FINAL REPORT

SEMP Integration Project

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14. ABSTRACT
The SERDP Ecosystem Management Project (SEMP) implemented three indicator studies and two threshold studies but had no formal plan for integration. SERDP funded this project in order to evaluate the data collected by those five components and begin to integrate them. The purpose of the integration was to focus the results of the research and monitoring programs on complementing Integrated Natural Resource Management Plan (INRMP) and improving environmental management of Fort Benning. Ultimately, the lessons learned at Fort Benning may provide an example of how to improve environmental monitoring and management of DOD installations in general. This work focused on indicators at the plot level. However, indicators at the watershed and landscape level were considered by the Technical Advisory Committee to be a part of integration and since those type of studies were part of other SEMP projects lead by Virginia Dale and Pat Mulholland, the highlights of those results are reported in the conclusions.

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Executive Summary

Background:
The SERDP Ecosystem Management Project (SEMP) implemented three indicator studies and two threshold studies but had no formal plan for integration. SERDP funded this project in order to evaluate the data collected by those five components and begin to integrate them. The purpose of the integration was to focus the results of the research and monitoring programs on complementing Integrated Natural Resource Management Plan (INRMP) and improving environmental management of Fort Benning. Ultimately, the lessons learned at Fort Benning may provide an example of how to improve environmental monitoring and management of DOD installations in general. This work focused on indicators at the plot level. However, indicators at the watershed and landscape level were considered by the Technical Advisory Committee to be a part of integration and since those type of studies were part of other SEMP projects lead by Virginia Dale and Pat Mulholland, the highlights of those results are reported in the conclusions (section 8) and presented in the slides (section 10) in this report.

Accomplishments:
We developed a framework for integrating and analyzing the data collected at Fort Benning by many researchers across the five teams. This retrospective analysis required an uncommon approach for the selection of indicators that best discriminated land-management categories. There were two key components to this work, (1) the development of land-management categories and (2) variable screening by multiple solutions. Although the data for this effort was not collected in a fashion commensurate with traditional statistical techniques, it was still possible to integrate the separate research efforts and score the results. The use of selection scores provided a straightforward comparison of each indicator and this was important in obtaining results

We first developed a land-management category (LMC) matrix, which provides a means of identifying areas on the base discretely according to the land-management goal for the area, the military activity that occurs in the area, and the frequency of that activity. Criteria for indicator selection were finalized through discussions with the research teams and with Fort Benning resource managers. Evaluation criteria were divided into two groups: those based on technical effectiveness and practical utility. Discussions with the Fort Benning resource managers were important to determining the criteria for practical utility.

Data from the individual indicator projects were collected from the research teams, and statistical analysis is complete. A clear and readable list of the indicators at the site, watershed, and landscape scale of resolution was prepared and has been distributed to the Technical Advisory Committee and Fort Benning resource managers. Conceptual models were developed that show how the indicators vary across time and space. These models also reflect great variation in the indicators across the biological hierarchy. A report was prepared that shows how the approach relates to the alliance vegetation layer prepared by The Nature Conservancy at Fort Benning.

A plan to map the land-management categories at Fort Benning was developed and approved in August 2004. Work on the mapping effort was completed and involved significant discussion with the resource managers at Fort Benning (both from the military and The Nature Conservancy).

The LMC's were mapped in order to provide a spatial interpretation of the categories developed. Two maps were made for this effort. The first map illustrates the land management goals and endpoints was created using data from different sources including the 2001 landcover, forest inventory data from Fort Benning and a vegetation map from The Nature Conservancy . Three main categories were included in this map – minimally managed areas, areas managed to restore or preserve upland forests and areas managed to maintain an altered ecosystem. Discussions with Fort Benning staff helped in uniquely assigning areas to these categories. The second map documents the cause of predominant ecological effect from military use of land. Different military training activities, such as using tracked or wheeled vehicles, firing ranges etc. are mapped with respect to the area they are allowed to occur on. Information on training activities and their restrictions were obtained from Fort Benning personnel and the Fort Benning environmental awareness training guidelines.

Major Findings:

- A collective vision for the land can be derived among resource managers with diverse objectives if care is taken to be sure that terms are communicated clearly and if all stakeholders have the opportunity to participate in discussions.
- Land-management categories can be developed based on management goal for each area, the use of the land, and the frequency of that use. These land management categories provide a meaningful way to resource managers to formalize their goals for the land given expected uses and to identify indicators that can be used to monitor if each goal is on track.
- Multivariate analysis supports our hypothesis that ecological indicators should come from a suite of spatial and temporal scales and environmental assets.
- Maps can be created that depict land management categories that cover both ecological interests and military land uses.
- Key indicators at the plot levels include:
    - Soil physical and chemical variables: soil "A" horizon depth, compaction, organic matter, organic layer N, NH_3, Total N, N mineralization rate, Total Carbon and % Carbon.
    - Soil microbiological indicators: biomarkers for fungi, Gram-negative Eubacteria, soil microbial respiration and beta-glucosidase activity.
    - Plant family and life form indicators: the Family Leguminosae, possibly Rosaceae, and the plant Life forms Therophyte, Cyptophyte, Hemicryptophyte and Chamaephyte as well as understory cover, overstory cover and tree stand characteristics.
- Key indicators at the watershed level are:
    - Disturbance intensity
        - % bare area on slopes > 3%
        - % road coverage
    - Dissolved organic carbon and pH
    - Stream physical habitat
        - Coarse woody debris (CWD), BPOM, and flashiness: good indicators and best explained by contemporary land use
        - Stability: weak indicator, explained by historic land use*
    - Macroinvertebrates
        - EPT (Number of taxa of the insect orders Ephemeroptera, Plecoptera or Tricoptera): good indicator, explained by historic land use
        - Chironomidae richness and GASCI: strong indicators and no legacy effect
    - Fish
        - Assemblage metrics: poor indicators, related to historic land use.
        - Population metrics: good indicators, both sensitive and tolerant populations related to contemporary land use
- Key indicators at the landscape level are:
    - Percent cover of cover types
    - Total edge (with border) of patches
    - Number of patches

- Mean patch area
- Patch area range
- Coefficient of variation of patch area
- Perimeter to area ratio of patches
- Euclidean nearest neighbor distance of patches
- Clumpiness of patches

Benefits:

The project identified a suite of indicators that Fort Benning resource managers can use to make judgments about the ecological condition of the installation. Specifically, the resource managers have noted that indicators will be useful for planning budgets, providing a “heads up” regarding compliance with environmental legislation, signaling whether the installation is on the right path toward achieving longer term goals, signaling whether the installation is on the right path to achieve shorter term objectives, and suggest need for targeted projects and research. SERDP’s Science Advisory Board (SAB) sees the approach set forth by this project as an effective framework to integrate the indicators so they relate to the needs of the land managers.

The approach of developing and mapping land-management categories should be useful for other locations. It provides a means for communication across the various uses of the land, a format for collecting and interpreting monitoring data, and a framework for designing and implementing management goal.

The specific indicators identified at Fort Benning are likely to be of great importance for other military installations in the southeast. The categories of important indicators are likely to important in all locations. The approach for analysis of indicators should be generally transferable.

Challenges and Concerns:

Because the integration project was initiated after the individual teams had designed and largely carried out their experiments, harmonizing the data into a format conducive to statistical analysis across all research teams has been challenging. The data were also restricted to those LMCs and structural, compositional and functional features which the research teams measured. Not all LMCs were sampled. The multivariate analysis was complicated by the diverse sampling approaches of the research teams. Even within some teams, the data on different indicators were collected in different places and/or at different times. Thus the focus of the analysis is on indicators as predictors of the LMCs. Because we did not have access to the data collected for the site condition index, the analysis is not as complete as it might otherwise be.

Data limitations required a new approach to integrating disparate data from several research teams at Fort Benning. Since the ecological indicator information was spread over several data sets, a way had to be established to integrate and compile the results. The approach of multiple solutions with scoring allowed us to compare the fitness of each indicator for the prediction of LMCs without the limitations of other more traditional statistical methods. The results and insights gained from this effort appear to be consistent with other work in ecological indicators.

OBJECTIVES

The purpose of the integration was to focus the results of the research and monitoring programs on complementing INRMP and improving environmental management of Fort Benning. In addition, the lessons learned at Fort Benning provide an example of how to improve environmental monitoring and management of DoD installations in general.

In collaboration with the SEMP Technical Advisory Committee (TAC), our team developed the following objectives for the SEMP Integration Project

- To focus SEMP efforts – current and future
- To identify potential ecological responses to management actions.
- To connect with the greater scientific and land management community beyond Fort Benning and DoD
- To identify how the different parts of the ongoing research relate to each other
- To identify any gaps, duplication, or contradictions in ongoing research
- To develop an understanding of how the individual research activities fit into the big picture of both understanding and managing the natural resources at Fort Benning
- To provide an integrated perspective on how what is being learned about indictors at Fort Benning can be applied to other DoD installations as well as other resource management issues

BACKGROUND AND OVERVIEW OF APPROACH

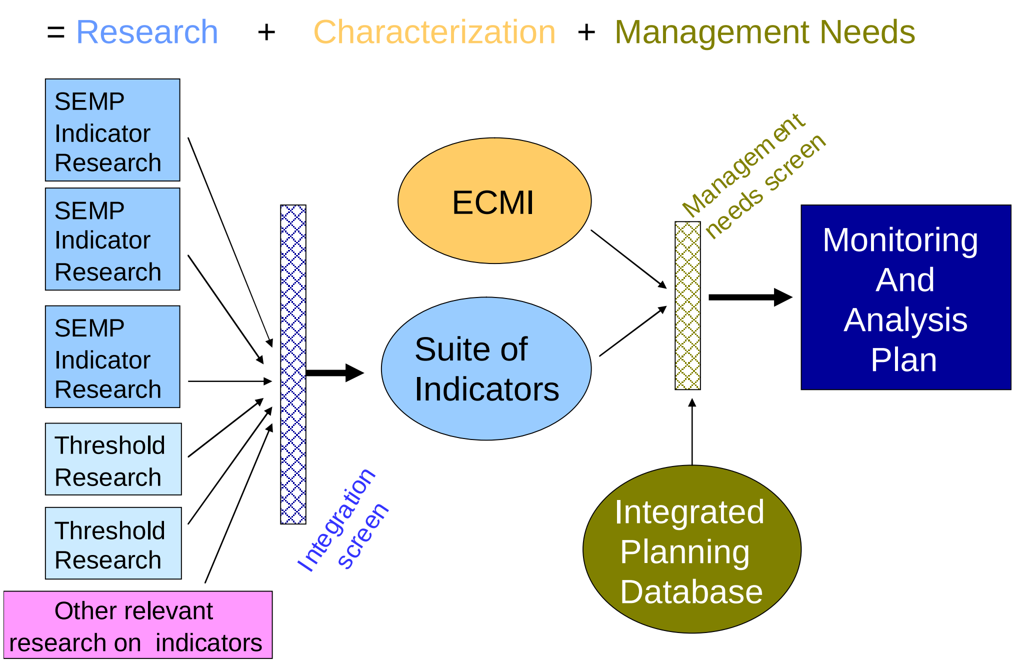
Background: In 1999 and 2000, SEMP initiated three indicator studies and two threshold studies. In addition, the design phase of the Ecological Characterization and Monitoring Initiative (ECMI) was completed. Furthermore, Fort Benning also completed its Integrated Natural Resource Management Plan (INRMP). At that juncture it was appropriate to evaluate these three components and begin to integrate them. The purpose of integration was to ensure that the components are complementary and interconnected and that, in sum, they improve environmental management. Another goal was to foster communication among the research teams so they consider themselves a part of the integration effort.

Endangered species have been and will continue to be an important part of the ecological effort at Fort Benning. Much work has also occurred at Fort Benning focusing on endangered species, and a recent study by R. Sharitz focused on how management action can affect endangered species. Because one of the key ecological management goals at Fort Benning is maintenance of endangered species and their habitat, these efforts will partially form the context into which the integration plan is placed.

Approach:

Figure 1 shows the general plan for integration and is further explained in Appendix I. The first step was to query the three indicator and two threshold research teams as to what their proposed indictors are. (This approach assumes that the threshold projects are a special case of the indicator work that will examine threshold conditions of particular indicators). The formal query asked for details of each proposed indicator (e.g., the spatial and temporal resolution, how it is measured and interpreted, etc). It also asked about data available to support the choice of the indicators and if there were any historical databases or other information that would provide more information.

Figure 1. Integration plan



The second step was be to conduct a preliminary screening of the proposed indicators against the criteria for indicators set forth by Dale and Beyeler (2001) based on their review of the indicator literature. Other studies and approaches developed since that 2001 review were also be considered for the criteria, such as the new book on *Monitoring Ecosystems* (Bursch and Trexler 2003). For another example, the survey of biodiversity indicators of forest sustainability being conducted by the Manomet Center for Conservation Sciences provides a way to categorize types of indicators. It was not our intent to develop a single metric of ecological integrity but rather to explore a suite of metrics that are useful for management issues at Fort Benning (and hence, potentially at other military installations). Even so, information proposed to evaluate candidate metrics (e.g., Andreasen et al. 2001) was useful in evaluating the suite. Comments from the five research teams and the environmental management staff at Fort Benning were also essential and extremely useful in finalizing the criteria for relevance and feasibility of the suite of ecological indicators.

This screening step required assessing the data against the criteria. In some case the screening involved decisions as to whether the criteria are met or not. Review of this interpretation by the five research teams and the Benning staff was an important step in the process. The screening also required analyses by a series of multivariate analyses to determine the set of indicators that best characterizes differences between land-management categories (LMC) (as is described below).

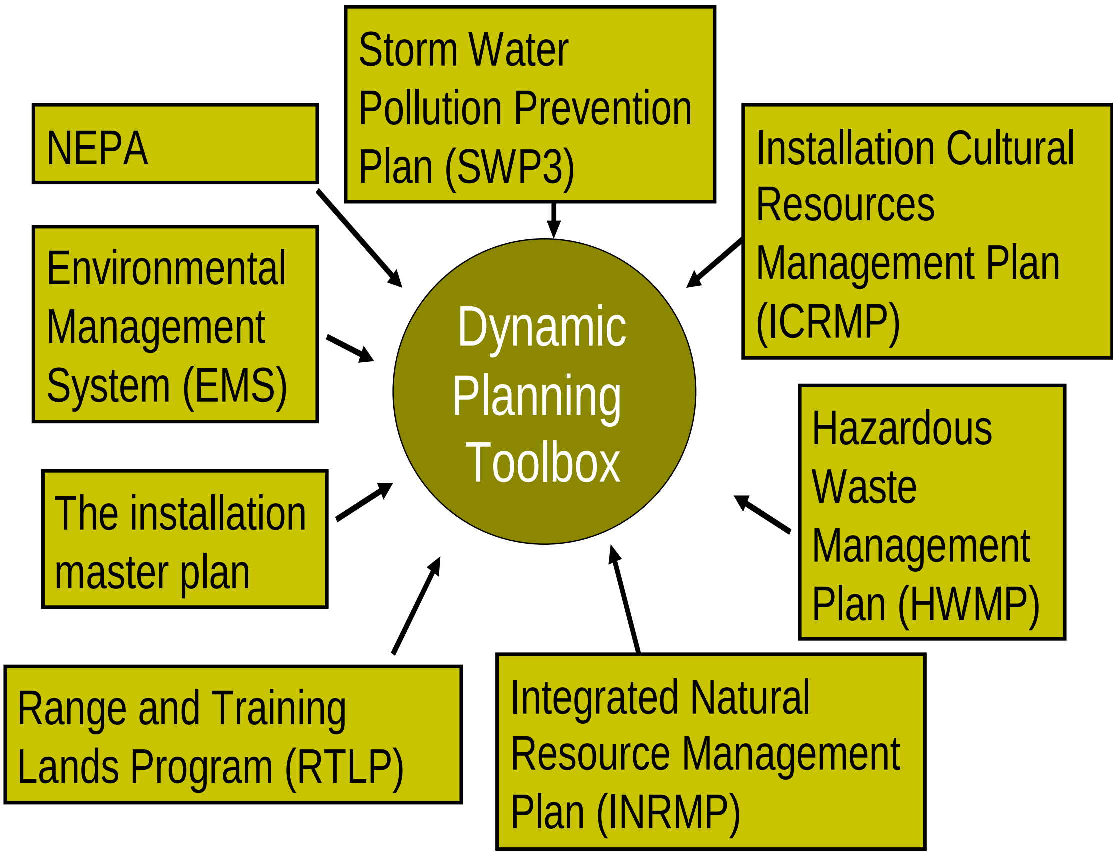
Before the analyses of indicators could be conducted, LMCs had to be determined. The determination required that the Fort Benning resource managers and each of the research teams to first agree upon the set of LMCs. A modified Delphi method was used to determine the specific categories. The Delphi technique is a means of achieving consensual validity among raters by providing them feedback regarding other raters' responses (e.g., Gokhale 2001, Mendoza and Prabhu 2000, Nagels et al. 2001). Once the LMCs were determined, each team assigned a category to each plot based on the information provided by Benning staff and direct observations. A map of the LMCs was also developed.

The LMCs were treated as independent variables in a multivariate analysis of the proposed indicators that make it through the first screen. In the case of similar indicators but different methods of collecting the data, the method of collection will be treated as a random effect in the model. The set of indicators that best explain the LMCs comprise the suite of final indicators. One final result will be a set of LMCs for Fort Benning that will likely transfer to other installations in the region that undergo similar land-use and management practices.

Modeling of selected indicators (dependent variables) against LMCs (independent variables) uses the assumption that change in that indicator or metric is related to ecosystem disturbance in a measurable and predictive way. Indicators produced during this project vary in scale, response, and method of measure. In order to compare indicators standardization of the response variables is one factor that must be considered. Additionally there are several ways to pursue validation of indicators once they are deemed potential candidates. Therefore, several multivariate techniques were used in the analysis. Another technique used was Artificial Neural Network Analysis, which “learn” from existing data and then “predict” when given new information.

The final result of this effort include a monitoring and analysis plan, which provides a list of measures, protocols for obtaining the data, and suggested means of analyzing the data. Dr. Jeff Fehmi, a researcher at the US Army Engineering Research and Development Center (ERDC), was responsible for developing this monitoring and analysis plan and interfacing with the management team at Fort Benning. The monitoring and analysis plan is part of the bigger picture of activities on an installation (Figure 2). Any installation has at least two objectives: the ultimate concern for military training and testing with which environmental objectives must mesh. Together these objectives determine the installation activities, which typically have some environmental impacts. While the environmental objectives may change depending on impacts, the overall goals for the environment are not likely to be altered.

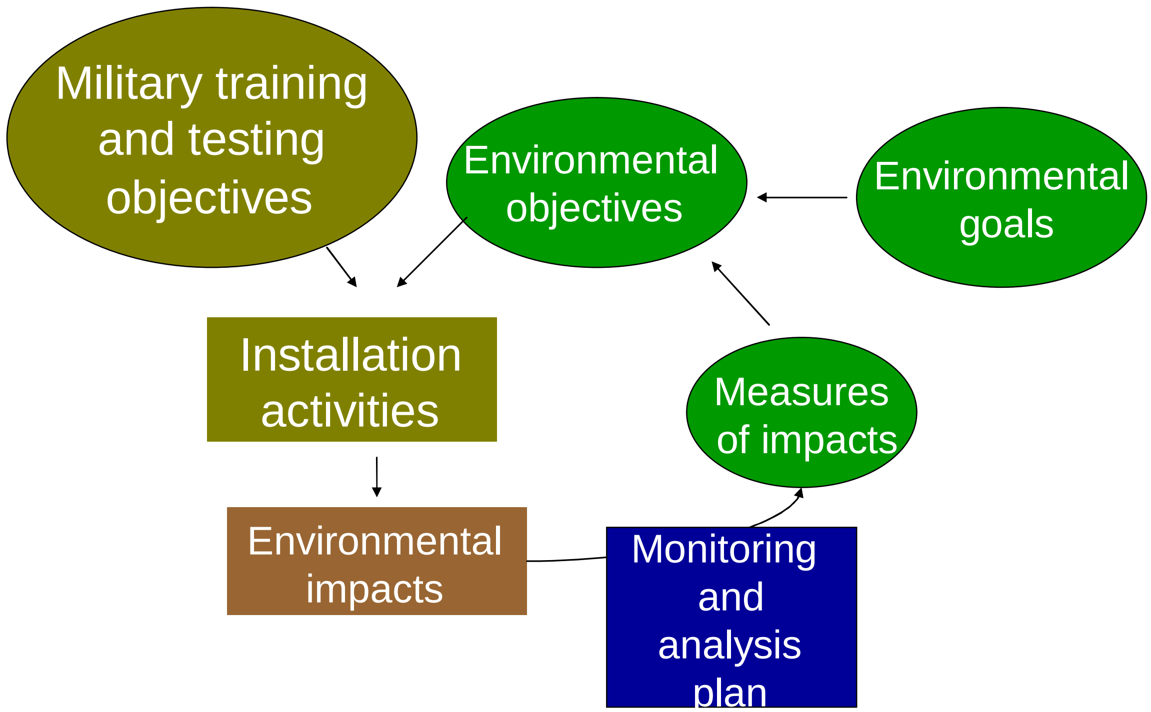
Figure 2. Components of the Dynamic Planning Toolbox



Over time, the monitoring and analysis plan may evolve, however (Figure 3). As the Dynamic Planning Toolbox evolves, it may influence both the environmental goals and objectives, which, in turn, affects planning. As planning is resigned, the monitoring and analysis plan may change in response to new management needs.

Data from the research teams was provided directly by the researchers and now can be accessed via the SEMP Data Repository. This repository is a web-accessible system in which SEMP researchers are already storing results and data from Fort Benning studies.

Figure 3. The Monitoring and Analysis Plan



Appendix I. Developing ecological indicators that are useful to decision makers (Dale, V.H., A.K. Wolfe, and L. Baskaran. 2005. In proceedings of the conference on Biodiversity: Science and Governance, Paris, France, January 24-28, 2005).

Introduction

Scientists contribute to decision-making processes by communicating information, building consensus, maintaining credibility, and discovering options for new policy and research directions (Dale 2002). Communication of information can occur via field tours, coverage by the press, scientific papers, and many other venues. Scientists can help build consensus about the scientific understanding of and contributions to management plans by sharing information, teaching, developing analyses, and taking part in scientific advisory groups. Scientific credibility can be maintained by publication of peer-reviewed articles and engagement in debates about scientific hypotheses. Finally, scientists can be effective in exploring options through engagement in experimental tests of hypotheses, modeling, and adaptive management. Most often, scientific information is used to advise the decision-making process (e.g., see Dale et al. 2002). Scientists and decision makers have different views of the world but must communicate in order for scientific perspectives to be a part of decision making. A general synopsis of these two perspectives can be seen by considering the typical personality characteristics of scientists compared to politicians (Tieger and Barron-Tieger 1992). Most scientists are visionary and excel at creating systems, can understand complex and difficult subjects, enjoy creative and intellectual challenges, are good at theoretical and technical analysis and logical problem solving, work well alone, and are determined even in the face of opposition. However, scientists can also be less interested in projects after creative problem solving is completed, may drive others as hard as they drive themselves, may be too independent to adapt to corporate culture, have difficulty working with or for others whom they consider less competent, and can be inflexible and single-minded about their ideas. Most decision makers tend to promote harmony and build cooperation, respect a variety of opinions, are decisive and organized, and are natural leaders. At the same time, decision makers can also have trouble dealing with conflict, tend to sweep problems under the rug, may not be attentive to factual accuracy, or may take criticism too personally. Even though they have differences, scientists and decision makers learn to communicate when policy questions involve science.

Communication is a two-way street. Decision makers are often not aware that science can pertain to a policy issue. Regular discussions between scientists and decision makers can enhance communications and build mutual respect. Scientific results are rarely expressed in terms that have meaning or value to decision makers.

Recognizing that there are broad differences between scientists' and decision makers' perspectives is a first step in improving communications between these groups. In the case discussed here, our goal was to assure that scientifically determined ecological indicators are of practical value for resource managers at a U.S. Army installation. Unless ecological indicators prove useful for resource managers, even the most technically sound indicators may be ignored. When asked how they might use ecological indicators, resource managers suggested that the ideal indicator should

- *Help resource managers comply with federal environmental legislation, including the Endangered Species Act.* Indicators should signal conditions that threaten to undermine an installation's efforts to achieve compliance with legal requirements.
- *Provide feedback on management practices.* The indicator should gauge the effectiveness of current resource-management regimes and identify where these regimes should be modified.
- *Provide quantifiable management targets.* Quantification of desirable indicator values should help resource managers identify goals, as well as help institutionalize targets for the resource-management process.
- *Maximize the ratio of sampling effort exerted to information yielded.*
  - *Sampling design and effort should be proportionate to need.* The value of the information obtained should justify the level of equipment, personnel, post-collection processing, etc., involved in collecting it.
  - *Sampling measurement should be cost-effective.* Acceptable cost thresholds can vary according to how useful the indicator is otherwise.
- *Be comprehensive.* Ideally, a single indicator should provide information either about a large area (e.g., at a watershed level rather than a plot level) or about more than one resource (e.g., both soil and water quality).

Procedure for including indicators in the decision-making process

To assure that technically accurate scientific information truly informs resource management decision-making, we developed a procedure for including scientific information in the decision-making process. Figure 1 illustrates this procedure, using ecological indicators as an example. The procedure is currently being implemented at the Fort Benning Military Installation in the southeastern United States, where management concerns focus on the impacts of land use on rare and endangered species and habitat degradation (Dale et al. 2004). The procedure includes scientific and resource management perspectives, ultimately integrating those two perspectives in analytically and visually in maps.

- *Send a query to researchers about indicators they are developing.* All research teams working in the study area were queried as to what their data suggest are key indicators for the area. Questions were asked about several aspects of their data (e.g., What is the spatial extent of the data? Are the data already placed in a repository?).
- *Compile the results of the query on the proposed indicators.* The results of the query were compiled and synthesized, then disseminated to both research teams and resource managers. There was much review and discussion with the research teams and management staff before the final report was completed to be sure that the terms were all explained clearly and that the sources of, and caveats about, information were properly described.
- *Conduct a preliminary screening of the criteria for indicators.* Research teams and resource managers were asked about a set of proposed criteria for what constituted "good" (useful) indicators, drawn from resource managers' responses and published criteria (Dale and Beyerler 2002[I may have wrong year; pub not in lit. cited]). Subsequently, a revised set of criteria was developed. Each research team was asked to evaluate its indicators against these criteria.
- *Derive land-management categories through use of a modified Delphi method.* Using existing information and categories where possible, the research teams and resource management staff came to an agreement on a set of land-management categories for the area (Wolfe and Dale, in review). These categories constituted a common framework within which to place indicators, incorporating resource management goals as well as military uses of the land. The Delphi method provided a means of achieving consensus among raters by providing feedback on other raters' responses. The final result is a set of land-management categories for the area that will probably be transferable to other locations in the region that have similar land uses and management practices.
- *Identify key management needs.* Working with the resource management staff and using existing management protocols, the teams identified the key ecological management needs of the installation. The time frame and spatial resolution as well as land-cover type and land-use conditions for each management need were considered.
- *Perform multivariate analysis of the proposed indicators arrived at after the first screening against land-management categories.* Each research team assigned a land-management category to each study site and thus each set of data. Then the data on proposed indicators were analyzed. The land-management categories were treated as independent variables in a multivariate analysis of the proposed indicators identified after the first screening. We are now determining how well the proposed indicators distinguish the land-management categories by using multivariate techniques (e.g., by creating dendrograms and conducting principal component and neural net analyses).
- *Develop a map of land-management categories.* A map depicting the location of the land-management categories is being compiled by using existing information for the region. The map has a base resolution of 30 m, since remote sensing data from Landsat forms one of the basic data layers.

