds—points at which there are major changes in the relationship between the parameters and the response—may exist for some parameters but not for others. Moreover, information on such relationships rarely exists. High levels of buffering also may allow ecosystems to tolerate significant short- or mid-term shifts in individual parameters without serious long-term detriment.

Yet, another important is whether a response is due to a treatment, such as forest harvest, or whether it is part of a broader pattern of variability. For example, small mammal populations typically vary widely from year to year in response to such variables as food supply and predation.

Hence, a major shift in abundance of small mammal species on treated areas may reflect a natural cycle rather than a treatment effect. Monitoring of untreated (control) ecosystems is necessary to provide the context to distinguish treatment effects.

Such issues make involvement of science and scientists critical to interpretation of results from monitoring programs. Involvement may include new research to provide additional information, synthesis of existing information, and participation as consultant and/or on expert panel.

In addition, the above issues underscore the difficulties associated with establishment of critical thresholds as a routine part of legally mandated monitoring programs. Establishment of threshold values may be appropriate where monitoring is being approached as an auditing process to assure conformance with values specified in programmatic documents (e.g., an EIS) or government regulations. Examples might be minimum required values for tree regeneration or forest growth rates. However, an evaluative process is appropriate when monitoring is being conducted to identify patterns and rates of change (trends), and there is no established scientific basis for selection of thresholds—as in the soil examples noted above.

In the case of the Rio Condor Project, CONAMA initially identified "thresholds" for all proposed parameters. Some examples of these thresholds were: a decrease of more than 0.2 g/cm 3/year in bulk density; an annual decrease of more than 10% in organic matter content of upper 30 cm of soil; and reduction of 0.2 pH units in upper 30 cm. of soil. In fact, these thresholds were completely arbitrary with no scientific evidence that these were actually critical values. Ultimately an evaluative process was proposed and accepted as an alternative to arbitrary threshold processes. A technical working group will meet at five-year intervals to evaluate the values and trends in the monitoring data.

The Role of Science in Assessing and Modifying Monitoring Programs

The adaptive management concept needs to be applied in monitoring as well as management programs. Adaptive management assumes a continuing cycle in which new information is used as the basis for evaluating and modifying practices. Monitoring is a critical component of the adaptive management cycle; however, monitoring also needs to be adaptive.

Adaptive monitoring programs mean recognizing at the outset that such programs must evolve as we gain experience and learn more about what works. Any monitoring program should be viewed as a series of approximations which will be modified periodically as: (1) initial parameters fail to adequately fulfill our objectives or improved designs and measurement technologies for these parameters emerge; (2) new and improved parameters are identified through empirical or theoretical research or become feasible due to availability of new technologies; and (3) monitoring objectives change. Furthermore, all stakeholders need to be a part of this process.

The Trillium Forestal monitoring program recognized the adaptive nature of monitoring programs and made periodic assessment and revision part of the monitoring plan. Assessing and revising the monitoring plan was made a part of the five-year technical review of monitoring results mentioned in the preceding section.

Acknowledgments

The authors would like to acknowledge the financial support from the Long-Term Ecological Research Program, both the central office and the H. J. Andrews site, and from the Wind River Canopy Crane Ecosystem Program. In addition, the authors wish to thank Dr. Mary Kalin Arroyo for her substantial contributions to these concepts and examples as a leader in preparation of the Rio Condor Monitoring Plan as well as the contributions of other members of the Independent Science Commission (Drs. Claudio Donoso, Juan Armesto, Roberto E. Murua, Edmundo E. Pisano, Roberto P. Schlatter, and Italo A. Serey. Mr. Edmundo Fahrenkrog of Trillium Forestal also contributed significantly to the development of the Rio Condor Monitoring Plan. The authors would also like to acknowledge the importance of discussions of monitoring concepts and specific techniques with Dr. Gene E. Likens (Institute of Ecosystem Studies), Dr. James Sedell (USDA Forest Service), Dr. Stanley Gregory (Oregon State University), Mr. Arthur Mckee (Oregon State University), Ms. Sarah Greene (USDA Forest Service), Dr. David Lindenmayer (Australia National University), and Mr. David Werntz (Greater Ecosystem Alliance).

Literature Cited

Arroyo et al. 1996. Towards an ecologically sustainable forestry project: Concepts, analysis and recommendations. Independent Science Commission.

Cissel, J.H, F.J. Swanson, P.J. Weisberg. Landscape management using historical fire regimes: Blue River, Oregon. Ecological Applications (Submitted).

Edmonds, R. L., ed. 1982. Analysis of coniferous forest ecosystems in the Western United States, US/IBP Synthesis Ser 14. Hutchinson Ross Publishing Co: Stroudsburg, PA.

Franklin, J.F., R.T.T. Forman. 1987. Creating landscape patterns by forest cutting: Ecological consequences and principles. Landscape Ecology 1(1):5-18.

Gregory, S., L. Ashkenas. 1990. Field guide for riparian management, Willamette National Forest. U.S. Department of Agriculture, Forest Service, Willamette National Forest.