- *Screen the resulting indicators for how well they address management concerns* A way to compare of suite of indicators with management needs was developed to identify any gaps in how the indicators relate to those needs. The potential impact of ongoing management on endangered species and their habitat was considered. Areas of redundancies in indicators will also be identified, and benefits and costs of these redundancies will be analyzed.
- *Develop a monitoring and analysis plan.* The final report will contain a monitoring and analysis plan so that the resource managers can implement an ongoing monitoring approach for indicators. The monitoring and analysis plan, to be implemented soon, will describe ways to change the monitoring procedures over time to accommodate new information and new knowledge.
- *Map land-management categories.* Working in conjunction with the resource managers, we are developing maps of the components of the land-management categories as described above. One key map is for the military uses of the installation. Another map depicts the land-management goals and endpoints.

References

Andreasen, J.K., O'Neill, R.V., Nosss, R., and Slosser, N.C. 2001. Considerations for the development of a terrestrial index of ecological integrity. Ecological Indicators 1: 21-35.

Busch, D.E. and Trexler J.C. 2003. Monitoring Ecosytems: Interdisciplinary Approaches for Evaluating Ecoregional Initiatives. Island Press, Washngton DC, 447 pages.

Dale, V.H. 2002. Science and decision making. Pages 139-152 *In* R. Costanza and S.E. Jorgensen, ed. Understanding and Solving Environmental Problems in the 21st Century: Toward a New, Integrated hard problem science. Elsevier, The Netherlands.

Dale, V.H. and Beyeler, S.C. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1(1): 3-10.

Dale, V.H., Mulholland, P., Olsen, L.M., Feminella, J., Maloney, K., White, D.C., Peacock, A., and Foster, T. 2004. "Selecting a Suite of Ecological Indicators for Resource Management," Pages 3-17 in *Landscape Ecology and Wildlife Habitat Evaluation: Critical Information for Ecological Risk Assessment, Land-Use Management Activities and Biodiversity Enhancement Practices*, **ASTM STP 11813**, L.A. Kapustka, H. Gilbraith, M. Luxon, and G.R. Biddinger, Eds., ASTM International, West Conshohocken, PA, 2004.

Gokhale, A.A. 2001. Environmental initiative prioritization with a Delphi approach: A case study. ENVIRON MANAGE 28 (2): 187-193.

Mendoza, G.A., Prabhu R. 2000. Development of a methodology for selecting criteria and indicators of sustainable forest management: A case study on participatory assessment. ENVIRON MANAGE 26 (6): 659-673.

Nagels, J.W., Davies-Colley, R.J., Smith, D.G. 2001. A water quality index for contact recreation in New Zealand. WATER SCI TECHNOL 43 (5): 285-292.

Tieger, P.D. and Barron-Tieger, B. 1992. Do what you are. Boston: Little, Brown and Company.

Wolfe, A.K. and V.H. Dale. In review. Using a Delphi Approach to Define Land-Management Categories and to Integrate Science and Practice. Journal of Environmental Management.

RESULTS AND ACCOMPLISHMENTS

(A) LAND MANAGEMENT CATEGORIES

Systematic and iterative Delphi-derived elicitations from both ecological researchers and resource managers produced a multidimensional matrix of land-management categories (LMCs) whose dimensions include cause of predominant ecological impact of military uses of land, land management goals and endpoints, and frequency and intensity of use. By providing a common framework for synthesizing diverse research projects, the matrix allows specific field plots to be assigned to unique land-management categories, regardless of whether those plots previously had been subjected to different uses or currently are used for multiple purposes.

Appendix II describes the process designed to integrate science with practice by developing a framework—agreeable to both scientists and practitioners. The framework was developed using a two-phase Delphi-derived approach as a means for negotiation among the SEMP scientists and the natural resource managers at Fort Benning. The Delphi-derived process allowed us to create a multi-dimensional integrating framework that should prove valuable in assuring that the data, models, and information produced by scientists are both useful and usable by the practitioners for whom the science was conducted.

Appendix III describes how we developed a procedure to integrate the SEMP scientific studies in a manner that would be meaningful and useful for resource managers. We discuss how that approach shifted from a Delphi expert elicitation to something more akin to facilitated negotiation. Appendix III ends with a discussion of the potential utility of this approach in other settings when the aim is to produce scientific results that meet practitioners' needs, specifically in the realm of ecological science and resource management.

Appendix II.

Using a Delphi-derived Approach to Negotiate a Common Framework within which to Integrate Science and Practice

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Abstract

Scientific studies often are intended to meet the needs of practitioners, decision makers, or policy makers. Yet, results from those studies frequently fail to meet those needs. This paper describes a process intended to integrate science with practice; our main objective was to establish a framework—agreeable to scientists and practitioners—within which this integration could occur. To achieve this goal, we used a two-phase Delphi-derived approach that, in essence, provided a mechanism for negotiation among scientists involved in five ecological indicator and ecological threshold research projects and between those scientists and natural resource managers at Fort Benning, Georgia. Systematic and iterative Delphi-derived elicitations from both ecological researchers and resource managers produced a multidimensional matrix whose dimensions include cause of predominant ecological impact of military uses of land, land management goals and endpoints, and frequency and intensity of use. By providing a common framework for synthesizing diverse research projects, the matrix allows specific field plots to be assigned to unique land-management categories, regardless of whether those plots previously had been subjected to different uses or currently are used for multiple purposes. Further, the Delphi-derived process allowed us to create a multi-dimensional integrating framework that should prove valuable in assuring that the data, models, and information produced by scientists are both useful and usable by the practitioners for whom the science was conducted.

key words: Delphi method; ecological indicators; land use; resource management

1. Introduction

Data, models, and information produced by scientists often fail to meet the needs of the practitioners, decision makers, or policy makers for whom the science is being conducted. The existence of this mismatch is well-known (see, as examples, Jones et al. 1999; Rayner et al. 2001; Steel et al. 2000–2001). Nevertheless, definitive and effective methods for resolving the mismatch have not emerged either from academic or applied literature. This paper describes the methods we used to resolve this mismatch.

For our undertaking, "the science" consisted of five projects conducted by separate research teams, all under the auspices of a single program, The Department of Defense's Strategic Environmental Research and Development Program (SERDP) Ecosystem Management

Project. Though conducted on a single site and for similar purposes, the extent to which project data and results overlapped was not immediately apparent. Thus, our main challenges were:

- how to specify a framework to guide the integration of plot-scale field studies that measure overlapping sets of parameters, when each study is performed on a single site, but in different locations and on plots of different sizes; and
- how to relate the science of ecological indicators to the continuing practice of resource management.

This two-phase integration process is a distinctive feature of our effort—integration among research projects and integration between science and management. We used a systematic, iterative Delphi-derived approach to achieve consensus among and between the involved ecological researchers and resource managers. Our formal application of the Delphi approach became less formal and more interactive over time. The result was negotiated framework to guide the integration of (a) divergent scientific studies and (b) site-specific ecological research results with natural resource management objectives. Land-management categories became the means to express common management goals among the resource managers and to relate data collected by different research teams for distinct purposes.

2. Background

2.1 Ecological indicator and threshold research at Fort Benning

Fort Benning, Georgia was the setting for our work. The ecological studies that constituted "the science" took place there; the resource managers for whom the science was conducted work there.

Fort Benning is a 75,503 hectare military training facility. Portions of the installation are used for—and managed to allow—such activities as tank maneuvering, firing ranges, drop zones, and bivouac areas. Other portions of the installation are managed for recreation, timber, and environmental protection of rare resources. As examples, upland pine forests are thinned as a part of a timber management program; portions of the understory are undergoing ecological restoration; and threatened, endangered, and special interest species, such as the red-cockaded woodpecker (*Picoides palustris*) and gopher tortoise (*Gopherus ployphemus*), are protected (Greene 2002). Maintaining habitat for the federally endangered red cockaded woodpecker requires that understory growth be regularly controlled by fire. The installation also includes a sizeable cantonment area, which houses residential, office, warehouse, motor pool, and other similar infrastructure. Activities within the cantonment can affect ecological conditions in surrounding areas.

Since the late 1990s, a set of projects intended to identify ecological indicators or ecological thresholds useful for planning, implementing, and monitoring the impacts of land-management practices at military installations have been funded by the SERDP (Strategic Environmental Research and Development Program) Ecosystem Management Project (SEMP). Once indicators and thresholds are identified at places like Fort Benning, the idea is to determine how they can be incorporated effectively into monitoring and management programs. Findings are intended to be installation-specific, but they should be applicable to other military installations with similar ecological conditions.

The five ecological research projects at Fort Benning are alike in centering on plot-scale investigations. They differ both in their focus (see Figure 1) and in where on the installation they were undertaken (Goran 2004, see also SEMP web site).

2.2 Developing an integration framework: An initial step in the integration process

The work described in this article is part of a larger effort that entails the actual integration of the results of the five ecological research projects in a manner that allows them to contribute more directly to existing Fort Benning resource management documents, tools, and practices. Integrating results of the five ecological studies is not simply a matter of combining data across studies and taking averages or running statistical tests because the data consisted of varying units and types over different periods of time. Therefore, developing a framework within which the integration could occur was a necessary first step in the overall integration process, from the standpoints of both the scientific data and resource managers' needs.

We initially thought that a suite of defined, discrete Fort Benning land-use categories would form the core of the integration framework. "Land use" would be familiar to scientists and resource managers as well as provide the benefits of geographic specificity (e.g., mapping, ground-truthing, etc.). Further, land-use categories were consistent with our plan for integrating the results of the ecological research projects at Fort Benning. That plan requires researchers to assign a single land-use category to each field research plot so that multivariate statistical analyses can be conducted to determine which suite of indicators collectively provide comprehensive and useful metrics to serve as a basis for improved environmental management. Adding this statistical layer to the land-use category designations produced during this phase of the overall integration effort was intended result in a robust suite of land-use categories for Fort Benning.

As will be described in this article, however, our early focus on land-use categories shifted to "land-management" categories as a result of our interactions with scientists and resource managers. It is these land-management categories that will be used in statistical analyses. We adopted the "land-management" phrase towards the end of the Delphi-derived process described in this article.

Land-management categories should prove effective for Fort Benning resource management activities and be transferable to other installations in the region to which similar military-use and land-management practices are applied. Likewise, our approach for determining land-management categories should be applicable to a variety of public and private resource managers. Although our integration framework development efforts occurred towards the end of the ecological research projects, our approach could be used prospectively in future applications.

In this case study, involving both research teams and resource managers in the development of land-management categories produced a set of categories that are useful and meaningful to both groups. Useful categories for resource managers help them establish and implement management goals on a complex landscape. Useful categories for researchers facilitate comparisons among studies. Part of the benefit of "land-management" categories is that they are distinct from both land cover and land use. "Land cover" is easy to measure and "land use" reflects current functions served by the land. However, neither land cover nor land use, alone, are sufficient for locations like the Fort Benning Military Reservation, which is managed to support multiple, potentially conflicting purposes—troop activities, built areas, and prime habitats for rare species. Moreover, the question of how to combine and synthesize existing ecological research is not only of academic interest. Such a synthesis is essential if ecological research is to be used by resource managers in meeting their responsibilities and addressing their concerns.

3. Methods

3.1 The Delphi method, in brief

The Delphi method, originally developed in the 1960s, is well-established approach for seeking group opinion (e.g., Fontana and Frey 1994; Soderstrom 1981). It often, but not always, is used to seek consensus. The Delphi process is iterative and goal-oriented. It uses a series of structured questions to elicit information from panelists in at least two rounds of engagement. After each round, responses are analyzed and results are presented to the panelists until the goal or consensus is achieved. Generally, the Delphi process is used with expert panelists who are queried separately, instead of face-to-face (though the method can be used in face-to-face situations). Avoiding face-to-face contact prevents problems associated with group interactions, such as dominating personalities, but heightens the analyzing, summarizing, and reporting responsibilities for the party running the Delphi process. The method is especially useful when there are substantial time constraints, as we faced in this project. It has been applied to a wide variety of topics, including resource planning or management (e.g., Gokhale 2001; Hess and King 2002; Matlack 2002; Mendoza and Prabhu 2000; Nagels *et al*. 2001; Taylor and Ryder 2003).

3.2 Using a Delphi approach to achieve consensus: pragmatic considerations

Developing an integration framework and using that framework to integrate ecological indicator and threshold data and results depended upon considerable input from the research teams. Members of ecological indicator and threshold research teams were charged with conducting their specific field investigations, not with integrating their research with other field research. In contrast, although Dale also led an ecological indicator field research project at Fort Benning, we were charged with cross-project integration.

All five SEMP ecological indicator and threshold research teams were apprised of our integration goals, but integration was not necessarily a shared goal. Therefore, two measures were taken to encourage researchers to engage seriously in the overall integration process. One step was institutional—SEMP provided additional funding to the research teams in recognition of the effort involved. The second measure appealed to a different kind of self-interest. We emphasized that, once what we eventually labeled "land-management categories" were agreed upon, researchers would be asked to assign each of their field sample plots to one category (perhaps in consultation with installation resource managers). In this manner, we stressed the importance of assuring that land-management categories made sense in terms of researchers' field experiences at Fort Benning.

3.3 An overview of our shift from a formal Delphi process to Delphi-derived negotiations for achieving consensus

To achieve consensus in what became land-management categories among SEMP researchers, and then assure that the land-management categories identified by the researchers were useful for Fort Benning resource managers, we intended to use a Delphi approach. However, what started as a formal Delphi procedure transformed into what we label a "Delphi-derived" approach. A schematic view of how we implemented this Delphi-derived process appears in the Figure 2. In brief, we began with a face-to-face meeting with Fort Benning resource managers to help us develop our first set of questions to use in a Delphi elicitation of scientists. We conducted two rounds of elicitations with the scientists. No consensus had yet been achieved, and the scientists raised challenging issues. It was at this point that the transformation from formal Delphi to a Delphi-derived process. We sought resource managers' input to resolve those challenging issues and used that input to develop the third-round elicitation for scientists. The results of this round prompted a series of rapid communications in which our role shifted from structuring and analyzing elicitations to facilitating multi-party negotiations. This negotiation facilitator role continued into a face-to-face meeting and finalization of the integration framework.

In many ways, the modifications we made in a formal application of the Delphi approach are analogous to adaptive management. Our goal of developing a consensus-based integration framework remained unchanged, but we found that we needed to modify our methodological approach to achieve that goal. In effect, our interim results drove our next methodological steps. Therefore, the next section provides a more detailed description of the Delphi-derived process we implemented together with interim results that, in turn, affected the next methodological steps we took.

4. Results: Feedbacks between methods and results

Our integration framework development efforts focused on two dilemmas—integrating across field studies and relating science and practice. We summarize results from the second dilemma first because developing such a relationship was central to, and the driver for, our entire integration undertaking.

4.1 Relating science to the practice of resource management

We began our integration framework development process by meeting face-to-face (one individual participated by telephone) with Fort Benning resource managers. These managers include individuals employed by both Fort Benning and The Nature Conservancy of Georgia, the latter working within the Fort Benning Environmental Management Division. The goal of this meeting was to develop an initial suite of land-use categories to use as a starting point in the Delphi elicitation of SEMP researchers.

This meeting highlighted the distinction between "land cover" versus "land use." "Land cover" is the ecological state and physical appearance of the land surface. Examples include closed forests, open forests, or grasslands (Turner and Meyer 1994). Change in land cover converts land of one type of cover to another, regardless of its use. Land cover also is affected by natural disturbances, such as fire and insect outbreaks, and subsequent changes through succession. Ecological conditions have been defined for some land-cover groups at Fort Benning (Greene 2002).

In contrast, "land use" refers to the purpose to which land is put by humans, such as protected areas, forestry for timber products, plantations, row-crop agriculture, pastures, or human settlements (Turner and Meyer 1994), and, in our case, different categories of military training. Change in "land use" may or may not cause a significant change in "land cover." For example, shifting from a selectively harvested forest to a protected forest will not cause much discernible land-cover change in the shortest term, but shifting to cultivated land will cause a large change in cover (Dale et al. 2000). During this first face-to-face meeting, resource managers agreed to focus on "land use" so as to emphasize the identification of indicators able to distinguish among land uses and signal when a particular area is becoming degraded.

This initial meeting also made clear that two land-management dimensions operate simultaneously: (1) military uses of land combined with the frequency of those uses, and (2) land management goals. Both dimensions are necessary to distinguish and make management decisions about different particular parcels of land.

The environmental effects of different military uses of land and of particular practices designed to achieve land management goals can be substantial. As examples, the type of traffic (tracked, wheeled, or foot) and frequency of use may make the greatest differences in environmental impact. Therefore, it is important to consider these attributes in conjunction with the military uses to understand ecological conditions and to support environmental decision making. The installation's land-management goals for particular areas are more stable than either the specific management practices undertaken in those areas or land-cover types. Therefore, the group categorized land areas within Fort Benning according to environmental management goals. In addition, practitioners noted that different environmental management goals can involve a variety of management activities, ranging from none or light ("extensive," in their language, as when no timber is harvested from bottomland hardwood forests) to heavy ("intensive," such as prescribed burns or logging).

The military use and environmental management dimensions became a cornerstone for land-use category development. Rather than delineate a simple list of land-use categories, the group juxtaposed the dimensions and created a land-use category matrix. This matrix concept was retained throughout the Delphi process, though the matrix itself was modified. Table 1 is the final version of land-management category matrix; each cell represents a unique combination of attributes. (Note that the designations of frequent or infrequent use within cells reflect two possible options for how to label specific plots; a single plot would either be used frequently or infrequently, not both.)

The initial matrix, however, formed the focus for the first round of the Delphi process with SEMP researchers (Figure 3 presents the questions asked). Some common themes emerged from researchers' responses to this elicitation. The most striking example was the question of how to categorize areas in which there are multiple military uses. Researchers suggested different ways of dealing with this challenge (e.g., categorize according to intensity of military use or by majority use). We proposed altering the title of this dimension to "*predominant* military uses of land," recognizing that the group would have to decide whether "predominant" referred to the most frequent military use or the military use causing the greatest ecological impact. This issue continued to be a sticking point throughout much of the Delphi process.

Two other issues raised during this round of the Delphi process persisted virtually throughout the process. These issues were how best to categorize those portions of Fort Benning (a) whose current ecological condition is dominated by past, but not current land uses, and (b) that are affected by adjacent land uses. Ultimately, at the face-to-face meeting at the end of the Delphi-derived process, the group decided that "predominant" military use of land referred to the use with the greatest ecological impact, no matter whether that impact was caused by one of multiple, past, or adjacent land uses. Labels used in different versions of what became the land-management matrix show the evolution of group (both researchers and practitioners) thinking. First, the label was "military use(s) of land". "Predominant military use of land" was the interim label. And, the final version (Table 1), though wordier, became quite specific—"cause of predominant ecological effect from military use(s) of land."

Researchers also suggested adding additional subcategories to various portions of the original proposed land-use table and ways to combine categories. In the second elicitation, we asked 10 questions to clarify researchers' views on the proposed changes (see Figure 4). We emphasized to researchers that the revised matrix that served as the basis for this second round of questioning offered one way to respond to their suggestions. In addition we reminded researchers that it was essential for the SEMP integration effort that they all deem the final suite of land-use categories acceptable and usable (i.e., they can assign a unique land-use category, later to become land-management category, to each field plot).

Again, researchers' responses were varied, and sometimes in conflict with one another. We had to make judgments in deriving the next proposed land-use category matrix. To help us make those judgments in ways likely to be compatible with real-world resource management, we turned once more to the Fort Benning resource managers. We asked them to help resolve specific issues, first by a formal e-mail request, then through a conference call and additional, informal e-mail interactions. This series of exchanges was necessary because the unresolved issues, together with researcher-initiated modifications to the suite of land-use categories, generated considerable discussion among the Fort Benning managers. Their subsequent input extended beyond the specific questions we posed, and we incorporated that input into the next set of material distributed to SEMP researchers. That set included the researchers' second-round responses, an explanation of the latest rendition of the suite of land-use categories, and only one bottom-line question, as follows:

Do you find the current land-use category matrix acceptable? If not, please provide specific suggestions that will make it acceptable to you.

In short, the group as a whole did not find the matrix fully acceptable. From that point, there were many interactions between SEMP researchers and us and between Fort Benning land managers and us. We incorporated new comments as rapidly as possible, but the pace of interactions was too rapid to allow formal, iterative summary-and-elicitation process that marked the early portion of the Delphi process. We became facilitators of a multi-party negotiation.

A previously scheduled face-to-face SEMP Integration Project meeting served as a forcing agent in two ways. First, we formally distributed a "final" (which became a "near final") version of the land-management matrix before the meeting. Second, a portion of the meeting was devoted to a discussion of the land-management categories. Our goal at this meeting was to finalize the suite of categories.

Meeting attendees included representatives of the five SEMP ecological indicator and ecological threshold research teams, including individuals who had and had not participated directly in the Delphi process. One Fort Benning land management representative (a Nature Conservancy employee) also was in attendance, as were researchers working on other SEMP projects at Fort Benning, and SEMP project/program managers. The resulting discussion among this broader group clarified many remaining issues, and resulted in the penultimate version of the land-management category matrix. After the meeting, we distributed this version of the matrix to researchers and land managers for their concurrence, which, after minor revisions, was finalized.

The final version of the land-management category matrix contains some substantive and organizational changes from previous versions. Not only did the "cause of predominant ecological impact…" label change, so did the label for the other dimension—to include endpoints as well as land management goals. Land management labels shifted from indicating the kind (intensity) of management activity toward specifying the purpose of management activities. Other label and categorization revisions were made to be more (a) compatible with researchers' and practitioners' perspectives; (b) understandable for individuals who may use the matrix in the future, particularly if they were not involved in the process of matrix creation; and (c) amenable to eventual application of the approach across all of Fort Benning. As one example, the "extensively managed" terminology of resource managers was confusing to most researchers. That language was changed to "minimally managed," to be more readily understandable both to researchers and potential future matrix users. Another illustration is the addition of the "built environment" subcategory, thereby including the cantonment area previously excluded from consideration.

4.2 Developing a framework to guide the integrating of plot-scale field investigations at different locations, different scales, etc.

The five independent field investigations (initiated well before integration efforts began) adopted different sampling strategies in accordance with divergent research designs and the spatial scale of field investigation ranged from points to ten or more hectares. Plot numbers also differed across projects. Examples include 32 plots for a threshold project and 50–60 plots per watershed for one of the indicator projects. Similarly, plot location varied, some falling in different watersheds, uplands or bottomlands, etc. At least one study took two different approaches simultaneously by investigating (a) surface hydrologic, soil, and understory parameters and (b) watershed-scale responses. Examples of plot layout include stratified random and grid patterns. There tended to be one or two sampling events annually, with the number of samples per sampling event ranging from 1 to a few thousand. Of course, the kinds of measurements taken varied tremendously, and included subsurface microbes, ant colonies, soil nitrogen or carbon, understory litter, among many others. Further, the time frame of analytical interest ranged from days to centuries.

Information provided during the Delphi-derived elicitation process made clear the diversity of subcategories across which projects distributed their field research plots. Because our integration effort began well after the research projects were underway, researchers could not have used the land-management categories that emerged in designing their field investigations. Decisions research teams made about how to categorize the installation for research design purposes did, however, reflect at least one dimension of what became the integration framework. Some projects, for instance focused on ecological "units" like upland pines, bottomlands, catchments, etc., and located their field plots within or across these units. Others placed field plots within or among installation categories that reflected "disturbance." For some projects, this disturbance primarily reflected by military uses of the land (vehicle versus foot traffic or areas not directly used by the military, as examples) implicitly in combination with intensity of those uses. Some projects incorporated an historical perspective, locating some field plots in areas formerly, but no longer used for various military training purposes. In other cases, plots sited across disturbance gradients emphasized "disturbance" associated with resource management practices (e.g., thinning, clearcutting, and prescribed burns), resource management goals (e.g., maintaining conservation areas, restoring habitats, erosion control), or both.

Had the land-management category matrix existed before SEMP field research projects began, we do not know if researchers would have distributed their field plots differently or if there would have been more consistency among projects in how they delineated "different" land-management categories or disturbance levels. Also unresolved at this point in time are the following issues: (a) whether the matrix will prove useful in designing new ecological indicator or threshold field research studies at Fort Benning or other areas; (b) if consistent use of the matrix would facilitate the synthesis and integration of results across projects; and (c) if using the matrix actually will enhance the usefulness of ecological research results for installation resource managers. These issues are more than idle speculation. Answers to them reflect the utility of the land-management category matrix for ecological researchers and for resource managers. Later stages of our overall integration effort, when SEMP studies are integrated in accordance with the land-management matrix, will provide some indications of the matrix's utility.

Our integration project deliberately focused on a plot-level spatial scale. It was in gathering information about the SEMP research projects as we were beginning the Delphi process that we decided to narrow our focus to plot-scale research efforts. The suite of SEMP research projects addressed different spatial scales; some components of a single research project centered on different scales. Many included plot-scale research, but some addressed other scales, like catchments and the entire Fort Benning landscape. We excluded these other studies from our Delphi effort for two related reasons. First, our desire for later phases of our integration efforts to have researchers assign a single land-use (later, land-management) category to a single piece of land did not mesh with the realities of larger-scale investigations. Catchment areas, for example, may include several different land-management categories. Second, as the difficulty of achieving consensus on land-management categories among researchers became apparent, we decided as a pragmatic matter that limiting the scale of interest to the plot-level might improve the likelihood of achieving that consensus. Both in initial Delphi interactions and as late in the process as the face-to-face meeting, researchers' comments sometimes strayed to catchment or landscape scales of interest.

Particularly when ecological processes and potential indicators for those scales were discussed in conjunction with plot scales, it became clear that the kinds of land-management categories we were trying to identify may not "scale-up," or transfer automatically beyond the plot level. We recognize that non-plot scale studies ultimately are important to include in the kind of integration effort in which we are involved. However, it is a matter of future empirical and experimental investigation to determine the extent to which discrete land-management categories aid or impede such integration efforts. One consideration in this vein is our emphasis on input from resource managers, which figured strongly in the identification of Fort Benning land-management categories. Scales that make sense from an ecological perspective, like catchments or landscapes, may not correspond directly to the scales at which resource management planning and, especially, practice occur. Some resource management planning endeavors are more concerned with land cover instead of land use. Further, resource management boundaries may be more likely to correspond to roads or other non-biological boundaries, such as the dividing lines between training areas, than to ecologically meaningful boundaries.

5. Discussion

We sought to develop a consensus-based framework to guide the integration of varied ecological field research projects in a manner that simultaneously would be scientifically sound and useful to resource managers. Our initial efforts to use land-use categories as the core of the integration framework shifted during the course of developing the framework. Instead, a consistent, consensus-based suite of land-management categories became central; the resulting land-management matrix is intended to help frame and focus later integration efforts.

Developing a land-management category matrix that both SEMP ecological researchers and Fort Benning resource managers found acceptable, like many endeavors, proved a more involved and challenging process than initially anticipated. Part of the difficulty is attributable to "cultural" differences among researchers and between researchers and resource managers. Both researchers and resource managers have different perspectives and research- or practice-oriented goals, so achieving consensus within a group could be challenging on its own. We compounded this difficulty, however, by simultaneously seeking consensus among and between SEMP researchers and Fort Benning resource managers in a two-part, but intertwined, integration process. Given the evolving and uncertain state of the ecological science and the intent to assure that the best available science is used in resource management application, we do not see an easier alternative. Seeking consensus only among researchers could provide a suite of land-management categories that are technically accurate but do not meet the needs of practitioners.

Similarly, consensus among resource managers may fail to the tests of scientific credibility and the ability to integrate the research projects. Management categories may not relate to ecological or geological systems. Moreover, military training managers may use another, entirely different, framework for designating land-management categories.

In addition to these cultural differences, we faced the challenge of integrating research studies retrospectively. Ours was a retrofitting, rather than a proactive, integration process. A proactive process, though initially time-consuming and likely to require adjustment as it is being implemented, may have the dual advantages of (a) identifying field research topics that will produce results likely to meet resource managers' needs (from resource managers' perspectives rather than solely scientists' perspectives); (b) making the integration of multiple field projects easier because issues like study location, scale, and data collection units could be more coordinated and, when appropriate, consistent from the start.

Nevertheless, in our situation, the five ecological indicator and threshold projects were well underway; some were drawing to an end. As a set, their original, funded proposals had different goals, methods, spatial scales of inquiry, field plot locations and sampling plans, and time frames of interest. Integration, therefore, entailed far more than simply compiling data. Conceptually, the land-management category matrix that emerged from the Delphi-derived process provides a common integrating framework for all the studies. Later phases of our integration project will test how robust this concept is. In addition, for future ecological field research studies that incorporate the multidimensional land-management categories from the start, the ability of a matrix of this type to facilitate integration remains to be seen.

Finally, the inherent complexity of land-use and land-management practices in a place like Fort Benning contributed to the unexpected difficulties we faced in producing the land-management category matrix. The installation is mission-oriented; it exists to achieve military training objectives. Therefore, it must be managed effectively to meet those goals. Training and the infrastructure needed to support training unquestionably affect ecological regimes in the short- and long-term, sometimes creating "unnatural" ecological states. These impacts will continue to occur. Perhaps the most extreme example is management of "sandboxes," areas used for tank maneuvers that virtually are devoid of vegetative cover. These sandboxes sometimes are re-graded, contoured, and re-seeded, and their use may be rotated. Nevertheless, management practices generally aim to maintain sandbox conditions and to avoid high levels of tank damage to other areas. At the same time, large installations like Fort Benning seek to achieve secondary, but important, conservation goals in addition to military training. Thus, considerable effort is spent in maintaining or restoring habitats conducive to threatened or endangered species like the red-cockaded woodpecker or gopher tortoise and, more generally, to maintaining or enhancing forested areas containing habitat such as mature upland pines or scrub oaks. Some of the practices undertaken to restore or preserve upland forests, such as thinning and prescribed burns, themselves affect ecological condition. It took some time and considerable thought and discussion to develop a land-management category matrix that simultaneously, systematically, and comprehensively included military uses of the land, the frequency or intensity of those uses, ecological conservation goals, and resource management practices. It became clear that considering only one of these dimensions was inadequate. Further, largely because the integration effort began towards the end of the five ecological research projects, the categories researchers used in selecting their field research plot locations inconsistently incorporated these various dimensions. Not only could these inconsistencies make integration of research projects more difficult, they also could diminish the utility of research results for resource managers who have to make decisions about what to do—or not do—on particular parcels of land.

6. Conclusion

We used a two-phase Delphi-derived approach to identify a suite of discrete land-management categories for Fort Benning. The shift from a formal Delphi approach to a Delphi-derived approach was our adaptive response to the interim results we obtained and the challenges that arose during the course developing a consensus-based integration framework. Resulting land-management categories are intended to serve as a vehicle for integrating research (multiple ecological indicator and ecological threshold studies), and for relating ecological research results to the practice of environmental resource management.

The Delphi-derived approach proved to be an effective tool for delineating land-management categories in a complex landscape such as found at Fort Benning. Participating researchers and resource managers developed a multi-dimensional land-management category matrix whose dimensions include cause of predominant ecological impact of military uses of land, land management goals and endpoints, and frequency and intensity of use. This matrix allows a specific field research plot to be assigned to a unique land-management category, even if that plot had been subjected to different uses in the past or currently is used for multiple purposes. Further, the resulting land-management categories provided a common framework within which to relate a series of research projects designed for different purposes, conducted at different locations and spatial scales, and focused on different temporal units.

Implementing two-phase Delphi-derived interactions with both ecological researchers and resource managers was directly responsible for the sophistication of the resulting land-management matrix. It is clear that the integration of ecological research conducted for the benefit of natural resource management should involve both researchers and resource managers. It also is clear that defining land-management categories by both land management goals and causes of predominant ecological impact allows the categories to be used for forward-thinking environmental management and to take into account past activities on the land. Using a Delphi process to create a specific, multi-dimensional integrating framework should prove valuable in assuring that the data, models, and information produced by scientists are both useful and usable by the practitioners for whom the science was conducted.

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References

V. H. Dale, S. C. Beyeler, and B. Jackson, Understory indicators of anthropogenic disturbance in longleaf pine forests at Fort Benning, Georgia, USA. Ecol. Indicat. 1(3) (2002) 155–170.

V. H. Dale, S. Brown, R .A. Haeuber, N. T. Hobbs, N. Huntly, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone, Ecological principles and guidelines for managing the use of land. Ecol. Applic. 10 (2000) 639–670.

V. H. Dale, P. Mulholland, L. M. Olsen, J. Feminella, K. Maloney, D. C. White, A. Peacock, and T. Foster, Selecting a Suite of Ecological Indicators for Resource Management, *Landscape Ecology and Wildlife Habitat Evaluation: Critical Information for Ecological Risk Assessment, Land-Use Management Activities and Biodiversity Enhancement Practices, ASTM STP 11813*, L. A. Kapustka, H. Gilbraith, M. Luxon, and G. R. Biddinger, Eds., ASTM International, West Conshohocken, PA, (2004)

A. Fontana, and J. H. Frey, Interviewing: The art of science, in N. K. Denzin and Y. S. Lincoln, (Eds.), *Handbook of Qualitative Research.* Sage Publications, 1994, pp. 361–376.

C. T. Garten, T. L. Ashwood, and V. H. Dale, Effect of military training on indicators of soil quality at Fort Benning, Georgia. Ecol. Indicat. 3(3) (2003)171–180.

A. A. Gokhale, Environmental initiative prioritization with a Delphi approach: A case study. Envir. Mgmt. 28(2) (2001) 187–193.

W. D. Goran (complier), *SERDP Ecosystem Management Project (SEMP): 2003 Technical Report.* ERDC SR-04-3. Engineer Research and Development Center, U.S. Army Corps of Engineers. Contributing authors: H. E. Balbach, B. S. Collins, V. Dale, J. S. Fehmi, C. T. Garten, W. D. Goran, R. M. Kress, A. J. Krzysik, K. R. Reddy, D. L. Price, and H. M. Westbury, March 2004.

T. A. Greene, *Management framework development and implementation of management goals and objectives associated with the Fort Benning Army Installation's Integrated Natural Resource Management Plan. Final Report.* The Nature Conservancy, 2002.

G. R. Hess, and T. J. King, Planning open spaces for wildlife: I. Selecting focal species using a Delphi survey approach. Landscape and Urb. Plan. 58(1) (2002) 25–40.

S. Jones, D. Lach, and B. Fischhoff. Evaluating the interface between climate change research and decision making. Clim. Change (1999) 1–19.

A. J. Krzysik, H. E. Balbach, J. J. Duda, J. M. Emlen, D. C. Freeman, J. H. Graham, D. A. Kovacic, M. P. Wallace, J. C. Zak, *Development of Ecological Indicator Guilds for Land Management, DACA42-00-2-0002, Team Annual Report FY2003,* Strategic Environmental Research and Development Program (SERDP), 2003, **http://www.cecer.army.mil/KD/SEMP/index.cfm?chn_id=1080**.

H. A. Linstone, and M. Turoff, eds.. *The Delphi Method: Techniques and Applications.* Digital version (reproduction of 1975 book), (2002) http://www.is.njit.edu/pubs/delphibook/.

K. O.Maloney, P.J. Mulholland, and J.W. Feminella, Influence of catchment-scale military land use on physicochemical conditions in small Southeastern Plains streams (USA). Envir. Mgmt. in press.

G. R. Matlack, Exotic species in Mississippi, USA: Critical issues in management and research. Nat. Areas J. 22(3) (2002) 241–247.

G. A. Mendoza, and R. Prabhu, Development of a methodology for selecting criteria and indicators of sustainable forest management: A case study on participatory assessment. Envir. Mgmt. 26 (6) (2000) 659–673.

J. W. Nagels, R. J. Davies-Colley, and D. G. Smith, A water quality index for contact recreation in New Zealand. Water Sci. Tech. 43 (5) (2001) 285–292.

A. D. Peacock, S. J. MacNaughton, J. M. Cantu, V. H. Dale, and D. C. White, Soil microbial biomass and community composition along an anthropogenic disturbance gradient within a longleaf pine habitat. Ecol. Indicat. 1(2) (2001) 113–121.

S. Rayner, D. Lach, H. Ingram, and M. Houck, *Weather Forecasts are for Wimps: Why Water Resource Managers Don't Use Climate Forecasts*. Final Report to the National Oceanic and Atmospheric Administration (NOAA) Office of Global Programs, 2001. Also published as Oregon Water Research Institute SR-2003-1 and available at http://cwest.oregonstate.edu/cwest_library/SR-2003-1.pdf.

R. Reddy, J.Prenger, W.Graham, J. Jacobs, A. Ogram, D. Miller, S. Rao, G. Tanner, *Determination of Indicators of Ecological Change. Quarterly Progress Report July 1–September 30, 2003*. SEMP Project CS-1114A-99, 2003. http://www.cecr.army.mil/KD/SEMP/index.cfm?chn_id=1078.

SEMP (SERDP Ecosystem Management Project) web site, http://www.cecer.army.mil/KD/SEMP/index.cfm?chn_id=1063, last viewed May 25, 2004.

SEMP (SERDP Ecosystem Management Project) Projects web site, http://www.cecer.army.mil/KD/SEMP/index.cfm?chn_id=1077, last viewed May 25, 2004.

E. J. Soderstrom, *Social Impact Assessment: Experimental Methods and Approaches*. Praeger, 1981, New York.

B. Steel, D. Lach, P. List, and B. Shindler, The role of scientists in the natural resource and environmental policy process: A comparison of Canadian and American Publics. J. Envir. Sys. 28(2) (2000–2001) 133–155.

J. G. Taylor, and S. D. Ryder 2003. Use of the Delphi method in resolving complex water resources issues. J. Amer. Water Res. Assn. 39(1): 183–189.

B. L., Turner II, and W. B. Meyer, Global land-use and land-cover change: an overview, in W. B. Meyer and B. L. Turner II, (Eds.), Changes in land use and land cover: a global perspective. Cambridge University Press, 1994, Cambridge, England, pp. 3–10.

Figure 1. Main goals of the five SERDP plot-level ecological research projects at Fort Benning

Indicators—Three Projects	*Thresholds—Two Projects*

• (2 projects) identify indicators that mark ecological change in intensely versus lightly used ecological systems, focusing on
  o suite of variables to measure changes at several scales, including forest understory, stream chemistry and aquatic biology, and soil microorganisms (Dale et al. 2002, 2004; Maloney et al. in press; Peacock et al. 2001)
  o multi-indicator approach, evaluating soil, understory vegetation, and surface hydrology parameters (Reddy et al. 2003)
• classifications of ecological indicators to assess and monitor ecological changes and thresholds (Krzysik et al. 2003)
	• compare military training compartments that are open or closed to tracked vehicles (e.g., tanks), where the underlying sandy or clay soils experimentally are subjected to different forest management practices (different burn cycles, thinning regimes, etc.) (Dilustro et al. 2002, Duncan et al. 2004)
	• define soil integrity, focusing on soil organic matter and nitrogen dynamics (Garten et al. 2003)

Figure 2. Schematic view of the Delphi-derived method as implemented to develop land-management categories, showing order of interactions (indicated by circles) with two main groups, mode of interaction, and topic of discussion

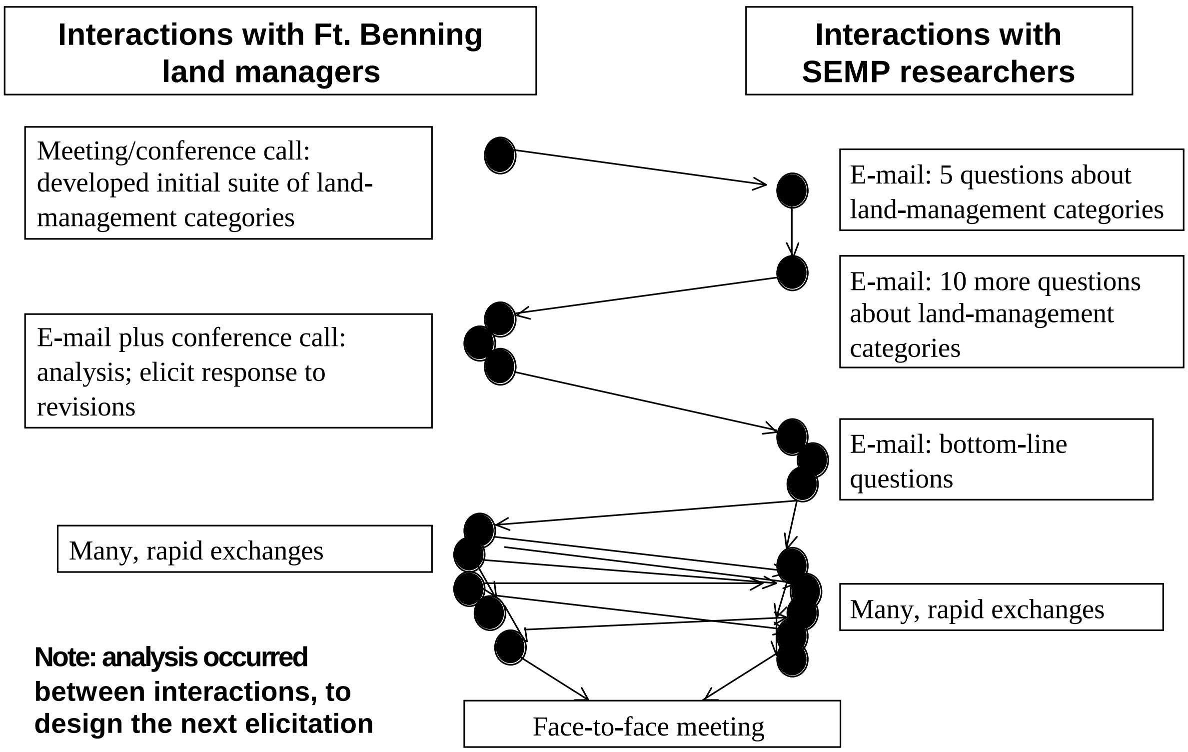

Figure 3. Questions used in the 1st-round elicitation of SEMP researchers

1. As a set, are the proposed land-use categories
   a. Well-defined?
   b. Comprehensive?

   Please explain your answers, providing as much specific detail as possible.
2. Are each of the land-use categories
   a. Sufficiently discrete?
   b. Focused appropriately (neither too broad nor too narrow)?

   Please explain your answers, providing as much specific detail as possible.
3. Do the proposed land-use categories capture the differences among field research plots about which your research team is concerned? Explain your answer, providing as much specific detail as possible.
4. Give a rough approximation of how your research team's field plots are distributed across the proposed suite of land-use categories (or, across the suite of categories according to your proposed revisions). Take only a few minutes to complete this question.
5. What land-use categories would you revise, add, or subtract? Please provide all of your suggested revisions.

Table 1. **Land-management categories as determined by military training and land management practices—final version**

Key '0' = *military uses* do NOT occur in areas managed in specified ways

'I' and 'F' = the relative frequency with which *military uses* occur in areas managed in specified ways (I = infrequent and F = frequent).

'+' = *land management* options in areas not used by the military

Land management goals and endpoints	**Cause of predominant ecological effect from military use(s) of land**								
	Tracked vehicles	**Wheeled vehicles**	**Foot traffic**	**Designated bivouac areas**	**Firing ranges**	**Impact areas**	**Drop or landing zones**	**No military effect**	**Admin-strative use**
1. Minimally managed areas									
1.1 Wetlands	I,F	I, F	I	0	0	0	0	+	0
1.2 Vegetation on steep slopes	I, F	I, F	I	0	0	0	0	+	0
1.3 Forests in impact zones	0	0	0	0	0	I,F	0	+	0
2. Managed to restore and preserve upland forest									
2.1 Upland forests 2.1.a Long leaf dominance 2.1.b Mixed pine 2.1.c Scrub oak pine mix	I	I,F	I, F	0	0	0	0	+	0
2.2 RCW mgmt clusters	I	I	I,F	0	0	0	0	+	0
2.3 Sensitive area designated by signs	0	0	I,F	0	0	0	0	+	0
3. Managed to maintain an altered ecological state									
3.1 Intensive military use areas	F	F	0	I,F	F	0	0	0	0
3.2 Wildlife openings	0	I	I	0	0	0	I	+	0
3.3 Mowed fields	0	I	I,F	0	I,F	0	I,F	+	0
3.4 Roads (paved and unpaved)	I, F	I, F	I, F	0	0	0	0	+	0
3.5 Built environment	0	0	0	0	0	0	0	0	+

APPENDIX III

Science versus practice: Using a Delphi-derived approach to reconcile world views

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Abstract

This article broadly addresses the question of how to assure that science conducted to assist practitioners achieves that goal. More specifically, it describes a case involving ecological science and natural resource management at Fort Benning, a U.S. Army installation in Georgia. Disparate ecological studies were funded by a single federal agency to enhance the ability of Fort Benning resource managers to achieve their resource management goals. Our project team's (consisting of an anthropologist, ecologist, microbiologist, statistician, and, later a geographic information systems specialist) role was to integrate the scientific studies in a manner that would be meaningful and useful for resource managers. We provide an account of the approach we took to develop a common framework to serve as the basis for this integration, describing how that approach shifted from a Delphi expert elicitation to something more akin to facilitated negotiation. The article ends with a discussion of the potential utility of our approach in other settings when the aim is to produce scientific results that meet practitioners' needs, specifically in the realm of ecological science and resource management.

key words: Delphi approach; ecological science; resource management; integrating science with practice; Fort Benning Military Installation

Introduction

How do you integrate emerging scientific findings into existing management practices? Stated another way, how do you assure that current management practices are appropriate, based on the latest science? These questions are at the crux of this article. Our challenge was to integrate a set of scientific studies in a way that would prove useful for resource managers, specifically at the U.S. Army military installation at Fort Benning, Georgia, in the southeastern United States. Here, we focus on the methods we used to achieve this integration, describing how they helped disparate parties achieve consensus over time.

Our challenge reflects broader issues that emerge from the persistent clash between science and practice. It is almost as if this clash plays out in different arenas. The "science" arena is one in which there are continuing calls for "science-based" decision making and greater science literacy, as well as expressions of frustration about the gulf between science and policy or practice (e.g., Aber et al. 2000; Carnegie Commission 1992; Sigma XI 1993; National Academies 2005). In contrast, the practitioner arena may be marked more by behavior than by words—data, studies, and models that do not prove useful simply are not used (see, as examples, Jones et al. 1999; Rayner et al. 2001; Steel et al. 2000–2001).

There are many explanations for why the disjunction between science and practice endures. Explanations range from the questionable view that science is objective and divorced from social influences, to the solicitation-plus-peer-review process that defines and constrains what science is funded, to the incentives or markers of success for scientists versus practitioners, to stereotypic motivations for scientists (seek knowledge) and practitioners (resolve problems), as examples. Other explanations emphasize cultural and sociological factors that influence scientists and practitioners working within their organizational settings, to adopt particular goals, objectives, and constraints. While this article does not explore these explanations, they clearly factor into the real-world challenges of reconciling science with practice. They largely created the context within which we worked and the need for an iterative, consensus-building process. They influence the kind and degree of reluctance or comfort scientists and practitioners may have in shifting from the familiar (their world views) to new territory.

We describe the methods we used in a specific case at the U.S. Army military installation at Fort Benning, Georgia. The science consisted of several years of ecological indicator and threshold studies at Fort Benning, funded with the broad intent of assisting installation resource managers. We label as "practitioners" Fort Benning resource managers, a group that includes both military personnel and staff of The Nature Conservancy, who are developing the Integrated Natural Resource Management Plan for Fort Benning. Our intent was to use a Delphi approach to achieve consensus. However, as the process unfolded our methods evolved to what we label a "Delphi-derived" approach. We believe these Delphi-derived methods may be applicable to other resource management settings, and perhaps to other cases in which scientific studies are conducted to enhance practice.

Resource Management and Ecological Indicator and Threshold Research at Fort Benning

Fort Benning, Georgia, is a 75,533 hectare (181,626 acre) military facility. The installation includes 5759 ha (14,231 ac) cantonment areas, which house residential, office, and other similar infrastructure that must be managed and maintained. Fort Benning's prime mission is military training and testing. Portions of the installation are used for—and managed to allow—such activities as tank maneuvering, firing ranges, drop zones, and bivouac areas. In addition, Fort Benning is subject to a variety of state and federal natural resource guidelines and regulations, and it is managed accordingly. As examples, resource managers thin upland pine forests; use fire to control understory growth; restore ecological conditions in the understory; and protect rare species like the red-cockaded woodpecker (Picoides borealis) and gopher tortoise (Gopherus polyphemus). Taking all of these elements together, the installation is faced with sometimes competing and conflicting planning objectives.

Beginning in the late 1990s, the SERDP (Strategic Environmental Research and Development Program) Ecosystem Monitoring Project (SEMP) funded a total of five projects at Fort Benning intended to identify ecological indicators (three projects) or ecological thresholds (two projects) that signal ecological change. Indicators and thresholds are intended to be useful for planning, implementing, and monitoring the impacts of military land-management practices at military installations. Once identified, the concept was to determine how indicators and thresholds can be incorporated effectively into Fort Benning's monitoring and management programs. These findings, then, should be applicable to other military installations with similar ecological conditions.

Aspects of the five Fort Benning projects center on plot-scale investigations, but have different goals and field-investigation sites (Goran 2004, see also the SEMP web site: http://www.cecer.army.mil/KD/SEMP/index.cfm?chn_id=1063).

- Threshold projects
  - compare military training compartments that are open or closed to tracked vehicles (e.g., tanks), where the underlying sandy or clay soils experimentally are subjected to different forest management practices (different burn cycles, thinning regimes, etc.) (Dilustro et al. 2002, Duncan et al. 2004).
  - emphasize soil integrity by focusing on soil organic matter and soil nitrogen dynamics (Garten et al. 2003).
- Indicator projects
  - seek to identify indicators that mark ecological change in intensely versus lightly used ecological systems by
    - identifying the suite of variables needed to measure changes at several scales (Dale et al. 2004) by investigating forest understory, stream chemistry and aquatic biology, and soil microorganisms (Peacock et al. 2001, Dale et al. 2002, Maloney et al. in press)
    - taking a multi-indicator approach to evaluate a set of soil, understory vegetation, and surface hydrology parameters (Reddy et al. 2003)
  - use classifications of ecological indicators to assess and monitor ecological changes and thresholds (Krzysik et al. 2003).

Our integration goals—creating a common framework

Our charge was to integrate these five ecological indicator and threshold projects to allow them to complement existing Fort Benning resource management documents, tools, and practices. In its entirety, this integration involves multivariate statistical analyses of SEMP project-derived indicators and geographic information system (GIS) mapping of analytical results. The integration effort was initiated well after these five multi-year projects; some were nearly completed. Integrating projects that collected different kinds of data, using different units of measurement, sampled with varying frequencies from disparate field locations and conditions poses obvious challenges. Conducting this integration in a way that simultaneously proves useful for resource management amplified those challenges.

A first step in the larger integration was to create a common framework within which to operate. We initially planned to delineate a suite of defined, discrete Fort Benning land-use categories acceptable to all SEMP researchers, thinking that “land use” would be an effective backdrop for integration. Agreed-upon land-use categories then would provide a framework that focuses and guides the integration of disparate indicators across the Fort Benning reservation. In this context, “integration” refers to an evaluation of the several proposed indicators to ensure that, collectively, they provide comprehensive and useful metrics that can serve as a basis for improved environmental management. The final result was intended to be a set of land-use categories for Fort Benning, effective for its land management activities and likely transferable to other installations in the region to which similar land-use and management practices are applied. However, as will be detailed below, because “land-use categories” proved inadequate as an integrator we shifted to what we label “land-management categories.” As will be described, this shift is far more than a semantic adjustment; it represents a considerably different basis for integration.

From a Delphi approach to a Delphi-derived approach for achieving consensus: an overview

We originally selected a Delphi approach to achieve consensus on the integration framework. The Delphi emphasis on expert opinion (representatives of the five SEMP research teams), ability to elicit information at a distance instead of face-to-face, and the iterative nature of our research fit well within our time and resource constraints. Because we wanted the land-use categories to be useful and clear to Fort Benning resource managers, we originally planned to engage them at two stages—before initiating the Delphi process with SEMP researchers to help develop our first set of questions and after the Delphi process was completed to check that the resulting integration framework made sense. However, we ended up consulting the land managers much more than anticipated and injecting their input into the interactions with SEMP researchers. Our Delphi approach morphed more into a facilitated (by us), iterative information elicitation and negotiation process that occurred primarily by e-mail, occasionally by telephone, and eventually by what emerged as a critical face-to-face meeting.

Insert Figure 1

A schematic view of how we implemented the Delphi process appears in the Figure 1. It starts with our face-to-face meeting with Fort Benning land managers[i] to develop the initial suite of land-use categories. And, though the figure ends with the face-to-face meeting with researchers and resource managers, our project team also continued interacting with both groups via e-mail to fine-tune the resulting framework, a land-management category matrix.

Preliminary consultation with land managers: developing an initial land-use framework

Our first discussion with Fort Benning land managers made clear that, though we categorize them as a single group, it is not a homogeneous group. Each individual has his or her professional objectives and perspectives; our meeting prompted a rare circumstance in which the group met face-to-face. Nevertheless, this first meeting raised many of the issues that we grappled with throughout the course of developing a consensual integration framework. At their core, many of these issues centered on articulating precisely what "entity" to use as the integrator. For instance, while ecological conditions have been defined for land-cover groups at Fort Benning, land cover (ecological state as conveyed by physical appearance—closed forests, open forests, grasslands, etc.) may mask land uses and the influence of natural versus human-caused elements. Participants in the initial meeting decided, instead, to focus the integration of land use (purpose to which land is put by humans, such as protected areas, forestry for timber products, pastures, etc.). The rationale was that some indicators may be able to distinguish among land uses and signal when a particular area is becoming degraded.

However, the meeting made clear that some land-use issues were important to resolve during the process of developing a limited set of land-use categories (the integration framework). As one example, some land areas are subjected to multiple uses, such as timber management and military training. In a different vein, the resource managers discussed the difficulties in determining when natural disturbance impacts and subsequent management actions should differ according to land use. Further, they highlighted elements that operate simultaneously at Fort Benning that are necessary to consider in distinguishing, and making management decisions about, particular parcels of land. These elements are (1) military uses of land, (2) the frequency of those uses, and (3) land-management goals.

Because military uses of land together with their frequency can dramatically influence ecological effects (e.g., tank traffic vs. occasional wheeled vehicle traffic, vs. foot traffic), the Fort Benning resource managers underscored the importance of distinguishing kinds of military use and their frequency. There also was considerable discussion of land-management goals and practices. The managers decided that the installation's land-management goals for particular areas are more stable than either the specific management practices undertaken in those areas or land cover types. Therefore, participants suggested categorizing land areas within Fort Benning according to land-management goals. In addition, practitioners noted that different land goals can involve varying kinds of land-management activity, ranging from light ("extensive," in their language) to heavy ("intensive").

Based on this meeting, military use and land management dimensions became a cornerstone for land-use category development. Rather than delineate a list of land-use categories, the group juxtaposed the dimensions and created a land-use category matrix (see Table 1 for the initial version, which showed all possible combinations rather than those specifically relevant to Fort Benning).