Harmon, M. E.; Franklin, J. F.; Swanson, F. J.; Sollins, P.; Gregory, S. V.; Lattin, J. D.; Anderson, N. H.; Cline, S. P.; Aumen, N. G.; Sedell, J. R.; Lienkaemper, G. W.; Cromack, K. Jr., and Cummins, K. W. 1986. Ecology of coarse woody debris in temperate ecosystems. *In* MacFadyen, A. and Ford, E. D., eds. Advances in ecological research, pp. 133-302. Academic Press, Inc, Orlando, FL.

Hauer, R. F., G. A. Lamberti (eds). 1996. Methods in stream ecology. Academic Press, New York.

Hinds, W. T. 1984. Towards monitoring of long-term trends in terrestrial ecosystems. Environmental Conservation 11(1):11-18.

Jones, J. A., G. E. Grant. 1996. Peak flow responses to clear-cutting and roads in small and large basins, Western Cascades, Oregon. Water Resources Research 32(4):959-974.

Likens, G. E. 1983. A priority for ecological research. Bull. Ecol.Soc. Amer. 64: 234-243.

Likens, G. E., F. H. Bormann. 1995. Biogeochemistry of a forested ecosystem (2nd edition. Springer-Verlag: New York.

Maser, C., R.F. Tarrant, J.M. Trappe, J.F. Franklin, tech. eds. 1988. From the forest to the sea: A story of fallen trees. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; U.S. Department of the Interior, Bureau of Land Management Gen. Tech. Rep. PNW-GTR-229, Portland, OR.

McKee, A. 1998. H.J. Andrews Experimental Forest. Bulletin of the Ecological Society of America 79(4):241-246.

Michener, W. K. (ed). 1986. Research data management in the ecological sciences. University of South Carolina Press, Columbia, SC.

The Montreal Process. 1995. Criteria and indicators for the conservation and sustainable management of temperate and boreal forests.

Stafford, S.G. 1985. A statistics primer for foresters: The science of using data isn't just for researchers. Journal of Forestry 83(3):148-157.

Stafford, S.G.1993. Data, data everywhere but not a byte to read: Managing monitoring information. Environmental Monitoring and Assessment 26:125-141.

Stafford, S. G., P. B Alaback, G. J. Koerper, M.W. Klopsch. 1984. Creation of a forest science data bank. Journal of Forestry 82(7):432-433.

Stafford, S. G., G. Spycher, M.W. Klopsch. 1988. Evolution of the forest science data bank. Journal of Forestry 86(9):50-51.

Swanson, F. J., C.T. Dyrness. 1975. Impact of clear-cutting and road construction on soil erosion by landslides in the Western Cascade Range, Oregon. Geology 3(7):393-396.

Tuchman, E. T., K.P Connaughton, L.E. Freedman, C. B. Moriwaki. 1996. The northwest forest plan. A report to the president and congress. USDA Office of Forestry and Economic Assistance, Portland, OR.

Van Cleve, K., S Martin. 1991. Long-term ecological research in the United States: A network of research sites (6th edition). Long-Term Ecological Research Network Office, Seattle, WA.

North American Science Symposium

Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources

Simposio Cientifico Norteamericano

Hacia un Planteamiento Unificado para Inventariar y Monitorear los Recursos de los Ecosistemas Forestales

Guadalajara, Jalisco, Mexico
November 2-6, 1998

Compilers:

Celedonio Aguirre-Bravo
USDA Forest Service
Rocky Mountain Research Station
Fort Collins, CO 80526

Carlos Rodriguez Franco
Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP)
Secretaria de Agricultura y Desarrollo Rural (SAGAR)
Mexico, D.F. Mexico.

Abstract

Aguirre-Bravo, Celedonio and Carlos Rodriguez Franco, compilers. 1999. **North American Science Symposium: Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources.** Guadalajara, Mexico (November 2-6, 1998). Proceedings RMRS-P-12. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO USA. 533 p.

The general objective of this Symposium was to build on the best science and technology available to assure that the data and information produced in future inventory and monitoring programs are comparable, quality assured, available, and adequate for their intended purposes, thereby providing a reliable framework for characterization, assessment, and management of forest ecosystems in North America. Central to the syntheses delivered in this Symposium was the conclusion that a fundamental improvement in the approaches used for inventorying and monitoring ecosystem resources is required to meet current and future environmental uncertainties. Specific actions were proposed to address these challenges. These strategic actions are described in the last chapter of these proceedings.

***Editors's Note**: In order to deliver symposium proceedings to users as quickly as possible, many manuscripts did not receive conventional editorial processing. Views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations or the USDA Forest Service. Trade names are used for the information and convenience of the reader and do not imply endorsement or preferential treatment by the sponsoring organizations or the USDA Forest Service.*

You may order additional copies of this publication by sending your mailing information in label form through one of the following media. Please specify the publication title and Proceedings number.

Fort Collins Service Center

Telephone (970) 498-1719

FAX (970) 498-1660

E-mail rschneider/rmrs@fs.fed.us

Web site http://www.fs.fed.us/rm

Mailing Address Publications Distribution
Rocky Mountain Research Station
3825 E. Mulberry Street
Fort Collins, CO 80524