Insert Table 1 here

Round 1 with SEMP researchers: Raising challenging issues

The matrix developed with Fort Benning resource managers became the focus for the first round of the Delphi process with SEMP researchers, in July 2003. We asked researchers five questions (Figure 2). The responses of the researchers raised three issues that remained contentious and unresolved throughout much of the modified Delphi process. One issue previously had been raised by Fort Benning resource managers, namely how to categorize areas in which there are multiple military uses. Researchers also suggested possible solutions such as categorizing according to intensity of military use or by majority use. In preparing questions for the second round of elicitations, we suggested using the label "predominant military uses of land" instead of "military uses of land" and asked whether "predominant" should be interpreted in terms of frequency of use or extent of ecological impact. This issue remained an unresolved, even after the second round of elicitations, which occurred later in July.

Insert Figure 2 here

Researchers also raised two "new" issues about how best to categorize those portions of Fort Benning (a) whose current ecological condition is dominated by past, but not current land uses, and (b) that are affected by adjacent land uses. It was only at the face-to-face meeting towards the end of our Delphi-derived process that the group decided that "predominant" military use of land referred to the use with the greatest ecological impact, no matter whether that impact was caused by one of multiple, past, or adjacent land uses. Labels used in successive versions of the evolving integration matrix show the evolution of the group's (both researchers and practitioners) thinking. First, the label was "military use(s) of land" (Table 1). "Predominant military use of land" was the interim label (Table 2). And, the final version (Table 3), though wordier, became quite specific—"cause of predominant ecological effect from military use(s) of land."

Round 2: Refining the integration matrix

Insert Figure 3 here

The second round SEMP researcher elicitation consisted of a summary of Round 1 and a new set of questions (Figure 2) based on the specific suggestions and issues raised during Round 1. Table 2 depicts the manner in which we incorporated most suggested revisions and identified questions for SEMP researchers to address. Changes from the initial proposed land-use table were denoted in a heavier, bold font. We emphasized to researchers that Table 2 offered one way to respond to their suggestions, and that it was essential for the SEMP integration effort that they all agree that the final suite of land-use categories is acceptable and usable. For researchers, "usable" meant that they would be able to assign one land-use category to each of their field plots, a task they were told they would be asked to do.

Insert Table 2 here

Round 3 and the face-to-face elicitation: The "final" integration matrix emerges

It was in preparing this third formal elicitation that we deviated from a typical Delphi approach, looking beyond our group of researcher experts for assistance and did so in an increasingly informal, rapid manner. Our reason for making this deviation was that, to create an integration matrix for round 3, we needed to make several judgments about how to handle issues researchers raised and variations in their responses to Round 2. Rather than make those judgments alone, we consulted with the Fort Benning resource managers to help assure that the integration process truly would serve their needs. We contacted Fort Benning resource managers initially by e-mail, then through a conference call, with subsequent e-mail and telephone contacts. This set of interactions evolved partly because the modified matrix and the issues raised by researchers generated considerable discussion among the resource managers. Ultimately, the matrix used in the Round 3 elicitation of August 2003 reflected researchers' and resource managers' input (Table 3; again, modifications are in bold). We also provided a summary the preceding round's result and briefly mentioned our interactions with Fort Benning resource managers.

We thought—or, perhaps, hoped—that Round 3 would be the final one. Thus, we asked just a single question, "Do you find the current land-use category matrix acceptable? If not, please provide specific suggestions that will make it acceptable to you." The matrix proved unacceptable, which generated a host of additional interactions, both between SEMP researchers and our project team and between Fort Benning land managers and our team. The pace of interactions was too rapid to allow formal, iterative summary-and-elicitation process that marked the early portion of the Delphi process. However, a previously scheduled face-to-face SEMP Integration Project meeting in September 2003 ended up serving as a venue in which to resolve remaining issues and develop a "final" (in actuality, the penultimate) version of the matrix. Because this meeting's objectives were not limited to our integration efforts, participants included representatives of SEMP research teams (including some who had not been direct participants in our process), a Fort Benning resource manager, and SERDP SEMP managers. Clearly, even if a traditional Delphi round included a face-to-face elicitation; participants would not vary from the original group of experts.

Insert Table 3 here

Apparently simple changes to the integration matrix may embody sophisticated thinking and considerable complexity. With that knowledge in mind, the changes to the integration matrix after rounds 1, 2, and 3 appear to be relatively simple refinements. The matrix that emerged from the face-to-face meeting, in contrast, was markedly different from previous versions (Table 4, with changes from preceding versions in bold—table includes minor revisions made after the face-to-face meeting, through e-mail exchanges). Changes were both substantive and organizational. The label for the “land management goals” dimension was amended to include endpoints as well as land management goals; “endpoints” is a term and concept familiar to ecologists engaged in indicator-related research. Land management labels shifted from indicating the kind (intensity) of management activity toward specifying the purpose of management activities. Other label and categorization revisions were made with the explicit intension of being more (a) compatible with researchers’ and practitioners’ perspectives; (b) understandable for individuals who may use the matrix in the future, particularly if they were not involved in the process of matrix creation; and (c) amenable to eventual application across all of Fort Benning. As one example, the “extensively managed” terminology was confusing to most researchers. That language was changed to “minimally managed,” to be more readily understandable both to researchers and potential future matrix users. Another illustration is the addition of the “built environment” subcategory, thereby including for future use the cantonment area excluded from consideration for the purposes of this integration project.

Next steps in the integration process—using the integration matrix

The analysis phase of integration continues and will be described in later articles. Briefly, each research team was asked to assign each of their field plots to a particular cell in the integration matrix. These assignments were checked and validated by our integration team and, where questions arose, by a Fort Benning resource manager especially knowledgeable about the installation’s ecology. Then, the field data associated with each cell were analyzed through multivariate statistics to determine the suite of indicators best able to describe a set of ecological conditions.

Results of these sets of analyses will be mapped in GIS layer, as well. To date, our team (especially Latha Baskaran) created detailed GIS maps of land-management categories in advance of the integration itself. Maps consisted of two layers, derived from the integration matrix: (a) land management goals and endpoints and (b) cause of predominant ecological effects from military use(s) of the land. Existing data were used to create these maps, but it also was necessary to consult with and obtain input from Fort Benning resource managers to assure their accuracy. Likewise, Fort Benning resource managers will review both sets of integration results—statistical and GIS—as a form of “ground-truthing.” All of these efforts are intended to lead to a set of ecological indicators for Fort Benning that are technically sound (defined by criteria established primarily by ecological researchers) and practically useful (defined by criteria established primarily by Fort Benning resource managers).

Discussion

This article details our efforts to develop a common, consensus-based framework for integrating several research projects, and to do so in a way that would be useful for practitioners. Our initial plan to use a Delphi approach with representatives of the research teams, eliciting input from Fort Benning resource managers before and after to help prepare the first elicitation and as a check on the resulting framework, proved overly simplistic. We anticipated that scientists and practitioners would act in accordance with substantially different perspectives, goals, and objectives. From a pragmatic perspective, we cared more about reconciling these differences than about analyzing underlying explanations for them. Still, we underestimated the diversity of perspectives within both resource manager and researcher groups. And, our decision to introduce an interim check by resource managers had the effect of altering our research approach—and results—substantially. What started as a Delphi approach morphed into a facilitated (by our project team) negotiation within and between groups, producing the desired integration framework.

These experiences made it clear that our overarching approach of consulting both practitioners and researchers in developing a commonly understood and agreed upon integration framework was appropriate. However, part of why reconciling practitioners' and scientists' world views was more challenging than we anticipated was that we were also reconciling varying perspectives and knowledge sets within each group. After our initial meeting with Fort Benning practitioners, some of them commented on how rare it was for that group to get together and talk with one another. Focusing on creating an integration framework revealed differences in participants' roles at the installation and in the kinds of ecological information needed for their jobs. Unlike the practitioners, SEMP researchers met periodically in review or information-sharing meetings to discuss their work. However, the researchers focused on their own work and not on producing a common, synthesized product (documents like annual reports to which researchers contribute usually are more compilations than syntheses). Producing the integration framework had the effect of forcing these researchers to confront how their disparate foci, measures, and findings could be combined to paint an ecological picture of Fort Benning useful as a basis for resource management decision making.

Once deciding that both practitioners and researchers should be involved in the process, the question of what methods to use in accomplishing this integration had to be resolved. This question was not simply one of how to incorporate science into decision making because neither "science" nor "practice" are singular entities. Science is disparate in its goals, measures, and findings; sometimes contradictory; evolving over time; and incomplete. Practice also entails different goals and approaches, even within a single installation. Considering these kinds of complexity together with our experiences, what methods would we use if we were undertaking a similar project again either after most research was completed, or, better, before research would be undertaken? Would we propose the "Delphi-derived" approach that emerged during our project?

There are multiple factors to consider in answering the previous questions. One factor was how we frame our work. The shift in our methods reflected a shift in how our project team conceptualized our task, although we might not have been able to articulate what that shift was as it was unfolding. When we were in the Delphi mode, we thought of our task as an expert elicitation. The Delphi approach has proven useful for conducting that kind of elicitation, particularly for parties who are geographically dispersed and when time pressures exist. Its iterative aspects were desirable in the context of our project goals because the feedback would allow us to check the accuracy of our interpretations and would prompt for new insights and information from participants. However, trying to implement a Delphi or Delphi-like approach simultaneously for two disparate groups of experts was awkward at best, particularly given our time constraints.

Information elicitation was not parallel between researchers and practitioners. We queried researchers as individuals, but because the initial purposes of the two groups were different, we queried practitioners as a group or through a key contact, who then would talk with others at Fort Benning. Thus, practitioners had the opportunity to exchange ideas and discuss matters directly. Two members of our team were parties to the initial meeting with practitioners, benefiting from hearing the interactions and observing the attention paid to the questions posed. We have no way of knowing the amount or kind of attention individual SEMP researchers paid to our inquiries (though they received additional funding for the purpose of assisting our integration effort). Nor do we know whether researchers were in any way upset or put off when we included Fort Benning resource managers and their input during the Delphi process.

It was adding the face-to-face meeting, however, that marked the greatest departure from the traditional Delphi approach. It also was the face-to-face meeting that embodied the shift from iterative knowledge elicitation and consensus building to facilitated negotiation. The meeting evolved from pragmatic project considerations—we were opportunistic in taking advantage of a previously planned meeting. We used the meeting as a forcing event that would, in a time-efficient manner, lead the groups to resolve remaining issues. Beyond its venue, several other factors operated to distinguish it from our e-mail elicitations.

First, before initiating discussion, we were asked to give a presentation summarizing our progress and integration matrix to date. This presentation and the question-and-answer session associated with it seemed to generate a deeper understanding of our objectives among some participants than the written background materials we provided with each elicitation. Second, there was a greater number and diversity of meeting participants than Delphi participants. Meeting participants included researcher team members who had, and who had not, participated in the Delphi elicitation; individuals who conducted other related research at Fort Benning; persons involved in Fort Benning resource management and operations; and SERDP managers. This broader group participated actively in developing the penultimate integration matrix. Third, meeting participants talked directly to one another—asking questions of each other (e.g., what do you mean by "x"), of the entire framework (e.g., why exclude the cantonment area), adding different perspectives (e.g., my unit of study is the watershed, not plot, but…), debating points (e.g., should we be looking at management goals or endpoints), and jointly resolving points of contention (e.g., how to categorize impacts to one locale caused by activities in an adjacent locale). Our project team's primary roles were to facilitate the discussion and record results. The extensive modifications of the integration matrix that resulted from this meeting reflect its dynamic and productive interactions.

On the one hand, the results from the face-to-face meeting were dramatically different from the marginal refinements after each Delphi round. The face-to-face meeting also led to consensus, unlike the preceding efforts. Would a face-to-face meeting occurring in the absence of the Delphi build-up have proved so effective? And, could a Delphi approach, alone, have produced the substantial revisions and consensus of the face-to-face meeting? We do not have the luxury of testing these questions systematically through controlled research projects. We would hypothesize, however, that an effective methodological approach would consist of three general stages that combine knowledge elicitation and negotiation:

- an initial and separate, non-confrontational elicitation of information (in our case, a preliminary integration framework or its necessary dimensions and components) from each group;
- documenting and synthesizing each group's position(s), assuring that each group finds its synthesis accurate; and
- sharing syntheses with both groups, and using the syntheses as a basis for negotiating a consensus-based product.

These stages could be operationalized in a variety of ways. For instance, the initial elicitations could be accomplished through a Delphi approach, nominal group process, or other methods. In a practicing (rather than academic) setting, it may be most efficient to "force" within-group consensus by structuring the initial elicitations around the goal of creating a tangible, though interim, product (e.g., a preliminary integration framework). Going through this initial process engages participants and starts them thinking about the issues at hand. Resulting interim products, together with a summary of the thought processes supporting them, give members of each group a glimpse into the other group's world view. The combination of initial consideration plus documentation may help participants articulate the sources of their discomfort or disagreement with the other group's proposition in later, negotiation stages. While it is possible that the facilitated negotiation stage could occur in various venues, our success with face-to-face interaction would encourage us to use that process in the future. Working from tangible interim products to create a final, consensus product also may help to focus discussions.

Assuring that science conducted to assist practitioners achieves that goal is deceptively difficult to achieve. Conducting scientific studies and reporting results is insufficient, even if that science explicitly is aimed at improving practice and especially when the studies produce different bits—and types—of information that do not automatically produce a coherent or comprehensive picture. The framework we sought to develop is intended to serve as an explicit foundation for integrating diverse scientific studies in a way that is useful for practitioners. Our experiences indicate that, in creating such a framework, delineating and conveying one group's perspectives and opinions to the other is a necessary, but insufficient step. We propose adding direct, facilitated, negotiation to the process. In the course of our work on ecological indicators for resource management, we will have at least two tests of the success of our process. First, we are completing the rest of the integration process for Fort Benning and will see (at least informally) if the results actually are useful for resource managers in an expanded form that now includes a mapping (GIS) component. Second, we hope to begin another project soon at a different military installation. This time, we will develop an integration framework with researchers and practitioners before scientific studies are conducted, checking and refining the framework during the course of the multi-year scientific investigations. We then will see if the findings for that set of scientific studies simply are documented in reports and peer-reviewed journal articles, or whether they are used by the resource managers they are intended to help.

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[1] One member of the SEMP integration project team participated by telephone.

References

Aber, J. et al. 2000 (Spring) Applying ecological principles to management of the U.S. national forests. Issues in Ecology, No. 6. The Ecological Society of America. Available at http://www.esa.org/science/Issues/TextIssues/issue6.php.

Carnegie Commission on Science, Technology, and Government. 1992 (September) Enabling the Future: Linking Science and Technology to Societal Goals.

Dale, V.H., Beyeler, S.C., and Jackson, B. 2002 Understory indicators of anthropogenic disturbance in longleaf pine forests at Fort Benning, Georgia, USA. Ecological Indicators 1(3): 155-170.

Dale, V.H. et al. 2004 "Selecting a Suite of Ecological Indicators for Resource Management," Pages 3-17 in Landscape Ecology and Wildlife Habitat Evaluation: Critical Information for Ecological Risk Assessment, Land-Use Management Activities and Biodiversity

Enhancement Practices, ASTM STP 11813, L.A. Kapustka, H. Gilbraith, M. Luxon, and G.R. Biddinger, Eds., ASTM International, West Conshohocken, PA, 2004.

Dilustro, J. J. et al. 2002 Soil texture, land-use intensity, and vegetation of Fort Benning upland sites. Journal of the Torrey Botannical Society 129(4):289–297.

Duncan, L. K., J. J. Dilustro, and B. S. Collins. 2004 Avian response to forest management and military training activities at Ft. Benning, GA. Georgia Journal of Science 62(2): 95–103.

Fontana, A. and J.H. Frey. 1994 Interviewing: The art of science. *In* N.K. Denzin and Y.S. Lincoln, eds. Handbook of Qualitative Research. Sage Publications, pp. 361–376.

Greene, T. A. 2002 Management framework development and implementation of management goals and objectives associated with the Fort Benning Army Installation's Integrated Natural Resource Management Plan. Final Report. The Nature Conservancy.

Jones, S., D. Lach, and B. Fischhoff. 1999 Evaluating the interface between climate change research and decision making. Climatic Change: 1–19.

Krzysik, A.J. et al. 2003 Development of Ecological Indicator Guilds for Land Management, DACA42-00-2-0002, Team Annual Report FY2003, Strategic Environmental Research and Development Program (SERDP), http://www.cecer.army.mil/KD/SEMP/index.cfm?chn_id=1080**.**

Maloney, K.O., P.J. Mulholland, and J.W. Feminella. In press. Influence of catchment-scale military land use on physicochemical conditions in small Southeastern Plains streams (USA). Environmental Management**.**

National Academies. 2005 Sustainability at the National Academies: Strengthening science-based decision making in developing countries. Web site and links to past and continuing efforts: http://www7.nationalacademies.org/sustainabilityroundtable/Type_II_Homepage.html.

Peacock, A. D. et al. 2001 Soil microbial biomass and community composition along an anthropogenic disturbance gradient within a longleaf pine habitat. Ecological Indicators 1(2):113-121.

Rayner, S. et al. 2001 Weather Forecasts are for Wimps: Why Water Resource Managers Don't Use Climate Forecasts. Final Report to the National Oceanic and Atmospheric Administration (NOAA) Office of Global Programs. Also published as Oregon Water Research Institute SR-2003-1 and available at http://cwest.oregonstate.edu/cwest_library/SR-2003-1.pdf.

Reddy, R. et al. 2003 Determination of Indicators of Ecological Change. Quarterly Progress Report July 1–September 30, 2003. SEMP Project CS-1114A-99. http://www.cecr.army.mil/KD/SEMP/index.cfm?chn_id=1078.

Sigma XI, The Scientific Research Society. 1993 Science and Public Policy: Linking Users and Producers. Washington, D.C.: The Carnegie Commission on Science, Technology and Government.

Steel, B. et al. 2000–2001 The role of scientists in the natural resource and environmental policy process: A comparison of Canadian and American Publics. Journal of Environmental Systems 28(2):133–155.

Taylor, J.G. and S.D. Ryder. 2003 Use of the Delphi method in resolving complex water resources issues. *J.* Amer. Water Res. Assn. 39(1):183–189.

Turner, B.L., II, and W.B. Meyer. 1994 Global land-use and land-cover change: an overview. Pages 3–10 *in* W.B. Meyer and B.L. Turner II, editors. Changes in land use and land cover: a global perspective. Cambridge University Press, Cambridge, England.

Wolfe, A. and D.J. Bjornstad. 2002 Why would anyone object? An exploration of social aspects of phytoremediation acceptability. Critical Reviews in Plant Sciences 21(5):429–438.Wolfe,

A. et al. 2002 A framework for analyzing dialogues over the acceptability of controversial technologies. Science, Technology, & Human Values 27(1):134–59.

Figure 1: Schematic view of the Delphi method as implemented

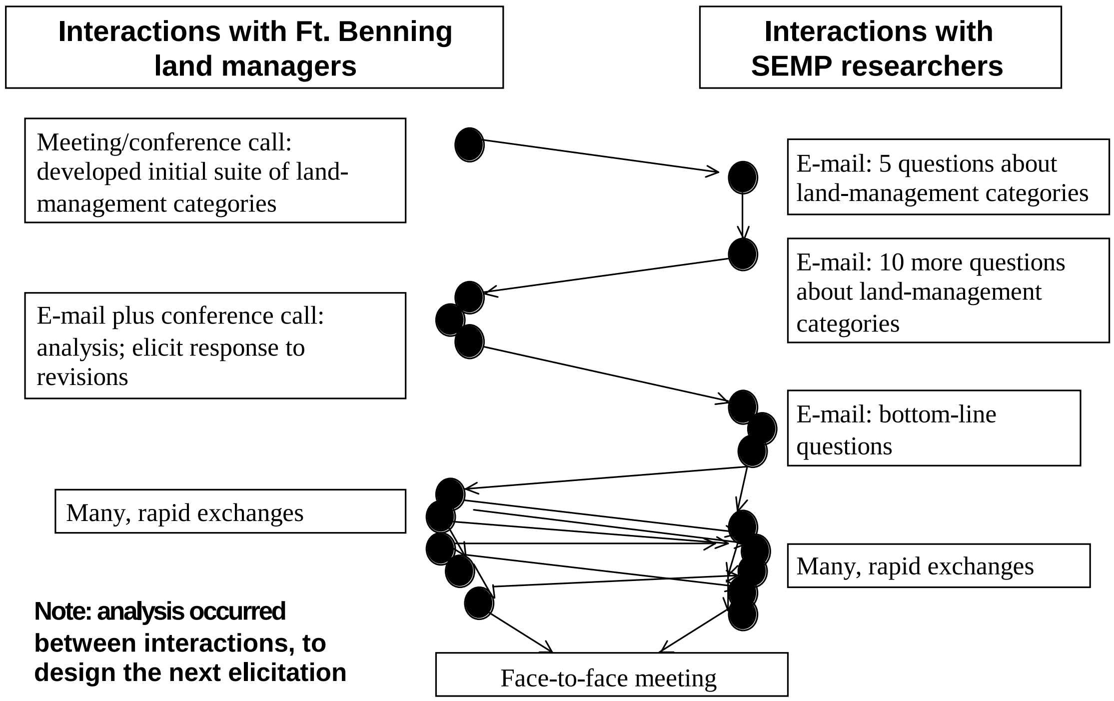


Figure 2. Questions used in first-round elicitation

1. As a set, are the proposed land-use categories
   a. Well-defined?
   b. Comprehensive?

   Please explain your answers, providing as much specific detail as possible.

2. Are each of the land-use categories
   a. Sufficiently discrete?
   b. Focused appropriately (neither too broad nor too narrow)?

   Please explain your answers, providing as much specific detail as possible.

3. Do the proposed land-use categories capture the differences among field research plots about which your research team is concerned? Explain your answer, providing as much specific detail as possible.

4. Give a rough approximation of how your research team's field plots are distributed across the proposed suite of land-use categories (or, across the suite of categories according to your proposed revisions). Take only a few minutes to complete this question

5. What land-use categories would you revise, add, or subtract? Please provide all of your suggested revisions.

Figure 3. Questions asked in 2nd-round elicitation regarding the proposed framework (minus answer options provided)

1. What is the best way to categorize land areas on which there are multiple military uses?

2. What is the best way to categorize land areas whose current ecological condition is dominated by past, but not current, land uses?

3. What is the best way to categorize “not used” lands that are affected by adjacent land uses?

4. What is the best way to categorize “modified management area” lands within the upland pine forests?

5. What other categories or subcategories should be merged into “modified area management” lands within the upland pine forests?
   You may wish to refer to the land use and management goal descriptions in the Appendix.*

6. What is the best way to categorize vehicle, foot, and bivouac military uses of land?

7. What is the best way to categorize forestry uses?

8. What is the best way to categorize pine plantation areas?

9. Considering previous responses, Table 2, and your answers to these questions, how would you revise Table 2 to reflect Fort Benning land-use categories?

10. Any additional comments?

*The Appendix to the questionnaire consisted of definitions and descriptions of terms and repeated material disseminated to researchers during the first elicitation.

Table 1. Land-use categories as determined by military training and land management practices, initial version

Key:

'0' = which *military uses* do NOT occur in areas managed in specified ways

'I' and 'F' = the relative frequency with which *military uses* occur in areas managed in specified ways (I = infrequent and F = frequent).

'+' = *land management* options in areas not used by the military

Land management goals	Military uses of land							
	Tracked vehicles	Wheeled vehicles	Foot traffic	Bivouac areas	Firing ranges	Impacts areas	Drop zones	Not used
Extensively managed areas	0	0	I,F	0	0	I,F	0	+
Intensively managed areas								
Upland pine forests								
- Set-aside areas	0	I	I	0	0	0	0	+
- Modified management areas	0	I	I,F	0	0	0	0	+
- Standard management	I	I,F	I,F	I,F	0	0	0	+
Mowed areas	0	I	I,F	0	I	0	I	0
Wildlife openings	0	I	I	0	0	0	I	+
Erosion control areas	I,F	I,F	I,F	I,F	I,F	I,F	I,F	+

Table 2. Land-use categories as determined by military training and land management practices—second version

Key:

'0' = which *military uses* do NOT occur in areas managed in specified ways

'I' and 'F' = the relative frequency with which *military uses* occur in areas managed in specified ways (I = infrequent and F = frequent).

'+' = *land management* options in areas not used by the military

Land management goals	**Predominant[1] military uses of land**								
	Tracked vehicles	**Wheeled vehicles**	**Foot traffic**	**Bivouac areas**	**Firing ranges**	**Impact areas**	**Drop zones**	Forestry	**Not used**
Extensively managed areas • Upland pine forests • Bottomlands • Other? [need to specify]	0	0	I,F	0	0	I,F	0		+
Intensively managed areas									
• *Upland pine forests*									
—Set aside areas	0	I	I	0	0	0	0		+
—Modified management area	0	I	I,F	0	0	0	0		+
▪ Unique ecological area									
▪ RCW mgmt zone									
▪ Gopher tortoise recovery zone									
▪ Other? [need to specify]									
—Standard management	I	I,F	I,F	I,F	0	0	0		+
• Pine plantations									
• Mowed areas	0	I	I,F	0	I	0	I		0
• Wildlife openings	0	I	I	0	0	0	I		+
• Erosion control areas	I,F	I,F	I,F	I,F	I,F	I,F	I,F		+

[1]Note—If SEMP researchers agree that the military land use category should reflect the predominant military use in areas where there are multiple uses, then researchers must define "predominant." Two possible options are (a) the most frequent of multiple military uses occurring in a single area; and (b) the military use with the most substantial impact on the land (intensity?)

Table 3. Land-use categories as determined by military training and land management practices—proposed revisions are in bold (August 12, 2003)
Key:

'0' = which *military uses* do NOT occur in areas managed in specified ways

'I' and 'F' = the relative frequency with which *military uses* occur in areas managed in specified ways (I = infrequent and F = frequent).

'+' = *land management* options in areas not used by the military

Land management goals	**Cause of predominant ecological effect from military use(s) of land**								
	Tracked vehicles	**Wheeled vehicles**	**Foot traffic**	**Bivouac areas**	**Firing ranges**	**Impact areas**	**Drop zones**	Sedimen-tation	**Not** affected
Extensively managed areas									
• Upland pine forests • Bottomlands • Other? [need to specify]	0	0	I,F	0	0	I,F	0		+
Intensively managed areas									
• *Upland pine forests*									
—Set aside areas	0	I	I	0	0	0	0		+
—Modified management area	0	I	I,F	0	0	0	0		+
▪ Unique ecological area									
▪ RCW mgmt zone									
▪ Gopher tortoise recovery zone									
▪ Other? [need to specify]									
—Standard management	I	I,F	I,F	I,F	0	0	0		+
• Pine plantations									
• Mowed areas	0	I	I,F	0	I	0	I		0
• Wildlife openings	0	I	I	0	0	0	I		+
• Erosion control areas	I,F	I,F	I,F	I,F	I,F	I,F	I,F		+

Table 4. Land-management categories as determined by military training and land management practices—final version

Key ‘0’ = *military uses* do NOT occur in areas managed in specified ways

‘I’ and ‘F’ = the relative frequency with which *military uses* occur in areas managed in specified ways (I = infrequent and F = frequent).

‘+’ = *land management* options in areas not used by the military

Land management goals **and endpoints**	Cause of predominant ecological effect from military use(s) of land: **Tracked vehicles**	**Wheeled vehicles**	**Foot traffic**	Designated **bivouac areas**	**Firing ranges**	**Impact areas**	**Drop** or landing **zones**	No military effect	Administrative use
1. Minimally managed areas									
1.1 Wetlands	I,F	I, F	I	0	0	0	0	+	0
1.2 Vegetation on steep slopes	I, F	I, F	I	0	0	0	0	+	0
1.3 Forests in impact zones	0	0	0	0	0	I,F	0	+	0
2. Managed to restore and preserve upland forest									
2.1 Upland forests **2.1.a Long leaf dominance** **2.1.b Mixed pine** **2.1.c Scrub oak pine mix**	I	I,F	I, F	0	0	0	0	+	0
2.2 RCW mgmt clusters	I	I	I,F	0	0	0	0	+	0
2.3 Sensitive area designated by signs	0	0	I,F	0	0	0	0	+	0
3. Managed to maintain an altered ecological state									
3.1 Intensive military use areas	F	F	0	I,F	F	0	0	0	0
3.2 Wildlife openings	0	I	I	0	0	0	I	+	0
3.3 Mowed fields	0	I	I,F	0	I,F	0	I,F	+	0
3.4 Roads (paved and unpaved)	I, F	I, F	I, F	0	0	0	0	+	0
3.5 Built environment	0	0	0	0	0	0	0	0	+

RESULTS AND ACCOMPLISHMENTS
(B) MAPPING OF LAND-MANAGEMENT CATEGORIES

OVERVIEW
Background:
SERDP's Ecosystem Management Program (SEMP) has initiated three indicator studies and two threshold studies. In addition, the design phase of the Ecological Characterization and Monitoring Initiative (ECMI) has been completed. Furthermore, Ft. Benning has now completed its Integrated Natural Resource Management Plan (INRMP). The SEMP Integration Plan (SIP) was developed to integrate the results of these five studies. As part of that integration, SIP developed a set of 54 land management categories using a Delphi process involving both the Fort Benning resource managers and the five research teams (see previous section). Once the categories were set forth, it became apparent that there would be great value for both resource managers and researchers to have a map of these categories for Fort Benning. The concept of mapping land management categories for Department of Defense (DoD) installations would facilitate management of all such military lands and their environmental resources. Hence the project is of specific value to Fort Benning and, more generally, illustrate how such a land management map might be created.

Purpose and Rationale:
The purpose of the mapping effect was to develop a map for Fort Benning of the land management categories that were derived by SIP. The map was designed to provide spatial interpretation for the research and monitoring programs and complement work being done under the INRMP. Ultimately, the map developed for Fort Benning illustrates how the development and use of land management categories can improve environmental monitoring and management of DoD installations in general.

Approach:
The first step was to develop an exclusion layer for each land management category. The idea here is that some land management categories cannot occur in some places. For example, tracked vehicles are not allowed with in 50 feet (15.24 m) of cavity trees [trees that contain nest of the federally threatened and endangered red cockaded woodpecker (RCW)]. Since the location of all current cavities is mapped, an exclusion layer for the absence of tracked vehicle around the cavity trees can be mapped. When all the exclusions for tracked vehicles are, a data layer (or map) can be created depicting places where tracked vehicles would not occur. Most of this information has been gathered from rules and regulations set by The Nature Conservancy and Fort Benning as part of the Fort Benning Environmental Awareness Program. Further development of this layer required close coordination with the resource managers and spatial analysts at Fort Benning. Therefore, we had many discussions with the resource managers and GIS staff at Fort Benning.

The second step was to create the map of the land management categories. The map built upon the land cover map obtained from the most recent Landsat remote sensing for the installation. This approach restricts the results to the 30 m resolution of Landsat data except where specific information is provided at a finer resolution (e.g., location of wetlands or clusters of red cockaded woodpecker nests). Use of satellite imagery means that the approach will have broad applicability because of the ubiquitous available of Landsat imagery (except where frequent cloud cover makes it impossible to obtain a clear scene). In some cases a land management category relates to certain land cover types. In other cases we obtained information from the resource managers about features that identify particular land management goals or military uses of the land. The Fort Benning staff were extremely cooperative and helpful in developing these land management categories (likely because they see value in having these categories defined and mapped for their own management needs). Selected use of aerial photos as well as site visits were useful as well.

Introduction

This document provides background material for the development of maps of land management categories (LMCs) at Fort Benning, GA. Contributors from Fort Benning include Rob Addington, John Brent, Rusty Bufford, Robert Cox, John Doresky, Christopher Hamilton, Wade Harrison, Bob Larimore, Pete Swiderek, Mark Thornton, and Hugh Westbury.

The purpose of this effort was to develop a map for Fort Benning of the LMCs that were derived by the SEMP Integration Plan (SIP). LMCs were developed using a Delphi process involving Fort Benning resource managers and five research teams (Table 1 and Appendix IV). The map is designed to provide spatial interpretation for research and monitoring programs. The LMC map developed for Fort Benning also illustrates how the development and use of land management categories can improve environmental monitoring and management of DoD installations and complements work being done under the INRMP (Integrated Natural Resource Management Plan).

The map is expressed in two distinct layers portraying:

(1) The *land management goals and endpoints* (these are the headers in the far left column of table 1)

(2) The *cause of the predominant ecological effects from military use(s) of the land* (the header row at the top of table 1)

Part 1 and 2 of this document describe the two layers for the mapping of these LMC's.

In addition to the two map layers, the SEMP Technical Advisory Committee (TAC) asked us to prepare a map of the current distribution of successional conditions within the map of *land management goals and endpoints* (focusing on variation within goal 2.1: upland forests)

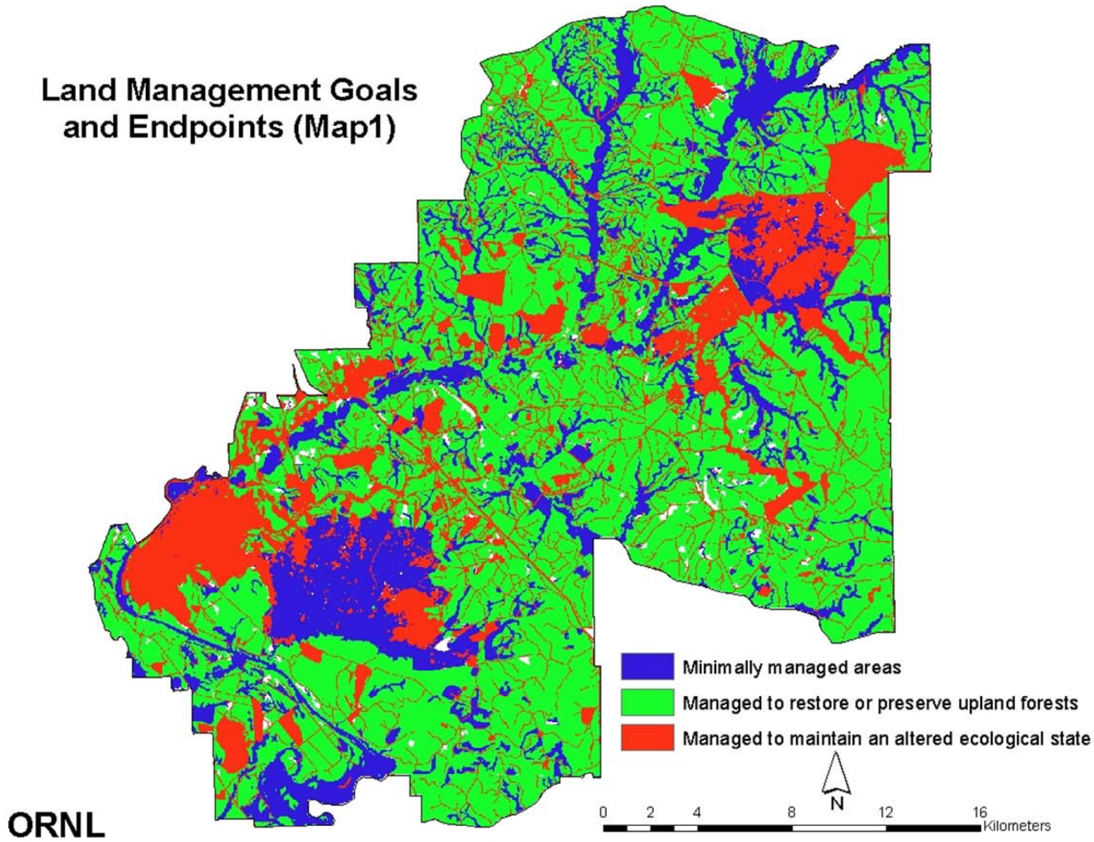
<u>Part 1: Mapping Land Management Goals and Endpoints</u>

Overview

Map 1 shows the distribution of the three land management goals and endpoints at the highest level of the *land management goals and endpoints* (the far left column of Table 1). Table 2 shows the percentage of the area occupied by each category.

Each of the broad categories in Map 1 has been mapped separately as Maps 2, 3, and 4. These maps each show how the subcategories of the *land management goals and endpoints* are spatially distributed.

One concern is that some regions occur in more than one management category. Table 3 shows the area covered by each management category map when it was mapped separately. However, these are not the same as the values in the combined map (table 2) because of overlap problems. The current hierarchy followed for giving preference for assigning an area to a management category is that "areas managed to maintain an altered ecological system" are highest preference, "areas managed to restore and preserve upland forests" is second preference and, "minimally managed area" is lowest preference.


Land Management Goals
and Endpoints (Map1)
Minimally managed areas
Managed to restore or preserve upland forests
Managed to maintain an altered ecological state
N
0 2 4 8 12 16
Kilometers
ORNL

Detailed Discussion of Mapping L*and Management Goals and Endpoints*

The major categories for the land management goals and endpoints is shown in Map 1. These areas were mapped from a variety of sources that are explained in the following sections. A list of the data sources is provided in Appendix V.

The map consists of three major types of land management goals.

(1) Minimally managed area include places where no active management occurs (in contrast with intensive, active management), and where the management goal is simply to minimize disturbance and keep the area ecologically intact. It consists of wetlands, vegetation on steep slopes and forests in impact zones.

(2) Areas managed to restore and preserve upland forests are currently the most common land management type for upland pine forests at Fort Benning. These areas are managed with the goal of restoring and maintaining uneven-aged longleaf pine forests and mixed longleaf pine-scrub oak woodlands. This goal is achieved via a combination of management practices, including timber harvesting, reforestation and prescribed fire. Most of the acreage in upland forested areas are designated as "Typical management areas", however "red cockaded woodpecker (RCW) clusters" and "Sensitive signed areas" are separated here because management practices in these areas may be slightly different. For example, cut-to-length forestry may be used over conventional forestry in RCW clusters because it is less destructive to the understory plant community.

(3) Areas managed to maintain an altered ecological state include areas where the land management goal is to maintain an altered ecological state, either for the purpose of military training or for some other stated purpose such as enhancing wildlife or wild-game populations. Erosion control areas are also included here, and the goal for these areas is simply to stabilize the erosion. This category also includes intense maneuver areas, wildlife openings, mowed fields, roads and built environment.

About 1% of the area is not attributed to any of the major categories and will not be further defined. We have followed explicit logic rules to develop the current map and do not want to stretch the logic in order to complete this small area.

The scheme to develop the map for each *land management goal and endpoint* and some questions that arose are given below.

1. <u>Minimally managed areas (Map2):</u>

1.1 Wetlands –The wetlands information for Fort Benning were obtained from two sources: the alliance level map prepared by the Nature Conservancy and the Forest Inventory map from Fort Benning. The following 'groups' from the Alliance map were included in the wetlands class – open water; river floodplains and cypress tupelo swamps; stream floodplains; small stream swamps and wooded seepage bogs; seasonal depression ponds; and gum/oak ponds. Table 4 lists the classes of the forest inventory data that were also included as wetlands. Discussions with Darrell Odom and Mark Byrd of Fort Benning, GA were useful in assigning these classes.

1.2 Vegetation on steep slopes - Vegetation classes (evergreen/planted forests, evergreen forests, hardwood forests, mixed forests, shrubs and herbs) from the 2003 landcover map of Fort Benning were clipped from the regions with slopes greater than 22 percent. The basis of this decision for including vegetation on slopes exceeding 22 percent was from spot checks in the field by Robert Larimore. The areas with vegetation in the 'steep slope' category polygons from the forest inventory coverage of Fort Benning were also included in this category.

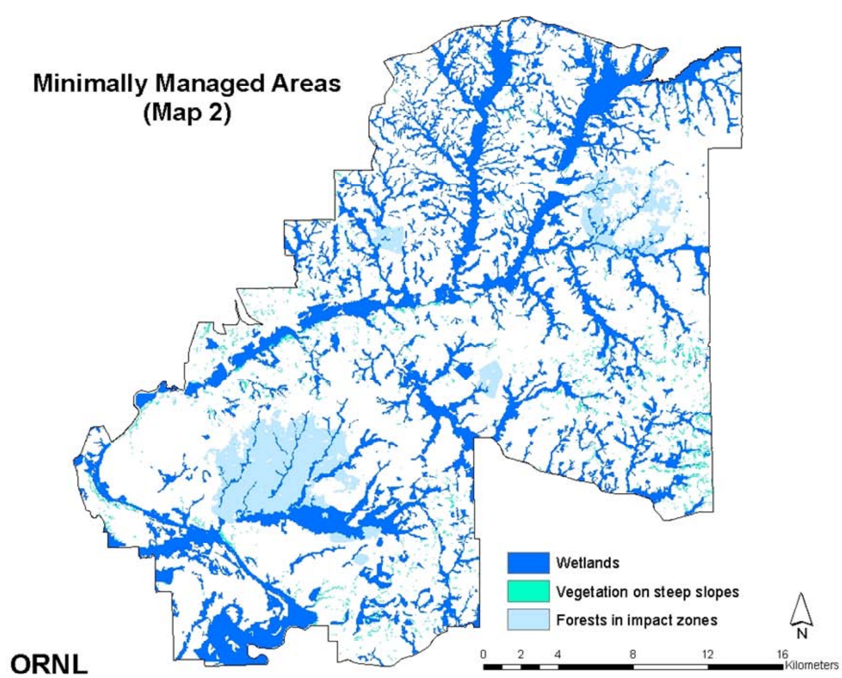
1.3 Forests in impact zones - The forest classes (evergreen/planted forests, evergreen forests, hardwood forests and mixed forests) from the 2003 landcover map of Fort Benning were clipped within the impact areas and included in this category.

2. <u>Managed to restore and preserve upland forests (Map 3):</u>

Areas under this management goal can be divided into three main categories – upland forests, RCW clusters, and sensitive area. There is some overlap among individual categories (for example, gopher tortoise burrows may be located in longleaf pine forests; the same location may also fall under the upland forest category). In displaying the map (Map 3), hierarchy of categories is as follows: RCW clusters, sensitive area, and finally upland forests.

2.1 Upland forests – This category was developed with information from various data sets:

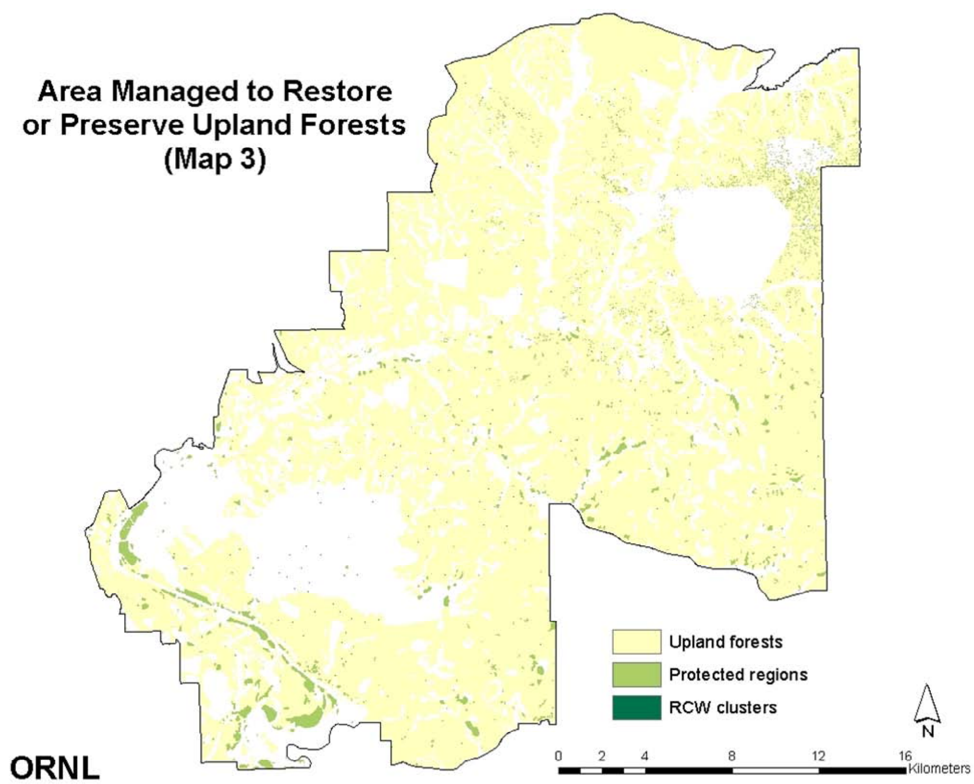
- Select classes of the forest inventory dataset (table 5) that occur as upland forests.
- Forests in impact zones (of map 2) were clipped and excluded from this category. They have been assigned to the minimally managed areas category.
- The regions falling within the 'army' global ranking of the TNC map were also excluded from here and included in the areas managed to maintain an altered ecosystem category.
- The alliance level data was used to obtain upland forest areas in the land swap region (since the forest inventory data base did not have this information). For that area, six groups of the alliance level data were considered as upland forests – mesic hardwood forests; dry-mesic hardwood and dry-mesic mixed hardwood/pine forests; longleaf pine loamhills; longleaf pine sandhills; plantations; and successional upland deciduous or mixed forests.

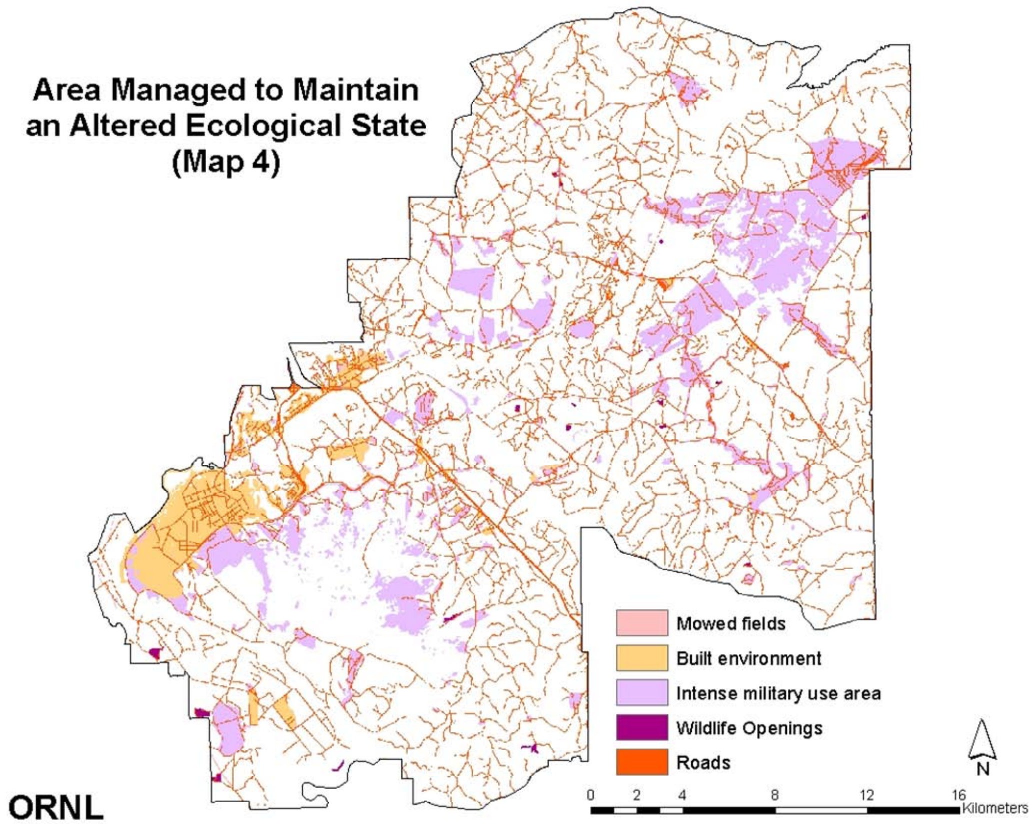


2.2 RCW Management clusters – The red cockaded woodpecker cluster locations in Fort Benning were converted to 28.5 m pixels and used to map the category. All clusters, active, inactive and deleted were considered under this management category (based on personal communication with John Doresky).

2.3 Sensitive areas designated by signs – This includes areas with gopher tortoise burrows, archeological ruins, and sensitive plants.

- All gopher tortoise burrows – active, inactive and abandoned are protected (personal communication with Mark Thornton, For Benning, GA) and hence come under this management category.
- The cultural resources data set (archeological sites) have an ineligible or protected status for each site. Sites with an 'ineligible' status are not considered as sensitive (personal communication with Christopher Hamilton, Fort Benning, GA) and hence those areas have been removed from this management category. Only sites with a 'protected' status are considered sensitive.
- The locations of rare plants (Relict trillium and pitcher plant) are included in this category (data obtained from Rusty Bufford and Mark Thornton). Some other rare plant locations are present in the region, but they are not protected since they only have general restrictions on training and hence not included in our map (personal communication with Mark Thornton, Fort Benning, GA). Most of these plants are not in areas of heavy training.





3. Managed to maintain an altered ecological state (Map 4):

3.1 Intensive military use area – Intensive military use areas include dud area, demolition area, tank trails, ranges, drop zones, the Digital Multi Purpose Range Complex (DMPRC) and Company Team Defense Area (CTDA). All these regions were gridded to 28.5 m pixels

- The army global rank classes of the TNC Alliance map have been included here.
- The 'military' class of the forest inventory data set is also included in this category.
- Currently authorized mechanized training area, ranges E-08 and Molnar field are not included (as per suggestions of Hugh Westbury and others).
- Regions in A-16 have been clipped to include only the army global rank regions of TNC Alliance map and exclude other regions within A16.
- The dud areas have been clipped to exclude forests (forests in impact zones come under minimum management).

3.2 Wildlife openings –

- The wildlife openings locations were obtained from the 'wildlife openings' class of the forest inventory map of Fort Benning.

- The ‘Other non forest land’ class of the forest inventory data set also contains wildlife and open fields (personal communication with Mark Byrd, Fort Benning, GA). Hence this class was also included in this category.

3.3 Mowed fields –

- Lee field is under a mowing contract and is considered as a drop zone (personal communication with Rusty Bufford, Fort Benning, GA). Hence it has been considered in the intense military use area.
- Transmission lines from the forest inventory data set have been included in this category

3.3 Roads – Paved roads, highways, unpaved roads and trails have been included in this class. The linear road features were transformed to a 28.5 m grid.

- The roads and railways class of the forest inventory dataset was also included in the category.

3.4 Built environment –

- The built environment category includes the cantonment area (obtained from the landcover map of Fort Benning) and the landing zones in Fort Benning (including the Dekkar and McKenna forward landing strips).
- During initial iterations of making the land management categories map, it was found that a large portion of the area that was close to the built area given by the landcover were unclassified. These regions were not part of a training area or forests. Since they are very close to the built area of Fort Benning, they have been considered part of the cantonment of Fort Benning.

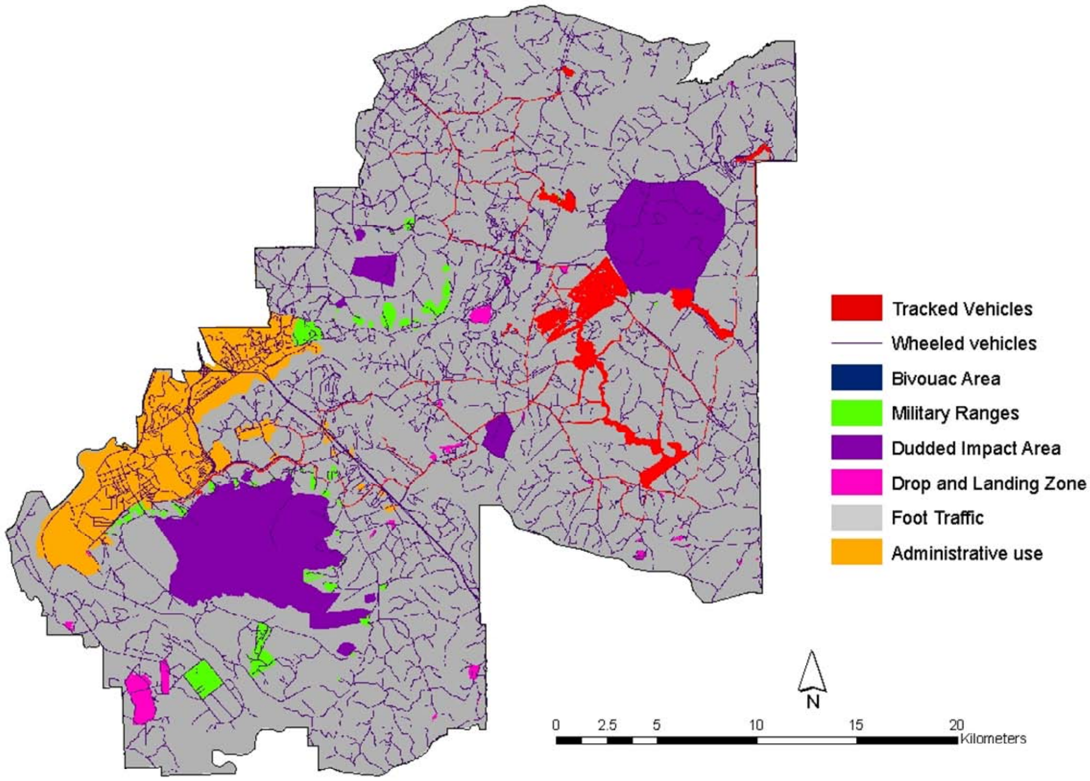
Other Areas

- During initial classifications of the land management categories map, some of the area in Fort Benning remained unclassified. A large proportion of the unclassified area was found to be within the ‘Brush species, nonstocked with management species’ class of the forest inventory map. Most of this land are ranges, pine beetle infested areas or sparse scrub oak forests etc. (personal communication with Darrell Odom, Fort Benning, GA). Discussions with Peter Swiderek and Rusty Bufford helped in assigning these unclassified regions to the appropriate categories.
- In addition, Pete Swiderek and Rusty Bufford reviewed the whole map and identified areas that needed updates and corrections. The corrections they suggested have been incorporated in the map.
- Owing to the use of different data sets (both raster and vector), there has been some loss of information while converting data from one form to another. When vector data was converted to 28.5 m raster pixels, some regions have been left out and remain unclassified. However this constitutes less than 0.15% of the area.

Part 2: Mapping Cause of predominant ecological effect from military use(s) of land

The purpose of this part of the effort is to develop a map for the causes of the predominant ecological effects from military uses of the land for Fort Benning. This is the second layer in the map of land management categories for Fort Benning.

Military Use of Land (Map 5)



Overview

Categories of military use at Fort Benning were mapped based on data from Fort Benning (provided by Rusty Bufford, Fort Benning, GA), information from the Integrated Natural Resource Management Plan (INRMP), Fort Benning, GA, and the Fort Benning Environmental Awareness Training website (http://www.benning.army.mil/nature/index.htm) (see Table 1 in Appendix II). For some categories, data was directly available. For others (e.g., wheeled vehicles), direct information on the occurrence of this activity is not available. Hence an exclusion approach was taken to map the military use (i.e., places where the activity is not allowed are mapped and then excluded from the whole area to give the locations where the activity occurs).

Detailed discussion of mapping *cause of predominant ecological effect from military use(s) of land*

Map 5 illustrates the following categories – tracked vehicles, wheeled vehicles, bivouac areas, foot traffic, military firing ranges, duded impact areas, drop and landing zones, the cantonment, and areas with no military activity. Each of these categories were developed using different data sources and methods as described below:

Tracked vehicles:
The Integration Natural Resources Management Plan describes the current training conditions in Fort Benning (INRMP 2001). Based on the information in the INRMP, the following areas were included as places that are used by tracked vehicles:

- Tank trails. These are trails authorized for tracked vehicle usage.
- Tracked vehicle ranges. In these ranges, transit on authorized trails and use of tracked vehicle training courses is allowed.
- The DMPRC (digital multipurpose range complex), which is currently under construction, has also been included.
- Underwood road has been expanded and Cactus OP has been included based on Pete Swiderek's recommendations.

Wheeled vehicles:
The roads and trails layer was used to depict the current use of wheeled vehicles.

Foot traffic:
Foot traffic is allowed in most of the areas of the installation.

Although foot traffic is limited to 2 hours in RCW clusters and sensitive areas (Fort Benning Environmental Awareness Training, 2005), those regions have not been considered for exclusion since foot traffic does have an effect there.

Designated bivouac areas:
Bivouac areas have been designated in the Permanent Training Sites Data set by ranges that are names with an 'A0' prefix (personal communication with Johnny Markham). Those sites have been mapped for this category. Since these areas are very small, they do not appear significantly on Map 5.

Firing ranges:
Various military ranges that can accommodate small arms to large caliber weapons have been included in this category.

Impact areas:
Dudded impact areas. Fort Benning has nine dud areas that can accommodate different types of munitions. This data layer was created by Johnny Markham of Fort Benning.

Drop or landing zones:
The following layers have been added in this category

- Drop and landing zones. Drop and landing zones are areas that support parachute and helicopter landing (INRMP 2001). This data layer was obtained from Rusty Bufford, Fort Benning.
- McKenna and Dekkar forward landing strips.

Administrative use:
The cantonment. The main post area/cantonment of Fort Benning is used for administrative use. This data set was obtained from the training area coverage of Fort Benning. In addition, the harmony church and Kelly hill cantonment areas have been included as per suggestions from Peter Swiderek.

No Military effect:
The area remaining after mapping all the other categories is considered to be locations within Fort Benning regions without military effect. This region is predominantly comprised of wetlands.

Table 1. Land-management categories as determined by military training and land management practices (September 12, 2003)

Key '0' = m*ilitary uses* do NOT occur in areas managed in specified ways
'I' and 'F' = the relative frequency with which *military uses* occur in areas managed in specified ways (I = infrequent and F = frequent).
'+' = *land management* options in areas not used by the military

Land management goals and endpoints	Cause of predominant ecological effect from military use(s) of land								
	Tracked vehicles	Wheeled vehicles	Foot traffic	Designated bivouac areas	Firing ranges	Impact areas	Drop or landing zones	No military effect	Admin-strative use
1. Minimally managed areas									
1.1 Wetlands	I,F	I, F	I	0	0	0	0	+	0
1.2 Vegetation on steep slopes	I, F	I, F	I	0	0	0	0	+	0
1.3 Forests in impact zones	0	0	0	0	0	I,F	0	+	0
2. Managed to restore and preserve upland forest									
2.1 Upland forests 2.1.a Long leaf dominance 2.1.b Mixed pine 2.1.c Scrub oak pine mix	I	I,F	I, F	0	0	0	0	+	0
2.2 RCW mgmt clusters	I	I	I,F	0	0	0	0	+	0
2.3 Sensitive area designated by signs	0	0	I,F	0	0	0	0	+	0
3. Managed to maintain an altered ecological state									
3.1 Intensive military use areas	F	F	0	I,F	F	0	0	0	0
3.2 Wildlife openings	0	I	I	0	0	0	I	+	0
3.3 Mowed fields	0	I	I,F	0	I,F	0	I,F	+	0
3.4 Roads (paved and unpaved)	I, F	I, F	I, F	0	0	0	0	+	0
3.5 Built environment	0	0	0	0	0	0	0	0	+

Table 2: Percentage of land management goals and endpoints in Map 1

Land Management goals and endpoints	Percentage of area
Minimally managed area	19.38
Managed to restore and preserve upland forests	57.75
Managed to maintain an altered ecological state	21.76
Other Area	1.1

Table 3: Percentage of area covered by the land management goals and endpoint maps

Map	Percentage of area covered
Map 2: Minimally managed area	30.12
Map 3: Managed to restore and preserve upland forests	65.98
Map 4: Managed to maintain an altered ecological state	21.76

Table 4: Classes of the forest inventory data set considered as wetlands and their percentage within Fort Benning

Forest inventory class	Percentage
Sweetgum-Water Oak-Willow Oak	7.51
Sweetbay-Swamp Tupelo-Red Maple	3.74
Bottomland Hardwood-Yellow Pine	2.84
Undrained Flatwoods	1.32
River or Stream	0.52
Lake	0.28
Laurel Oak-Willow Oak	0.10
Sweetgum	0.05
Inaccessible Physical Barrier[a]	0.04
Water Oak	0.04
River Birch-Sycamore	0.02
Blackgum	0.01

[a] A backwater area with small islands

Table 5: Classes of the forest inventory data set considered as uplands and their percentage within Fort Benning

Forest inventory class	Percentage
Mixed Pine	17.16
Loblolly Pine	11.67
Mixed Pine - Longleaf	8.14
Loblolly Plantation	5.47
Yellow Pine-Upland Hardwood	4.10
Longleaf Pine	3.57
Yellow Pine-Cove Hardwood	3.01
Cove Hardwood-Yellow Pine	2.99
Sweetgum-Yellow Poplar	2.20
White Oak-Red Oak-Hickory	2.17
Loblolly Pine-Hardwood	2.03
Longleaf Pine Plantation	1.93
Oak-Hickory	1.92
Scrub Oak	1.77
Upland Hardwood-Yellow Pine	1.48
Shortleaf Pine	0.94
Southern Scrub Oak-Yellow Pine	0.93
Yellow Poplar-White Oak-Laurel Water Oak	0.80
Slash Pine Plantation	0.61
Mixed Pine Plantation	0.32
Longleaf Pine-Hardwood	0.29
Mixed Pine - Longleaf Plantation	0.23
Slash Pine	0.07
Shortleaf Pine-Oak	0.03
Southern Red Oak	0.01

Appendix IV

Descriptions of Proposed Land-Use Categories at Fort Benning for the SEMP Integration Plan

Military uses [Cause of predominant ecological effect from military use(s) of land]

Attributes of military uses of land can influence the ecological effects of those land uses significantly. As examples, the type of traffic (*tracked, wheeled, or foot*) and frequency of use may make the biggest differences in ecological impact. Therefore, it is important to consider these attributes in conjunction with the military uses, themselves, to understand ecological conditions and support land management decision making.

- ***Tracked vehicles*** occur both on and off roads. Down slope impacts of sedimentation from tracked vehicles can occur.
- ***Wheeled vehicles*** can occur on road or other areas. In many areas impacts from other tracked vehicles are more intensive than from wheeled vehicles.
- ***Foot traffic*** can occur throughout much of the installation but in some areas impacts from other military uses are more intensive than from foot traffic.
- ***Designated bivouac areas*** occur anywhere assigned for soldiers to stay overnight. These areas are prepared and may or may not be placed in conjunction with ranges. Bivouac areas are affected by wheeled vehicle and foot traffic on a regular basis and include such other activities as digging, tenting, etc. With regard to frequency, all designated bivouac areas are used on a regular basis; this category does not include undesignated areas where soldiers may stay occasionally. Although bivouac areas generally are heavily impacted, they tend not to be subject to directed land management actions.
- ***Firing ranges*** generally are kept either clear of vegetation or covered by low-growing vegetation. Thus, the two main management activities at ranges are maintenance (grading, putting up targeting, etc.) and vegetation control (fires—maybe naturally occurring, mowing, herbicides). Frequency also is an attribute of firing ranges, for some ranges are used almost daily whereas others are not used as much (it is possible to obtain data on frequency of use of each range). Ranges are managed differently depending on whether or not they are used heavily (for example, frequently used ranges have firebreaks to reduce the potential of fire to spread).
- ***Impact areas*** are places in which unexploded ordnance is found. Therefore, essentially no management occurs in these areas, although resource managers may enter them for such activities as woodpecker work. The intensity and/or frequency of munitions within different portions of impact areas are highly variable. Hence, the attribute of frequency is useful for understanding and assessing impact areas. Impact areas with frequent use are the dud areas, and those with infrequent use are the buffers. In any case, people cannot enter an impact area without special permission.
- ***Drop or landing zones*** are open fields created for parachutists to land. These areas are affected by wheeled vehicle and foot traffic. Infrequently used drop zones support wildlife openings, and are thus also affected by mowing, disking, planting and other activities associated with wildlife openings. Landing Zones for helicopters are slightly different from drop zones. Landing zones are used less frequently and are impacted by

aircraft weight, heat and air movement. Some landing zones are planted wildlife openings, but all of the drop zones are mowed fields.

- ***Areas with no military training*** may be within impact areas or outside of them.
- ***Administrative areas*** that represent the cantonment

Land management goals

"Land management goals" provide a long-term orientation for the integration effort. These goals tend to be more stable than either specific management practices undertaken in particular areas (e.g., thinning or logging) or land cover types. Therefore, categorizing land areas within Fort Benning according to land management goals is efficacious. Designated "unique ecological areas" can occur in several categories.

Different goals can involve a range of land management activity, ranging from extensive (light) to intensive (heavy). Much of the military reservation is managed extensively. Land management goals at Fort Benning vary according to their focus on:

1. Minimally managed areas—include places where no active management occurs (in contrast with intensive, active management), and where the management goal is simply to minimize disturbance and keep the area ecologically intact.

1.1 Wetlands —includes floodplains and bottomland hardwood forests where no timber is harvested

1.2 Vegetation on steep slopes — where abrupt topography limits management

1.3 Forests in impact zones — where no management occurs because access is restricted.

2. Managed to restore and preserve upland forest — currently the most common land management type for upland pine forests at Fort Benning. These areas are managed with the goal of restoring and maintaining uneven-aged longleaf pine forests and mixed longleaf pine-scrub oak woodlands. This goal is achieved via a combination of management practices, including timber harvesting, reforestation and prescribed fire. Most of the acreage in upland forested areas are designated as "Typical management areas", however "RCW clusters" and "Sensitive area" signed areas are separated here because management practices in these areas may be slightly different. For example, cut-to-length forestry may be used over conventional forestry in RCW clusters because it is less destructive to the understory plant community.

2.1 Upland forest areas — includes all of the upland forested areas that are not designated as RCW clusters or sensitive areas. It includes stands dominated by long leaf pine, mixed pine stands, and scrub oak and pine mix.

2.2 RCW (red cockaded woodpecker) management clusters—Areas that contain RCW cavity trees

2.3 Sensitive area designated by signs — those sites designated by signs as being sensitive to human disturbance and include areas with gopher tortoise, archeological ruins, and sensitive plants.

3. Managed to maintain an altered ecological state — includes areas where the land management goal is to maintain an altered ecological state, either for the purpose of military training or for some other stated purpose such as enhancing wildlife or wild-game populations. Erosion control areas are also included here, and the goal for these areas is simply to stabilize the erosion. Such erosion control projects are generally short-term. The area managed to maintain an altered ecological state contains several subcategories:

- **3.1 Intensive maneuver areas —** support intensive military use and often are associated with mechanized operations. These areas are sometimes referred to as “sandbox” or sacrifice areas, for they have only limited management.
- **3.2 Wildlife openings** — can be cultivated with crops of special value to wildlife for either cover or forage. Sometimes these areas are mowed.
- **3.3 Mowed fields —** cut regularly to maintain grasses and other low-growing vegetation.
- **3.4 Roads** — Both paved and unpaved roads and a small buffer area around them.
- **3.5 Built environment** — Buildings and open areas associated with the cantonment

Combination of military use and land management

A matrix of all possible combinations of military land use with land management (Table 1) shows 41 possibilities for Fort Benning. Of these possibilities, three types are in erosion control areas. While discussion participants anticipated that distinguishing “frequent” from “infrequent” military use would be valuable, they suggested evaluating the value of the distinction as the SEMP Integration exercise progresses. Furthermore, it is apparent that both military use and management goal categories are important to know because they differ in cause and effect. It is essential for the integration effort that each SEMP research team’s field sites be identified with a unique land-use category. At the present time, however, researchers may need to confirm with Fort Benning staff (especially Pete Swiderek) the correct categorization of their sites. Identification can be based on location together with knowledge of land cover, patterns of military use, and land management practices for Fort Benning.

Appendix V: List of Data Sources

Name	Description	Source (downloaded from the SEMP data repository unless indicated otherwise)	Use in developing map of land management goals and endpoints (map 1)	Use in developing map of cause of predominant ecological effect from military use(s) of land (map 5)
2003 land cover map of Fort Benning	2003 land cover map of Fort Benning originally derived from Landsat ETM images.	Developed by the Engineer Research and Development Center (ERDC) Environmental Laboratory, Vicksburg, MS	Vegetation on steep slopes for minimally managed areas; forests in impact zones for minimally managed areas; built area in areas that are managed to restore an altered ecological state	
Forest Inventory data	Current forest stands/timber management areas at Fort Benning	Produced by the Land Management Branch, Fort Benning, GA	Wetlands for minimally managed areas; upland forests for areas managed to restore and preserve upland forests; wildlife openings in areas that are managed to restore an altered ecological state; mowed fields in areas that are managed to restore an altered ecological state; roads in areas that are managed to restore an altered ecological state	Wheeled vehicles exclusion layer; Foot traffic exclusion layer
TNC's Alliance Map	Alliance level vegetation map prepared for Fort Benning	Provided by The Nature Conservancy, Fort Benning Project	Wetlands for minimally managed areas; upland forests for areas managed to restore and preserve upland forests	Wheeled vehicles exclusion layer; Foot traffic exclusion layer
Military layers at Fort Benning	Military drop zone, military landing zone, duded impact area, demolition area, lee field, McKenna and Dekkar forward	Developed by Johnny Markham and provided by Rusty Bufford and Robert Cox	Forests in impact zones for minimally managed areas; intensive military use area in areas that are managed to restore an altered ecological state; mowed fields in areas that are managed to restore an altered ecological state	Tracked vehicles; Wheeled vehicles exclusion layer; Firing ranges; Impact areas; Drop or landing zones

	landing strips, military ranges, tank trails and tracked vehicle ranges			
Digital Multipurpose Range Complex (DMPRC)	The DMPRC is a new range complex that is currently being constructed	Provided by Hugh Westbury	Intensive military use area in areas that are managed to restore an altered ecological state	Firing ranges
Permanent training sites at Fort Benning	Range like facilities that also include bivouac area	Developed by Johnny Markham and provided by Rusty Bufford		Bivouac areas
Training areas of Fort Benning	Boundaries of all the training areas in Fort Benning	Developed by the US Army Infantry Center, Fort Benning, GA		Wheeled vehicles exclusion layer; Administrative use area
Red cockaded woodpecker clusters	Location of red cockaded woodpecker populations in Fort Benning	Fort Benning Terrestrial Resources Inventory Report 1995-1999. Conducted By: U.S. Fish and Wildlife Service West Georgia Field Sub-Office	RCW management clusters in areas managed to restore and preserve upland forests	Wheeled vehicles exclusion layer
Sensitive areas marked by signs at Fort Benning	Sensitive area data set include cultural resources data, gopher tortoise burrows and protected plant locations	Developed by Christopher Hamilton and Mark Thornton and provided by Rusty Bufford	Sensitive areas in areas managed to restore and protect upland forests	Wheeled vehicles exclusion layer
Topography	10 m grid DEM	Developed by the US Army Infantry Center, Natural Resources Management Branch, Fort	Vegetation on steep slopes for minimally managed areas	

		Benning, GA		
Roads	Transportation network (2 and 4 lane highways, interstates, paved and non paved roads and trails) within Fort Benning	Developed by the US Army Infantry Center, Natural Resources Management Branch, Fort Benning, GA	Roads in areas that are managed to restore an altered ecological state	

RESULTS AND ACCOMPLISHMENTS

(C) DATA FOR INDICATOR SELECTION

Institution (Data set)	Indicator	Brief Description	How the Indicator Is Measured	Units	What It Measures	Why the Indicator Is Important
Prescott College (P)	Ant Community Structure	The ground/litter ant community species composition and their relative abundances	Systematic clusters of pit-fall traps along perpendicular transects with a random orientation; pit-fall traps are 9oz plastic cups with 2 cm of propylene glycol	abundances of all ant species	Ant community structure (relative population sizes and species composition)	Integrates the response of a very important animal community to ecosystem type, condition, and relative disturbance; very critical for our ecological indicator set
SREL (S1)	% Ground Cover Vegetation	% coverage of vegetation less than 1.4m high	This % cover was derived from a 6 meter line transect at 25 points in each 100m and 100m plot, and thus is not an ocular estimate based on a circular plot or square quadrat - The 'cover' would be any cover at a point along the transect (all species combined).	%	Plant colonization of an area	It acts as an integrated measurement for positive environmental properties enabling plant growth.
UF (FL)	Herbaceous Vegetation Cover	Aerial herbaceous vegetation cover	Estimated using foliar ocular observation in 2-1 m2 quadrats within a 10 m2 plot	%	Ground cover, primary production	Indicator of recent disturbance level and recovery
ORNL1 (O3)	Total Understory Cover	Percentage cover of all understory vegetation (<1 m in height)	Visual estimation within 5m radius plots set along transects within training classifications	%	Response of total vegetation to various levels of training intensity	Total cover may differ in its ecological response to environmental disturbance
Prescott College (P)	Bare Ground	% of bare ground	Estimated from % bare ground in 0.58 m2 circular quadrats systematically-random located on 4 perpendicular transects with a random orientation	%	Lack of surface litter	A composite indicator for the direct loss of vegetation in all vegetation strata; a good stand-alone indicator; very critical for our integrated ecological indicator set
ORNL1 (O3)	Ground Cover (Bare)	% exposed soil	Visual estimation within 5m radius plots set along transects within training classifications	%	Response of vegetation to various levels of training intensity	% bare ground may differ in response to environmental disturbance

ORNL1 (O3)	Ground Cover (Litter)	% cover of litter on ground surface	Visual estimation within 5m radius plots set along transects within training classifications	%	Response of vegetation to various levels of training intensity	% litter may differ in response to environmental disturbance
UF (FL)	Herbaceous community Structure	Vegetation cover by species	Estimated using foliar ocular observation and species identification in 2- 1 m2 quadrats within a 10 m2 plot	species abundance	Species composition of herbaceous community	Relative contribution of weedy, invasive species versus disturbance sensitive species gives indication of level of disturbance and time since disturbance
ORNL1	Understory Cover by Family	% cover of understory plants by taxonomic family	Visual estimation by Braun-Blanquet cover category within 5m radius plots set along transects within training classifications	%	Response of vegetation to various levels of training intensity by family	Taxonomic families may differ in their ecological response to environmental disturbance
ORNL1 (O3)	Understory Cover by Life Form	% cover of understory plants by Raunkiaer life form	Visual estimation by Braun-Blanquet cover category within 5m radius plots set along transects within training classifications	%	Response of vegetation to various levels of training intensity by lifeforms	Raunkiaer lifeforms may differ in their ecological response to environmental disturbance
ORNL1 (O3)	Overstory Cover	Amount of canopy cover above plot	Average of four measures of canopy densiometer readings within each 5m radius plots set along transects within training classifications	%	Amount of clear sky viewable hemispherically above plot	Measure of photosynthetically active radiation for understory
SREL (S1)	Tree Density	# of trees within study site in trees per ha	4 trees at each of 25 points in each 100meter x 100-meter stand were measured (diameter and distance to the point). Point quarter calculations were done to provide tree/ha estimates for each stand.	#/area	Density of trees	It is the density of trees in the stands and influences light for understory, litter amount and quality and many other stand characteristics.
ORNL1 (O3)	DBH of Trees Greater than 5 cm	Diameter at breast height of trees	DBH tape within 5m radius plots set along transects within training classifications	m^2	Stand basal area	Intertree competition and shading

ORNL1 (O3)	Stand Age	Maximum stand age	Greatest of two perpendicular increment bores from the 4 largest trees near each transect within a training classifications	years	Age of oldest tree in transect	Time since last stand-clearing disturbance
Prescott College (P1)	Soil A-Horizon Depth	Thickness of A-Horizon, depending on varying specific definitions, includes O_a layer, and may include O_e layer	Surface litter is brushed away and a small garden trowel is used to remove a soil plug, based on color change the A-Horizon thickness is measured with a stainless steel metric ruler	mm	Soil integrity and erosion losses	Soil integrity is a major indicator of ecosystem condition; a good stand-alone indicator
SREL (S1)	Soil A-Horizon Depth	Depth of soil A-horizon	12 random A depth measurements in each 100meter x 100-meter stand were recorded. Measurements were done in the field using a cm ruler and soil corer.	cm	Depth of A soil horizon	It is the development of soil A layer which is a cumulative indicator of soil development and quality over longer time periods
UF (FL2)	Soil A-Horizon Depth	Mineral horizon formed at the surface or below an O horizon and containing accumulated decomposed organic matter	By visual estimation of A horizon development using a 1 inch soil probe.	cm	Soil carbon and soil structural integrity	Indicates recent disturbance, erosion, mixing of soil horizons
ORNL1 (O3)	Soil A-Horizon Depth	Thickness of A-Horizon	Soil probe used to obtain sample. Depth of A horizon measured in field with a ruler from bottom of surface litter layer (if present) to change in color indicating bottom of A horizon	cm	Amount of undisturbed soil	Quantitative measure of disturbance
Prescott College (P2)	Soil Compaction	Soil compaction	Lang Penetrometer, Lang Penetrometer, Inc.	Lang Penetrometer units	Relative compaction of soil surface	Direct indicator of degree of vehicle activity, relative habitat disturbance, ecosystem relevance for biological activity and water infiltration; very critical for our integrated ecological indicator set

ORNL2 (O3)	Soil Density	Grams of dry soil per cubic centimeter of soil	Determine the dry mass of a known volume of soil	g/cc	Soil compaction	High soil density inhibits root growth and the infiltration of water
UF (FL1)	Soil Respiration	Aerobic carbon mineralization	CO2 production determined in soil slurries incubated at standard temperature (30oC) by GC (Zibilske, 1994)	ugCO2/g soil/hour	Competence of soil microbiota to mineralize carbon; quality of soil carbon stocks	Undisturbed soil will have higher overall respiration than eroded soils, but may have lower ratio of CO2 production/unit total carbon
UF (FL1)	Soil Total Carbon	Total carbon content of soil	Total carbon; dry combustion method (Nelson and Sommers, 1996).	g C/kg dry soil	g C /kg dry soil	Carbon is an indicator of primary productivity inputs and soil structure, and is an important determinant of soil fertility.
ORNL2 (O3)	Soil Carbon Concentration	Grams of carbon per gram of dry soil	Measured by combustion of the soil sample (elemental analysis) in a LECO CN-2000	% dry mass	Soil carbon is related to organic matter	Organic matter imparts many favorable qualities to soil (nutrients, soil structure, water retention, etc.)
ORNL1 (O1)	Soil Carbon Concentration	Grams of carbon per gram of dry soil	Measured by combustion of the soil sample (elemental analysis) in a LECO CN-2000	% dry mass	Soil carbon is related to organic matter	Organic matter imparts many favorable qualities to soil (nutrients, soil structure, water retention, etc.)
ORNL2 (O1)	Carbon Concentration in MOM	Concentration of carbon in the silt and clay fractions from mineral soil samples	Mineral-associated organic matter is physically separated from mineral soil by wet sieving after soil dispersion and the dry MOM (silt and clay size fractions) is analyzed on an elemental analyzer for its carbon concentration	g C / sq. m	Carbon associated with mineral-associated organic matter is generally considered to be more humified than POM-C	MOM-C has a longer mean residence time in the soil than POM-C and is a less favorable energy source for some soil microorganisms
ORNL2 (O1)	Soil Carbon Stocks	Grams of carbon per unit area of ground to a specified soil depth	Calculated as the product of soil density and soil carbon concentration	g C / sq. m	Amounts of soil organic matter on an area basis	Organic matter imparts many favorable qualities to soil (nutrients, soil structure, water retention, etc.)
ORNL1 (03)	Soil Carbon	Grams of carbon per unit area of ground to a specified soil depth	Calculated as the product of soil density and soil carbon concentration	mg C / sq. cm	Amounts of soil organic matter on an area basis	Organic matter imparts many favorable qualities to soil (nutrients, soil structure, water retention, etc.)

ORNL2 (O1)	Carbon Stock in POM	Mass of soil carbon found in particulate organic matter present in the mineral soil	Particulate organic matter is physically separated from mineral soil samples by wet sieving after soil dispersion and the dry POM (sand size fraction) is analyzed on an elemental analyzer for its carbon concentration; the stock is calculated as a product of POM amount and carbon concentration in POM	g C / sq. m	Carbon in particulate organic matter is generally free or released from soil macro-aggregates; it is thus considered to be more readily available as a carbon source for heterotrophic soil microorganisms that promote soil carbon mineralization	Amounts of particulate organic matter are generally regarded as a good indicator of soil quality (i.e., a readily available pool of labile soil carbon to support soil microorganisms)
ORNL2 (O1)	Carbon Stock in MOM	Mass of soil carbon in mineral-associated organic matter from the mineral soil	Mineral-associated organic matter is physically separated from mineral soil by wet sieving after soil dispersion and the dry MOM (silt and clay size fractions) is analyzed on an elemental analyzer for its carbon concentration; the stock is calculated as a product of concentration and amount of mineral-associated organic matter	g C / sq. m	It is an amount rather than a concentration; carbon associated with mineral-associated organic matter is generally considered to be more humified than POM-C	MOM-C has a longer mean residence time in the soil than POM-C and is a less favorable energy source for some soil microorganisms
ORNL2 (O1)	Fraction of Soil Carbon in POM	Fraction of total soil carbon (to a specified soil depth) in particulate organic matter	Calculated -- it is the amount of carbon in POM normalized by the total soil carbon stock	fraction of total soil carbon	Relative amounts of labile soil carbon pool in the mineral soil	Amounts of particulate organic matter are generally regarded as a good indicator of soil quality (i.e., a readily available pool of labile soil carbon to support soil microorganisms)
ORNL2 (O1)	Soil Nitrogen Concentration	Grams of nitrogen per gram of dry soil	Measured by combustion of the soil sample (elemental analysis) in a LECO CN-2000	% dry mass	The concentration of a critical plant nutrient in soil	Nitrogen is usually the single most important soil nutrient that constrains biomass production
ORNL1 (O1)	Soil Nitrogen Concentration	Grams of nitrogen per gram of dry soil	Measured by combustion of the soil sample (elemental analysis) in a LECO CN-2000	% dry mass	The concentration of a critical plant nutrient in soil	Nitrogen is usually the single most important soil nutrient that constrains biomass production

ORNL2 (O1)	Nitrogen Concentration in MOM	Concentration of nitrogen in the silt and clay fractions from mineral soil samples	Mineral-associated organic matter is physically separated from mineral soil by wet sieving after soil dispersion and the dry MOM (silt and clay size fractions) is analyzed on an elemental analyzer for its nitrogen concentration	% dry mass	A pool of soil nitrogen with a relatively long mean residence time	Under some conditions, MOM can be an important source of slow-release soil nitrogen
ORNL2 (O1)	Soil Nitrogen Stocks	Grams of nitrogen per unit area of ground to a specified soil depth	Calculated as the product of soil density and soil nitrogen concentration	g N / sq. m	The amount of soil nitrogen (total soil nitrogen)	N\itrogen is the single most important soil nutrient that constrains biomass production
ORNL1 (O3)	Soil Nitrogen	Grams of nitrogen per unit area of ground to a specified soil depth	Calculated as the product of soil density and soil nitrogen concentration	mg N / sq. cm	The amount of soil nitrogen (total soil nitrogen)	Nitrogen is the single most important soil nutrient that constrains biomass production
ORNL2 (O1)	Soil C:N Ratios	Ratio of soil carbon concentration to soil nitrogen concentration	Calculated from soil carbon and nitrogen concentration data	none (ratio)	The amount of soil carbon relative to nitrogen	High soil C:N ratios indicate that soil microbes are N limited rather than C limited and so N is immobilized during microbe growth; low soil C:N ratios indicate that soil microbes are more C liimited than N limited and so N is released (mineralized) during decomposition of soil organic matter
Prescott College (P3)	Soil Nitrate	Soil concentration of nitrate and ammonium	Systematic-random collection of soil samples, composited, lab analysis	µg/kg-dry wt soil	Absolute and relative amounts of nitrate and ammonium in the soil	Nitrogen has been identified as an important integrator of ecosystem condition, successional stage, and productivity; often the limiting macro-nutrient in terrestrial ecosystems; most critical for our integrated ecological indicator set

SREL (S1)	Soil Extractable N	Extractable mineral nitrogen in soil	A hammer corer (AMS, American Falls, ID) was used to extract two soil cores (15.2 cm deep by 5.1 cm diameter) beneath each organic layer sample at 4 random points in each 100m x 100m plot. The cores were stored at 5 oC until processing. In the laboratory, one of each pair was passed through a 6.3 mm sieve; roots were sorted and removed from the soil. A subsample of the sieved soil (ca. 10 g) was extracted using 2 M KCl (10 ml soln:1 g soil). The solution was shaken mechanically for two hours and allowed to clear overnight at 4 oC. The clear extract was pipetted off for NO3-N and NH4-N analysis using automated colorimetry (Alpkem FS3000) with a detection limit of 0.01 ppm.	ug/g soil	Extractable mineral nitrogen in the soil	It is the current level of extractable nitrogen for the soil.
ORNL2 (O1)	Extractable Soil Nitrate-N	Grams of nitrate-N that can be extracted from the mineral soil	Soils are extracted with 2 molar potassium chloride and nitrate-N is displaced from anion adsorption sites in the soil	μg N / g soil	A chemically available form of soil nitrogen that may indicate the availability of nitrate-N to plant roots	Soil nitrate is highly mobile and readily leached from the plant rhizosphere if it is not immobilized by soil microorganisms or taken up by plant roots
ORNL2 (O1)	Potential Net Soil Nitrogen Mineralization	Potential for transformation of organic soil nitrogen to inorganic soil nitrogen	Laboratory incubations over a specified period of time to determine the production of inorganic soil nitrogen during decomposition of organic matter	μg N / g soil / week or month	The relative availability of soil nitrogen to plants and the net potential of the soil to produce inorganic soil nitrogen	Soil nitrogen mineralization is the primary process by which nitrogen is made available to plant roots

SREL (S2)	Soil Potential N	Defined as mineral nitrogen production in the laboratory. It is a potential estimate and the exact definition depends on the time interval and mineral nitrogen components used in the calculations.	Soil cores were prepared as for extractable N. The remaining soil was incubated in the dark at room temperature (21 oC) in 800 ml jars to measure potential net Nmin. Laboratory soil mineralization incubations are the preferred method to isolate the effect of substrate because other factors can be maintained at nonrestrictive levels. Lids were removed briefly once a week to keep the incubations aerobic. After 42 days, a 10 g soil sample was removed, extracted as described above, and analyzed for NH4-N and NO3-N using automated colorimetry (Alpkem FS3000) with a detection limit of 0.01 ppm. These second extracts were compared to the first to determine production of NH4-N, NO3-N, and total N. A final extraction was performed after 84 days to check for a lag phase for nitrification.	ug/g soil	Potential mineral nitrogen in the soil based on laboratory incubations under favorable conditions	It is the potential nitrogen production for the soil and represents the production of nitrogen available from soil components under favorable conditions.
ORNL2 (O1)	Potential Net Soil Nitrification	Potential for transformation of ammonium nitrogen to nitrate nitrogen in mineral soil samples	Laboratory incubations over a specified period of time to determine the production of nitrate during decomposition of organic matter	μg N / g soil / week or month	The relative activity of nitrifiers in the soil	Nitrification produces nitrate from ammonium and nitrate is a highly mobile and leachable form of soil nitrogen
ORNL2 (O1)	Extractable Inorganic Soil Nitrogen	Grams of inorganic soil nitrogen that can be extracted from the mineral soil	Soils are extracted with 2 molar potassium chloride	μg N / g soil	Chemically available forms of soil nitrogen (a relative measure of soil nitrogen availability to plant roots)	Soil nitrogen is the primary nutrient limiting plant growth

Prescott College (P3)	Soil Ammonium	Soil concentration of ammonium	Systematic-random collection of soil samples, composited, lab analysis	μg/kg-dry wt soil	Absolute and relative amounts of nitrate and ammonium in the soil	Nitrogen has been identified as an important integrator of ecosystem condition, successional stage, and productivity; often the limiting macro-nutrient in terrestrial ecosystems; most critical for our integrated ecological indicator set
ORNL2 (O1)	Extractable Soil Ammonium-N	Grams of ammonium-N that can be extracted from the mineral soil	Soils are extracted with 2 molar potassium chloride and ammonium-N is displaced from cation adsorption sites on the soil	μg N / g soil	A chemically available form of soil nitrogen that may indicate the availability of ammonium-N to plant roots	Some plant roots preferentially absorb ammonium nitrogen
Prescott College (P3)	Soil Organic Matter	Organic matter in the soil	Based on soil samples collected for nitrogen analysis; loss of weight on ignition		Absolute and relative amounts of organic matter and carbon in the soil	Soil carbon and organic content is directly linked to biological productivity and ecosystem condition; very critical for our integrated ecological indicator set
SREL (S1)	Soil Organic Layer Mass	Oven dry mass of pooled organic layers Oi, Oe and Oa.	From a destructive harvest of pooled organic layers in the field. A circular sampling guide of 495 cm2 was laid on the soil surface. Clippers were used to cut around the perimeter of the guide to the mineral soil surface. All organic layer sample was removed up to the mineral soil interface. Surface organic layer samples were collected at 8 random points in each study site.	g/m2	Mass of organic layer on an aerial basis	It acts as an integrated measurement for litter input, decomposition, erosion and fire for a plot

ORNL2 (O1)	O-Horizon Dry Mass	Grams of O-horizon per unit area	The O-horizon is removed from a known area of ground and its dry mass is determined	g dry mass / sq. m	It can represent several different things but is basically a measure of the balance between litter inputs and litter decomposition	O-horizons promote water retention and help prevent erosion; O-horizons are an important source of nutrients for plant roots and they provide protection for decomposer organisms that help breakdown litter for the supply of plant nutrients
SREL (S1)	Soil Organic Layer %N	% N composition of pooled organic layer samples	See organic layer mass. Physical sample ground in a Wiley mill then a subsample was ground in a Spex ball mill then analyzed for nitrogen using a CHN analyzer	%	Nitrogen content of organic layer	It acts as an integrated measurement for quality of litter inputs and the pool of nitrogen.
ORNL2 (O1)	O-Horizon Nitrogen Stock	Grams of nitrogen present in the O-horizon per unit area of ground	Calculated as the product of O-horizon nitrogen concentration and O-horizon dry mass	g N / sq. m	An important nitrogen pool that is released to supply plant nutrients as the litter decomposes	Plant growth on sandy, nutrient poor soils is highly dependent on recycling of nitrogen through the O-horizon
ORNL2 (O1)	O-Horizon Carbon Stock	Grams of carbon present in the O-horizon per unit area of ground	Calculated as the product of O-horizon carbon concentration and O-horizon dry mass	g C / sq. m	The amount of soil carbon in the O-horizon	It is directly correlated with the amount of surface organic matter which can be important in water retention and an important source of nutrients for plant growth and soil microorganisms

ORNL2 (O1)	O-Horizon C:N Ratio	Ratio of O-horizon C concentration to O-horizon N concentration	Calculated from O-horizon C and N concentrations	none (ratio)	Generally believed to be a measure of litter quality; litter with a high C:N ratio undergoes slow initial rates of decomposition because N limits decomposer activity while litter with a low C:N ratio undergoes high initial rates of decomposition (i.e., decomposition and release of nutrients proceeds more quickly in litters with a low C:N ratio)	It can indicate the rate at which litter will decompose and the rate at which nutrients are released to the mineral soil
Prescott College (P)	Microbial Biomass Carbon			mg/g-dry wt soil	The amount of microbial carbon in the soil	
ORNL1 (O4)	Soil Microbes: Biomass	We are measuring the total amount of microbial biomass (as PLFA) in the soil.	Quantitative measure of the phospholipid fatty acid content of the soil is extracted, purified and anayzed by GC.	pmol/g dry wt. Of soil	The viable PLFA content of the soil.	Because bacteria and fungi are involved in decomposition and nutrient cycling in all ecosystems, they represent critical integrators of ecosystem structure and dynamics
Prescott College (P4)	Bacteria Total Activity	We are measuring the total activity and functional diversity of the fungal and bacterial communities	Systematic-random soil samples are composited and taken to the lab where they are tested with BioLog protocols. Biolog GN-2 microplates are inoculated with a 10-4 dilution of each individual soil sample. Plates are read every 12 hrs beginning at 24 hrs for 72 hrs. Plates are incubated at 25 C. Values are from the 72 hr reading time.	sum of optical density on a plate after five days	Relative degree of bacteria and fungal activity to a wide range of nutrient substrates	Because bacteria are involved in decomposition and nutrient cycling in all ecosystems they represent critical integrators of ecosystem structure and dynamics; most critical for our ecological indicator set

Prescott College (P4)	Bacteria Functional Diversity	We are measuring the total activity and functional diversity of the fungal and bacterial communities	Systematic-random soil samples are composited and taken to the lab where they are tested with BioLog protocols. Biolog GN-2 microplates are inoculated with a 10-4 dilution of each individual soil sample. Plates are read every 12 hrs beginning at 24 hrs for 72 hrs. Plates are incubated at 25 C. Values are from the 72 hr reading time.	number of carbon compounds out of 95 that have an optical density greater than 0.1	Ability of soil bacteria to use carbon	Because bacteria are involved in decomposition and nutrient cycling in all ecosystems they represent critical integrators of ecosystem structure and dynamics; most critical for our ecological indicator set
Prescott College (P4)	Fungi Total Activity	We are measuring the total activity and functional diversity of the fungal and bacterial communities	Systematic-random soil samples are composited and taken to the lab where they are tested with FungiLog protocols. Values are based on inoculation of Biolog SFN-2 microtiter plates with soil organic matter sieved from each sample through a 500 to 250 µm sieve. Material from the 250µm sieve is used to inoculate the plates. Plates are read every 24 hrs for five days. Plates are incubated at 25 C.	sum of optical density on a plate after five days	Relative degree of bacteria and fungal activity to a wide range of nutrient substrates	Because fungi are involved in decomposition and nutrient cycling in all ecosystems they represent critical integrators of ecosystem structure and dynamics; most critical for our ecological indicator set
Prescott College (P4)	Fungi Functional Diversity	We are measuring the total activity and functional diversity of the fungal and bacterial communities	Systematic-random soil samples are composited and taken to the lab where they are tested with FungiLog protocols. Values are based on inoculation of Biolog SFN-2 microtiter plates with soil organic matter sieved from each sample through a 500 to 250 µm sieve. Material from the 250µm sieve is used to inoculate the plates. Plates are read every 24 hrs for five days. Plates are incubated at 25 C.	number of carbon compounds out of 95 that have an optical density greater than 0.1	Ability of soil fungi to use carbon	Because fungi are involved in decomposition and nutrient cycling in all ecosystems they represent critical integrators of ecosystem structure and dynamics; most critical for our ecological indicator set
ORNL1 (O4)	Soil Microbes Community Composition	Measuring distribution of different classes of microbes	Specific classes of PLFA are extracted and quantified.	mol%	Amount of the group of PLFA in picomols	Because bacteria and fungi are involved in decomposition and nutrient cycling in all ecosystems, they represent critical integrators of ecosystem structure and dynamics

UF (FL1)	Beta-Glucosidase Activity	Activity of soil ectoenzyme involved in cellulose degradation	Measured in aqueous soil dilutions by production of methyl-umbelliferone from the artificial substrate MUF-glucoside (Sinsabaugh et al., 1997)	μmole product g^{-1} dry soil $hour^{-1}$	Competence of soil to degrade cellulose; microbiological activity.	An indicator of microbial nutrient cycling
Prescott College (P5)	Nutrient Leakage: Nitrate	The measurement of leachate ions ½ m below soil surface	Water collected from field lysimeters; ion concentrations measured in lab	ions in ppm	Anions and cations that are being leached from top soil	Direct measure of the loss or “leakage” of major and minor nutrients from soils; very critical for our integrated ecological indicator set
Prescott College (P5)	Nutrient Leakage: Ammonium	The measurement of leachate ions ½ m below soil surface	Water collected from field lysimeters; ion concentrations measured in lab	ions in ppm	Anions and cations that are being leached from top soil	Direct measure of the loss or “leakage” of major and minor nutrients from soils; very critical for our integrated ecological indicator set
Prescott College (P5)	Nutrient Leakage: Phosphate	The measurement of leachate ions ½ m below soil surface	Water collected from field lysimeters; ion concentrations measured in lab	ions in ppm	Anions and cations that are being leached from top soil	Direct measure of the loss or “leakage” of major and minor nutrients from soils; very critical for our integrated ecological indicator set
Prescott College (P5)	Nutrient Leakage: Sulfate	The measurement of leachate ions ½ m below soil surface	Water collected from field lysimeters; ion concentrations measured in lab	ions in ppm	Anions and cations that are being leached from top soil	Direct measure of the loss or “leakage” of major and minor nutrients from soils; very critical for our integrated ecological indicator set

Integration

Introduction

Land use has been defined as "the purpose to which land is put to use by humans" (Dale, Brown et al. 2000). Some general land-use categories include agriculture, forestry, mining and settlement. The way a given land asset is administered by humans is defined as land management (Dale, Brown et al. 2000). Some examples of land management include till versus no-till agriculture, open cast versus drift mining, and various forestry harvesting methods. In each of these examples, those people responsible for the administration of the land assets decide how to use limited and often non-renewable resources. Central to the management of land resources are the management goals (or endpoints) for which the land resource is to be used (Dale and Haeuber 2000). However, there has often been a disconnect between land management, land use, and land management goals (Wolfe and Dale 2006). Frequently this disconnect is exacerbated by the methods and procedures used for monitoring the land resources.

A major challenge for land managers is to decide what ecological variable or variables to measure to indicate that land is being used commensurate with land management goals, or in other words how to monitor degradation or improvement in land resources (Dale and Beyeler 2001). Much data has been and is currently collected that relates to land management (e.g., the Land Condition Trend Analysis (LCTA) data collected for military bases (Diersing, Shaw et al. 1992)), but this information is not always appropriate or useful in the context of land use or land management goals. There are several reasons why information collected under various mandates may not be suitable for coherent land management. Many of the programs that are currently used were not designed to answer questions about land management goals. For example the LCTA used at military installations was established to assess long term trends in ecological data, but the LCTA approach does not address day to day or month to month land-use issues that arise at these installations and is not flexible. In order to address the disconnect between land management, land use, and land management goals, we have developed a two-step approach that (1) identifies land management categories that encompass land management goals and (2) selects ecological variables that best predicts these management categories. The creation of land-management categories is a necessary step in the establishment of land-use goals and, once specified, provide land managers with the data they need to allocate resources. The approach is first described and then illustrated by an example of its use at Fort Benning, Georgia. This chapter focuses specifically on the procedure used to select indicators that differentiate the land-management categories.

Overview of Approach

Data, models and information (peer reviewed publications) produced by scientists often fail to meet the needs of land mangers (Jones, Lach et al. 1999; Steel, Lach et al. 2000-2001; Rayner, Lach et al. 2001). In order to connect land management with accurate data about current land conditions we developed a method to select specific indicators of land suitability. The overall approach was to screen the indicators that best discriminated between the land-management categories and involved three steps: (1) use a Delphi approach to establish land-management categories (2) Collection of potential indicator data by category, and (3) Use of variable selection techniques to screen for useful indicators. Figure 3-1 illustrates the steps of this method. The first step involves the use of a modified Delphi process to query resource managers and scientists regarding current land use and land management practices and was the focus of prior work. In order to address the disconnect and to set the groundwork for future integration and screening efforts, Wolfe and Dale (Wolfe and Dale 2006; Wolfe Dale, et al. 2006) developed an iterative Delphi process to facilitate integration between ecological scientists and land managers. The Delphi method is an approach that seeks to establish a group opinion and was originally developed in the 1960s (Soderstrom 1981; Fontana and Frey 1994). In short, participants were asked a round of questions to elicit information. This process was iterated until a consensus was achieved. The participants were queried separately to avoid problems with group interactions. The goal of the Delphi process in this case was to identify Land-Management Categories. These categories were derived from goals for the land use coupled with the current impact from diverse uses. Because the categories were initially set by the perspective of the resource managers, and it was anticipated that the results would then have meaning to land managers.

Once the Land-Management Categories had been established, the second step in the process was to collect ecological data. The type of ecological data collected may differ from region to region but would most likely include soil physical and chemical parameters, plant abundance and diversity, animal abundance and diversity, and other data that are known to be useful to land managers in a given ecosystem. In our case, the choice of potential indicators drew from the hypothesis that a suite of indicators could best explain land-use conditions (Dale, Mulholland et al. 2004).

The third part of the approach was to take the assembled indicator data describing the different Land-Management Categories and distill the collected information into a suite of indicators that best describes the particular category. Indeed one of the heuristics of science is to seek the simplest solution, and we used a multiple solutions approach (Lee, Lee et al. 2002) to elucidate important indicators as they relate to Land Management Categories. Using the distilled data, a manager would be able to monitor degradation or improvement within Land-Management Categories and hence be able to better manage the land. Herein we describe this selection process for data appropriate for differentiating between Land-Management Categories that can be used by resource managers at Fort Benning, GA.

An example: Land-Management Categories at Fort Benning, Georgia

Managers at military installations are responsible for allocating a finite amount of land resources for the use and training of military personnel. Military training often requires the use of ordnance or engineering activities that are inconsistent with sustainable land-use practices; therefore an effective monitoring program that accurately assesses the status of land resources becomes integral to ensure the long-term viability of those lands for training purposes. In a broad sense, managers at military installations must address the issue of competition for limited resources and provide the stewardship necessary to the continued mission of troop readiness.

Several ecological disturbances occur at Fort Benning, including military training and testing, timber harvest and thinning, natural and anthropogenic fire, insect outbreaks, and the spread of introduced invasive species (as described in the Integrated natural Resource Management Plan for Fort Benning). External activities also impact Fort Benning such as surrounding land-use change, encroachment, and general climatic changes (heating or cooling) that may lead to changes in precipitation or other climatic effects (Efroymson, Dale et al. 2005. A viable and relevant set of ecological indicators could provide managers with early warning of abnormal conditions of resources, data to better understand the dynamic nature and condition of installation ecosystems, data to meet legal and Congressional mandates, and a means of measuring suitability of land for training purposes or for a go no-go decision for continued training in a certain area (Davis 1997).

Study Site

The studies were conducted at the Fort Benning Army Installation located in the lower Piedmont Region of central Georgia and Alabama, six miles southeast of Columbus, Georgia. The

Post consists of approximately 736 square kilometers of river valley terraces and rolling terrain. The climate at Fort Benning is humid and mild with rainfall occurring regularly throughout the year. Annual precipitation averages 105 cm with October being the driest month. Most of the soils at the base are heavily weathered Ultisols. (– as described in the Integrated Natural Resource Management Plan for Fort Benning).

Land Management Categories

Land-Management Categories were established for the base according to the work of Wolfe and Dale (Wolfe, Dale et al. 2006). Wolfe and Dale (2006) summarize the Land-Management Categories as defined from the matrix consisting of goals and endpoints, impacts from use, and frequency of use. This matrix shows the three major land management goals and endpoints for Fort Benning and subgoals as compared to the cause of predominant ecological effect from military use of the land. Each element in the matrix denotes a Land-Management Category. The Land-Management Categories are not of themselves land management goals but are determined by them. The Land-Management Categories are further delineated by the frequency of use each a category may receive. The establishment of Land-Management Categories allowed the assessment of the ecological indicators for this project. The end result of the effort of Wolfe and Dale (2006) was a multidimensional matrix of Land-Management Categories that included cause of predominant ecological impact of military uses of land, land management goals and endpoints, and frequency of use. The Land-Management Categories provided a common framework for synthesizing diverse data from several research projects (first chapter this work), the approach allowed specific field plots to be assigned to unique Land-Management Category, regardless of whether those plots previously had been subjected to different uses or currently are used for multiple purposes.

Data Collected on Ecological Attributes

Environmental indicator data from the five Strategic Environmental Research Development Programs, Ecosystem Management Program (SERDP SEMP, defined in chapter 1) sponsored projects used in this analysis were available from the SEMP Data Repository (https://sempdata.erdc.usace.army.mil/) and consisted of 13 separate datasets that, in turn, included 112 indicators and 4283 total observations. Each dataset, the associated indicators, and descriptive statistics are listed in Table 3-2 Parts A-C. A detailed listing of all indicators, the methods of collection, measurement units and investigator justification are listed in Appendix V. The collected datasets contained environmental indicators that represented soil, plant, and microbial data at the plot level from various plot and point locations at Fort Benning.

Variable Selection Approach

Several variable selection techniques were used to identify a subset of important ecological indicators from the pool of candidate indicators that best discriminated the Land-Management Categories. The selection was accomplished by using a four-step method of data analysis: (1) data exploration, using descriptive and general statistics; (2) matrix conditioning that included filtering outliers, imputing missing values and transforming variables where necessary; (3) variable selection using Regression, Neural Network and Decision Tree models; and (4) the assessment and scoring of output to identify common traits of important indicators that were strong discriminators of the Land-Management Categories.

Although the framework of Land-Management Categories facilitated the comparison of multiple indicators across research teams, the basic issue of how to perform the actual indicator (variable) selection remained. There were many concerns with how the selection would take place. Concerns included aspects of the way the data were collected: (1) That Land-Management Categories were applied retroactively to the plots at Fort Benning, and data collected was not intended to explain Land-Management Categories; (2) Land-Management Categories were not equally distributed across the base, and the sampling across Land-Management Categories was not even; (3) Not all indicators were equally sensible for all Land-Management Categories; and (4) Land-Management Categories were not equally important to resource managers.

In order to compensate for the shortcomings in the data, we used a strategy of multiple solutions by employing several parametric and nonparametric indicator selection techniques. The underlying assumption of this approach was that the union of or intersection between indicator results would reduce uncertainties from a single method result. The hypothesis was that certain important ecological indicators would discriminate between Land-Management Categories that were representative of military land use and its effects on ecological systems. Once identified, the important indicators could be identified for each Land-Management Category and then used in a management program.

Descriptive Statistics and Matrix Conditioning

Each indicator was assessed with series of descriptive statistics to ascertain the shape of the distribution and frequency of values. Histograms were plotted and a Shapiro-Wilk W statistic was computed for each variable. If the Shapiro-Wilk W test result was < 0.7 showing non normality (A. Saxton, Personal Communication), then a transformation of the variable was performed and the distribution of the variable was again assessed until a suitable transformation was found (Table 3-2 Parts A-C). Outliers were filtered at five standard deviations from the mean. If it was found that values represented acceptable data, then the filter was broadened to accommodate that data. Mean imputation was used in a couple of datasets in order to keep as many observations as possible for model generation and assessment.

Regression

Logistic Regression (Dreiseitl and Ohno-Machado 2002) was performed using SAS Enterprise Miner 4.2 software (SAS Cary, NC). Forward, stepwise, and standard variable selection were used to screen indicators against the Land-Management Categories. All regression models used LOGIT as the link function and deviation coding. Forward and Stepwise selection criteria were set at the significance level of 0.05 for entry and or stay in the model. Indicators from the regression analysis were considered important if the overall predictive model was significant at 0.05 and the individual indicator was also significant at 0.05.

Neural Network

Neural network (NN) identification was performed with early stopping by cross-validation and topology optimization by bootstrapping (selection criteria: median cross-validated error) using microCortex web based neural computing environment (www.microCortex.com) (Almeida 2002). NN models were considered relevant if the r^2 statistic for any trained NN (for any Land-Management Category) was greater than 0.6. The relative importance of each input parameter in predicting the target values was calculated by performing sensitivity analysis on the trained NN (Masters 1993). In this study, sensitivity of an output parameter $Out_{j=1,2,\ldots,nj}$ (for nj output parameters) to an input parameter $In_{i=1,2,\ldots,ni}$ (for ni input parameters) was defined as the normalized ratio between variations caused in Out_j by variations introduced in In_j and is represented by the following equation:

$$NS_{i,jc} = (dOut_{j,c} / d\, In_{i,c})(In_{i,c} / Out_{j,c})$$
$$S_i = \left[\Sigma_{j=1,2,\ldots,nj;\, c=1,2,\ldots,nc} (NS_{i,jc}) \right] / \left[\Sigma_{i=1,2,\ldots,ni;\, j=1,2,\ldots nj;\, c=1,2,\ldots,nc} (NS_{i,jc}) \right] \qquad \text{(eq. 1)}$$

i= 1, 2, ..., ni; input index
j= 1, 2, ..., nj; output index
c= 1, 2, ..., nc; sample (case) index

The normalized sensitivity for an individual profile c, $NS_{i,jc}$ was calculated for every single combination of input, i, and output parameters, j, and for every single profile (for nc profiles). The overall sensitivity to an input, S_i, was determined by taking the average over all profiles and all binary outputs used to classify them. Finally, the sensitivity values obtained are represented as relative values, calculated as a percent value of the sum of all sensitivities (Eq1, Si) (Masters 1993). If the indicator sensitivity was greater than 10%, then it was considered important and scored.

Decision Tree

The Tree-growing algorithms (Answer Tree v3.1 SPSS Chicago, IL) Exhaustive Chi-squared Automatic Interaction Detector (Kass 1980; Biggs, Ville et al. 1991) and Classification and Regression Trees (C&RT) (Breiman, Friedman et al. 1984) were used to select a subset of predictors from the indicator data that predicted the Land-Management Category. Indicators resulting from the decision rules from Tree models were considered relevant if the model had a misclassification rate less than or equal to 40%.

Results Scoring

We chose to employ a strategy of multiple solutions by using several parametric and nonparametric indicator selection techniques as described above. In order to summarize the indicator selection outcomes, a selection score was calculated from the union of or intersection between indicator results. If a given indicator was significant (as defined above) within a given overall significant model, then it was scored. The selection score was calculated as the sum of the number of models (union of or intersection between) for which a given indicator was significant. The maximum selection score an indicator could receive was six because that was the number of indicator selection techniques used. Higher selection scores for indicators within data sets are interpreted as meaning those indicators are more robust in regards to defining the Land-Management Categories.

Results for Fort Benning
Variable Selection

The variable selection analyses resulted in several strong ecological indicators that described the Land-Management Categories. Table 3-3 Parts A-C shows the results from the indicator selection techniques used in this effort. Three basic types of ecological indicator data were available for this analysis and included: (1) soil physical, chemical and microbiological parameters; (2) plant family, life form; and (3) cover data (Appendix V). Soil physical and chemical variables that received high selection scores included soil “A” horizon depth, compaction, organic matter, organic layer N, NH_3, Total N, N mineralization rate, Total Carbon and % Carbon. Soil microbiological indicators that received high selection scores included biomarkers for fungi, Gram-negative Eubacteria, soil microbial respiration and beta-glucosidase activity. Plant family and life form indicators that received high selection scores were Family Leguminosae, possibly Rosaceae, and the plant Life forms Therophyte, Cyptophyte, Hemicryptophyte and Chamaephyte. Understory cover, overstory cover and tree stand characteristics also scored well in the ability to discriminate between Land-Management Categories.

Discussion for Fort Benning

Circumstances necessitated an uncommon approach for the selection of indicators that best discriminated Land-Management Categories. There were two key components to this work, (1) the development of Land-Management Categories and (2) variable screening by multiple solutions. Although the data for this effort were not collected in a fashion commensurate with traditional statistical techniques, it was still possible to integrate the separate research efforts and score the results. The use of selection scores provided a straightforward comparison of each indicator, and this was important in obtaining results.

Similar indicators were measured by several research teams, and the overlap of the results provided confidence in the validity of those selected indicators. Soil "A" horizon depth scored high in two out of three data sets where it was measured. Soil horizons are layers of soil or soil material that are approximately parallel to the land surface and differ from adjacent related layers by chemical, physical or biological properties. The soil "A" horizon is a mineral horizon in which the emphasized feature is the accumulation of humified organic matter intimately associated with the mineral fraction and develops partially from organic matter accumulation (Boul, Hole et al. 1994).

Soil compaction was found to be an important indicator of Land Management Categories and is defined as the volume change produced by momentary load application on the soil (Bradford and Peterson 2000). Many of the Land-Management Categories at Fort Benning are defined by the amount of military traffic they receive. The traffic consists of dismounted infantry (foot traffic), wheeled vehicles, and tracked vehicles. Soil compaction decreases void space, increases bulk density, and decreases compressibility and permeability. Soil compaction may also alter the growth of trees in forest systems and affect the water regime and organic matter content (Greacen and Sands 1980).

Soil organic matter (SOM) is defined as the sum of all natural and thermally altered biologically derived organic material found in the soil or on the soil surface irrespective of its source, whether it is living or dead, or stage of decomposition, but excludes the aboveground portion of living plants (Baldock and Nelson 2000). As defined, the amount and quality of SOM is determined by the inputs of the plant and animal community and has been linked to the resilience of ecosystems to disturbance (Szabolcs 1994). SOM serves as a reservoir of metabolic energy, a source of macronutrients, and stabilizes soil structure. The amount and quality of SOM in the soils at Fort Benning were found to be important in discriminating the Land-Management Categories. Several measures of soil carbon and nitrogen, which are integral parts of the SOM, were also diagnostic for discriminating Land-Management Categories at Fort Benning.

Soil microbiological properties were also found to be good indicators of Land Management Categories (Peacock, Macnaughton et al. 2001). Soil microbiological activity as defined by Soil Respiration, although shown to be variable (Raich and Tufekciogul 2000), is directly related to nutrient cycling and photosynthetic activity (Högberg, Nordgren et al. 2001) and was important in discriminating Land-Management Categories. Additionally N mineralization rate (the transformation of organic to inorganic N forms (Norten 2000)) was also found to be a good predictor of Land-Management Categories. Beta glucosidase activity was assessed at several point and plot locations at Fort Benning. Beta glucosidase activity has been linked to soil microbial activity and numbers (Taylor, Wilson et al. 2002) and has been studied as a potential indicator for effects of agriculture on ecological systems (Bandick and Dick 1999).

Several plant associated indicators were also very useful in discriminating the Land-Management Categories. Understory cover, overstory cover, and tree stand characteristics were indicative of differences in these categories. That these measures are important is not surprising, for cover data are intuitive and have been a widely used as indicators ((Thysell and Carey 2000) and references therein). The plant family Leguminosae, which support nitrogen fixation, has been shown to add to the quality and amount of soil organic matter (Robles and Burke 1997) and was an important indicator. Plant life form (Therophyte, Cryptophyte, Hemicryptophyte and Chamaephyte) was also a good predictor of land-use (Dale, Beyeler et al. 2002).

Conclusions for Fort Benning

Data limitations required a new approach to integrating disparate data from several research teams at Fort Benning. In order to solve the particular problem of relating land management to current challenges, Wolfe and Dale (2006) and Wolfe, Dale et al. (2006) developed a matrix of Land-Management Categories that enabled a statistical (multiple solutions) approach to assess which ecological indicators would be the best candidates for inclusion in a relevant monitoring program. Since the ecological indicator information was spread over several data sets, a way had to be established to integrate and compile the results. The approach of multiple solutions with scoring allowed us to compare the fitness of each indicator for the prediction of Land-Management Categories without the limitations of other more traditional statistical methods. The results and insights gained from this effort appear to be consistent with other work in ecological indicators.

This approach fulfilled the expectations for these data and could be used at other sites where there are existing data that were not collected in a way commensurate with traditional statistical methods.

References

Almeida, J. S. (2002). "Predictive non-linear modeling of complex data by artificial neural networks." Current Opinion in Biotechnology **13**(1): 72-76.

Baldock, J. A. and P. N. Nelson (2000). Soil Organic Matter. Handbook of Soil Science. M. E. Sumner. New York, CRC Press**:** B25-B84.

Bandick, A. K. and R. P. Dick (1999). "Field management effects on soil enzyme activities." Soil Biology and Biochemistry **31**(11): 1471-1479.

Biggs, D., B. Ville, et al. (1991). "A method of choosing multiway partitions for classification and decision trees." Journal of Applied Statistics **18**(1): 49-62.

Boul, S. W., F. D. Hole, et al. (1994). Soil Genesis and Classification. Ames, Iowa State University Press.

Bradford, J. M. and G. A. Peterson (2000). Conservation Tillage. Handbook of Soil Science. M. E. Sumner. New York, CRC Press**:** G247-G270.

Breiman, L., J. H. Friedman, et al. (1984). Classification and regression trees. Belmont, CA, Wadsworth Adv. Book Program.

Dale, V. H. and S. C. Beyeler (2001). "Challenges in the development and use of ecological indicators." Ecological Indicators **1**(1): 3-10.

Dale, V. H., S. C. Beyeler, et al. (2002). "Understory vegetation indicators of anthropogenic disturbance in longleaf pine forests at Fort Benning, Georgia, USA." **1**(3): 155-170.

Dale, V. H., S. Brown, et al. (2000). "Ecological Principles and Guidelines for Managing the Use of Land." Ecological Applications **10**(3): 639-670.

Dale, V. H. and R. A. Haeuber (2000). "Perspectives on land use." Ecological Applications **10**(3): 671-672.

Dale, V. H., P. Mulholland, et al. (2004). Selecting a Suite of Ecological Indicators for Resource Management. West Conshohocken, PA, ASTM International.

Davis, G. E. (1997). General ecological monitoring program design, implementation, and applications: a case study from Channel Islands National Park, California. Washington, D.C, Smithsonian Institution.

Diersing, V. E., R. B. Shaw, et al. (1992). "US Army Land Condition-Trend Analysis (LCTA) program." Environmental Management **16**(3): 405-414.

Dreiseitl, S. and L. Ohno-Machado (2002). "Logistic regression and artificial neural network classification models: a methodology review." Journal of Biomedical Informatics **35**(5-6): 352.

Efroymson, R. A., V. H. Dale, L. M. Baskaran, M. Chang, M. Aldridge, and M. Berry (2005). Planning transboundary ecological risk assessments at military installations. Hum. Ecol. Risk Assess. 11:1193-1215.

Fontana, A. and J. H. Frey (1994). Interviewing: The art of science, Sage Publications.

Greacen, E. L. and R. Sands (1980). "Compaction of Forest Soils. A review." Australian Journal of Soil Research **18**(2): 163-189.

Högberg, P., A. Nordgren, et al. (2001). "Large-scale forest girdling shows that current photosynthesis drives soil respiration." Nature **411**(6839): 789-792.

Jones, S., D. Lach, et al. (1999). "Evaluating the interface between climate change research and decision making." Climatic Change: 1-19.

Kass, G. (1980). "An Exploratory technique for investigating large quantities of catagorical data." Applied Statistics **29**(2): 119-127.

Lee, I.-N., S.-C. Lee, et al. (2002). "Important variable selection techniques with multiple solutions for medical information applications." Medical Informatics & the Internet in Medicine **27**(4): 253-267.

Masters, T. (1993). Practical neural network recipes in C++. New York, Academic Press.

Norten, J. M. (2000). Nitrogen Mineralization Immobilization Turnover. Handbook of Soil Science. M. E. Sumner. New York, CRC Press**:** C148-C181.

Peacock, A. D., S. J. Macnaughton, et al. (2001). "Soil microbial biomass and community composition along an anthropogenic disturbance gradient within a long-leaf pine habitat." Ecological Indicators **1**(2): 113-121.

Raich, J. W. and A. Tufekciogul (2000). "Vegetation and soil respiration: Correlations and controls." Biogeochemistry **48**(1): 71-90.

Rayner, S., D. Lach, et al. (2001). Weather Forecasts are for Wimps: Why Water Resource Managers Don't Use Climate Forecasts, Oregon Water Research Institute.

Robles, M. D. and I. C. Burke (1997). "Legume, Grass, and Conservation Preserve Program Effects On Soil Organic Matter Recovery." Ecological Applications **7**(2): 345-357.

Soderstrom, E. J. (1981). Social Impact Assessment: Experimental Methods and Approaches. New York, Praeger.

Steel, B., D. Lach, et al. (2000-2001). "The role of scientists in the natural resource and environmental policy process: A comparison of Canadian and American Publics." Journal of Environmental Systems **28**(2): 133-155.

Szabolcs, I. (1994). The Concept of Soil Resilience. Soil Resilience and Sustainable Land Use. D. J. Greenland and I. Szabolcs. Wallingford, CAB International**:** 33-39.

Taylor, J. P., B. Wilson, et al. (2002). "Comparison of microbial numbers and enzymatic activity in surface soils and subsoils using various techniques." Soil Biology and Biochemistry **34**(3): 387-401.

Thysell, D. R. and A. B. Carey (2000). Effects of Forest Management on Understory and Overstory Vegetation: A Retrospective Study, United States Department of Agriculture Forest Service**:** 45.

Wolfe, A. K. V. H. Dale, and T. Arhtur (2006). "Science versus practice: Using a Delphi approach to reconcile world views." Human Organization.

Wolfe, A. K. and V. H. Dale (2006). "Using a Delphi Approach to Define Land-Management Categories and to Integrate Science and Practice." Journal of Environmental Management.

Figures

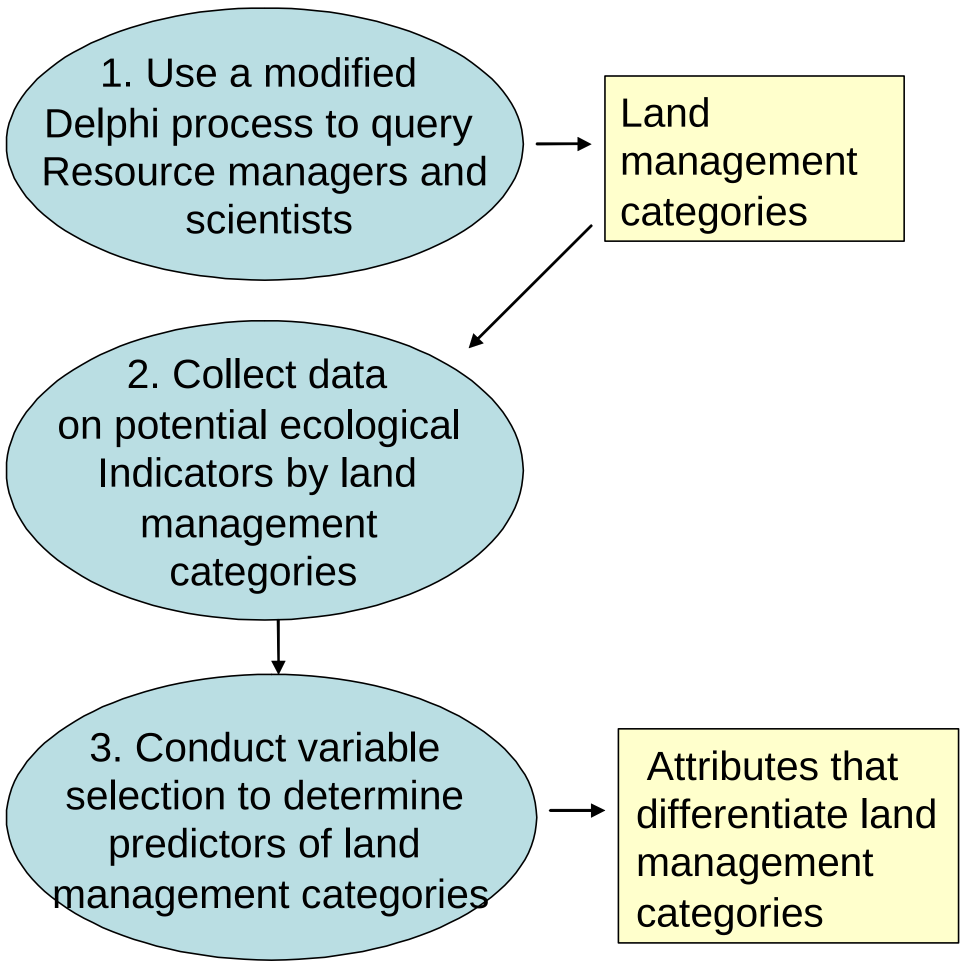


Figure 3-1. The three steps involved in determining those ecological attributes that best differentiate Land-Management Categories.

Table 3-2 Part A. Indicator properties as collected by the SEMP research teams

Data Set[1]	Indicator[2]	N	Mean	Minimum	Maximum	Lower Quartile	Median	Upper Quartile	Range	Std.Dev.	Shapiro-Wilk W	Transformation
P1	Soil Depth (cm)	216	0.784	0.000	4.000	0.000	0.500	1.500	4.000	0.855	0.844	
P2	Lang	1080	7.637	0.000	20.000	4.000	7.000	11.000	20.000	4.931	0.965	
P3	NO3-N	144	3.239	1.110	7.740	1.925	3.075	4.420	6.630	1.450	0.938	
P3	NH4-N	108	10.350	4.870	32.508	7.140	8.955	12.702	27.638	4.713	0.851	
P3	MBC	144	163.692	4.341	1308.932	49.926	106.364	215.985	1304.591	182.770	0.720	
P3	SOM	144	3.081	0.435	26.700	1.598	2.272	3.513	26.265	2.988	0.606	log
P4	ftac	252	69.753	30.250	148.375	58.282	67.398	78.315	118.125	16.263	0.955	
P4	fdiv	252	78.857	54.000	95.000	74.000	80.000	84.000	41.000	7.644	0.983	
P4	btac	252	40.071	0.601	114.835	21.541	39.493	54.920	114.234	22.065	0.978	
P4	bdiv	252	54.468	2.000	90.000	44.000	57.000	68.000	88.000	18.548	0.962	
P5	ammonium	414	0.042	0.000	4.840	0.000	0.000	0.000	4.840	0.301	0.122	Binary
P5	nitrate	414	0.316	0.000	25.940	0.000	0.000	0.000	25.940	1.730	0.174	Binary
P5	phosphorus	414	0.026	0.000	2.660	0.000	0.000	0.000	2.660	0.212	0.101	Binary
P5	sulfate	414	27.842	2.740	233.170	10.620	19.405	34.260	230.430	28.870	0.667	
S1	SoilDEPTH	384	0.654	0.000	6.500	0.000	0.000	1.000	6.500	0.955	0.724	
S1	OrgLMass	256	47.356	2.640	238.740	24.280	37.660	56.510	236.100	37.460	0.762	
S1	Massm2	256	956.679	53.333	4823.030	490.505	760.808	1141.616	4769.697	756.765	0.762	
S1	treesha	35	335.857	132.000	822.000	219.000	278.000	440.000	690.000	161.891	0.885	
S1	treesacre	35	135.946	53.300	333.000	88.500	112.000	178.000	279.700	65.606	0.885	
S1	Percover	32	0.413	0.120	0.657	0.340	0.392	0.511	0.537	0.138	0.965	
S1	OrgLayerN	221	0.703	0.176	1.230	0.556	0.700	0.821	1.054	0.195	0.995	
S1	NO3	128	0.052	0.000	0.830	0.000	0.021	0.063	0.830	0.120	0.402	log
S1	NH3	128	0.817	0.000	6.129	0.149	0.523	1.136	6.129	1.002	0.755	
S1	NO32	128	0.885	0.000	15.320	0.000	0.056	0.813	15.320	2.032	0.478	log
S1	NH32	128	1.940	0.000	19.678	0.125	0.697	2.543	19.678	2.842	0.682	log
S1	NO3M1	128	0.833	-0.167	14.490	0.000	0.040	0.736	14.657	1.951	0.488	log
S1	NH3M1	128	1.123	-1.720	17.603	-0.087	0.286	1.642	19.323	2.499	0.700	log
S1	NO33	128	4.514	0.000	29.595	0.000	1.751	6.925	29.595	6.103	0.759	log
S1	NH33	128	2.898	0.000	26.973	0.275	0.990	4.226	26.973	4.270	0.683	log
S1	NO3M2	128	4.460	-0.167	28.765	0.000	1.712	6.909	28.932	6.049	0.761	log
S1	NH3M2	128	2.073	-2.933	24.898	-0.214	0.640	3.028	27.831	3.900	0.738	log
S1	totalN	128	6.533	-0.688	28.818	2.178	5.176	9.258	29.507	6.178	0.864	
O1	O-HORgN/m2	119	6.238	0.000	28.413	2.781	5.206	9.102	28.413	5.225	0.908	
O1	0-10gN/m2	123	60.958	0.000	212.505	38.778	54.771	83.560	212.505	35.136	0.957	
O1	0-10g/cm3	123	1.235	0.834	1.709	1.064	1.199	1.408	0.875	0.230	0.957	
O1	00-10[C]%	123	1.447	0.039	4.691	0.906	1.342	1.814	4.653	0.922	0.926	
O1	O-HORgC/m2	119	335.713	0.000	1064.010	163.580	352.060	476.890	1064.010	229.943	0.950	
O1	0-10gC/m2	123	1620.111	62.950	4029.650	1153.210	1546.000	2089.140	3966.700	829.963	0.968	
O1	0-20gPOM-C/m2	123	794.624	24.792	2224.888	505.500	762.397	1060.143	2200.096	453.410	0.968	
O1	0-20gMOM-C/m2	123	1621.583	92.298	4146.301	1174.464	1483.545	1999.044	4054.003	853.424	0.942	
O1	0-10[N]%	123	0.054	0.000	0.203	0.030	0.047	0.069	0.203	0.036	0.926	
O1	O-HORC:N	101	61.205	25.073	145.852	45.358	53.646	71.360	120.779	25.300	0.869	
O1	0-10C:N	119	29.274	3.080	122.989	21.989	28.527	34.064	119.909	13.447	0.773	log
O1	T0ugNO3N/g	123	0.163	-0.088	1.839	0.000	0.074	0.201	1.927	0.294	0.573	log
O1	T0ugNH4N/g	123	2.228	0.045	19.309	0.931	1.455	2.453	19.264	2.519	0.628	log
O1	T0ugTOTN/g	123	2.392	0.255	19.965	1.097	1.675	2.665	19.710	2.514	0.608	log
O1	MOM[C]%	123	2.776	0.222	10.173	1.119	2.164	3.954	9.951	2.098	0.887	
O1	MOM[N]%	123	0.136	0.022	0.409	0.073	0.118	0.173	0.387	0.083	0.909	
O1	fPOM-C	123	0.325	0.136	0.602	0.258	0.325	0.394	0.466	0.095	0.989	
O1	O-HORg/cm2	118	0.089	0.000	0.307	0.042	0.089	0.130	0.307	0.061	0.962	
O1	NMINRATE	123	4.442	-13.560	40.300	0.570	2.430	6.550	53.860	7.214	0.777	log

Table 3-2 Part B. Indicator properties as collected by the SEMP research teams

Data Set[1]	Indicator[2]	N	Mean	Minimum	Maximum	Lower Quartile	Median	Upper Quartile	Range	Std.Dev.	Shapiro-Wilk W	Transformation
O2	Acanthaceae	70	0.000	0.000	0.005	0.000	0.000	0.000	0.005	0.001	0.202	None/Binary
O2	Aizoceae	70	0.000	0.000	0.005	0.000	0.000	0.000	0.005	0.001	0.098	None/Binary
O2	Amaranthaceae	70	0.000	0.000	0.005	0.000	0.000	0.000	0.005	0.001	0.314	None/Binary
O2	Anacardiacea	70	0.007	-0.003	0.090	0.000	0.005	0.005	0.093	0.014	0.528	None/Binary
O2	Aquifoliaceae	70	0.009	0.000	0.625	0.000	0.000	0.000	0.625	0.075	0.106	None/Binary
O2	Boraginaceae	70	0.000	0.000	0.005	0.000	0.000	0.000	0.005	0.001	0.098	None/Binary
O2	Cactaceae	70	0.000	0.000	0.005	0.000	0.000	0.000	0.005	0.001	0.158	None/Binary
O2	Campanulaceae	70	0.000	0.000	0.005	0.000	0.000	0.000	0.005	0.001	0.158	None/Binary
O2	Caryophyllaceae	70	0.000	0.000	0.010	0.000	0.000	0.000	0.010	0.001	0.201	None/Binary
O2	Cistaceae	70	0.001	0.000	0.005	0.000	0.000	0.000	0.005	0.002	0.519	None/Binary
O2	Compositae	70	0.116	0.000	0.885	0.010	0.033	0.120	0.885	0.194	0.635	None/Binary
O2	Convolvulaceae	70	0.000	0.000	0.005	0.000	0.000	0.000	0.005	0.001	0.282	None/Binary
O2	Cyperaceae	70	0.001	0.000	0.030	0.000	0.000	0.000	0.030	0.005	0.195	None/Binary
O2	Ebenaceae	70	0.004	0.000	0.030	0.000	0.005	0.005	0.030	0.007	0.509	None/Binary
O2	Ericacae	70	0.038	-0.073	0.380	0.000	0.000	0.015	0.453	0.086	0.559	None/Binary
O2	Euphorbiaceae	70	0.001	0.000	0.005	0.000	0.000	0.000	0.005	0.002	0.473	None/Binary
O2	Fagaceae	70	0.006	0.000	0.185	0.000	0.000	0.005	0.185	0.023	0.249	None/Binary
O2	Graminae	70	0.427	0.000	5.005	0.040	0.200	0.440	5.005	0.845	0.439	None/Binary
O2	Hamamelidaceae	70	0.020	-0.008	0.625	0.000	0.000	0.000	0.633	0.084	0.260	None/Binary
O2	Hypericaceae	70	0.004	0.000	0.060	0.000	0.000	0.005	0.060	0.010	0.484	None/Binary
O2	Juglandaceae	70	0.001	0.000	0.030	0.000	0.000	0.000	0.030	0.004	0.229	None/Binary
O2	Lamiaceae	70	0.000	0.000	0.005	0.000	0.000	0.000	0.005	0.001	0.098	None/Binary
O2	Lauraceae	70	0.002	0.000	0.085	0.000	0.000	0.000	0.085	0.010	0.175	None/Binary
O2	Leguminosae	70	0.025	0.000	0.130	0.000	0.015	0.035	0.130	0.033	0.741	None/Binary
O2	Liliaceae	70	0.009	0.000	0.380	0.000	0.000	0.005	0.380	0.045	0.154	None/Binary
O2	Loganiaceae	70	0.001	0.000	0.005	0.000	0.000	0.000	0.005	0.002	0.505	None/Binary
O2	Myricaceae	70	0.001	0.000	0.030	0.000	0.000	0.000	0.030	0.005	0.213	None/Binary
O2	Passifloraceae	70	0.000	0.000	0.005	0.000	0.000	0.000	0.005	0.001	0.098	None/Binary
O2	Pinaceae	70	0.008	0.000	0.195	0.000	0.000	0.005	0.195	0.028	0.324	None/Binary
O2	Polypodiaceae	70	0.019	0.000	0.375	0.000	0.000	0.000	0.375	0.070	0.301	None/Binary
O2	Rosaceae	70	0.014	0.000	0.085	0.000	0.005	0.015	0.085	0.019	0.682	None/Binary
O2	Rubiaceae	70	0.000	0.000	0.005	0.000	0.000	0.000	0.005	0.001	0.098	None/Binary
O2	Scopulariaceae	70	0.001	0.000	0.010	0.000	0.000	0.000	0.010	0.002	0.425	None/Binary
O2	Solanaceae	70	0.001	0.000	0.005	0.000	0.000	0.000	0.005	0.002	0.490	None/Binary
O2	Violaceae	70	0.000	0.000	0.008	0.000	0.000	0.000	0.008	0.001	0.209	None/Binary
O2	Vitaceae	70	0.000	0.000	0.005	0.000	0.000	0.000	0.005	0.001	0.205	None/Binary

Table 3-2 Part C. Indicator properties as collected by the SEMP research teams

Data Set[1]	Indicator[2]	N	Mean	Minimum	Maximum	Lower Quartile	Median	Upper Quartile	Range	Std.Dev.	Shapiro-Wilk W	Transformation
O3	BD	70	1.431	1.020	1.720	1.320	1.450	1.540	0.700	0.155	0.977	
O3	SOIL-C	70	174.850	19.790	510.840	94.790	176.460	228.690	491.050	100.865	0.960	
O3	SOIL-N	70	6.627	0.940	14.820	4.430	5.990	7.960	13.880	2.932	0.925	
O3	C:N	70	27.517	4.400	68.400	17.900	26.400	36.500	64.000	13.831	0.967	
O3	DepthA	70	2.102	0.000	12.000	0.000	0.000	4.000	12.000	3.144	0.721	
O3	oldtree	70	35.714	0.000	120.000	0.000	7.500	80.000	120.000	43.115	0.768	
O3	Ccover	70	13.789	0.000	44.500	0.000	2.200	27.300	44.500	16.322	0.774	
O3	Ucover	70	48.914	0.000	100.000	23.000	57.000	69.000	100.000	28.120	0.911	
O3	Urich	70	20.564	0.000	39.000	11.000	24.000	29.000	39.000	11.120	0.920	
O3	Thero	70	4.157	0.000	17.000	2.000	3.000	5.000	17.000	3.918	0.827	
O3	Cypto	70	19.936	0.000	44.000	10.000	20.500	30.000	44.000	11.782	0.955	
O3	Hemic	70	8.193	0.000	24.000	2.000	8.500	13.000	24.000	6.935	0.921	
O3	Chamae	70	3.114	0.000	11.000	0.000	3.000	5.000	11.000	2.753	0.896	
O3	Phanero	70	12.243	0.000	56.000	1.000	10.500	20.000	56.000	11.929	0.878	
O4	pmolgram	70	19027.451	152.281	106023.713	2402.172	16925.164	27769.853	105871.433	19136.984	0.790	
O4	Nsats	70	21.153	16.675	28.256	19.978	21.023	21.966	11.581	1.914	0.955	
O4	MBSats	70	17.360	9.874	35.520	13.572	15.842	20.108	25.646	5.118	0.901	
O4	TBSats	70	15.943	10.055	22.342	14.317	15.815	17.697	12.287	2.473	0.994	
O4	Bmonos	70	3.578	2.416	7.392	3.189	3.478	3.867	4.976	0.696	0.818	
O4	Monos	70	36.361	24.578	44.425	34.187	36.488	39.056	19.847	3.984	0.975	
O4	Polys	70	5.605	0.621	13.489	3.116	5.637	7.518	12.868	3.029	0.973	
FL1	TC	298	36.822	0.520	290.140	5.324	10.553	51.700	289.620	56.026	0.656	
FL1	SoilResp	220	2.619	0.000	18.787	0.269	0.666	4.252	18.788	3.950	0.678	
FL1	BetaGlActiv	230	7.598	-0.210	46.433	3.367	4.910	9.814	46.643	7.698	0.740	
FL2	A Horizon	40	2.440	0.000	8.300	0.700	2.200	3.350	8.300	2.162	0.900	

[1]Data set: P=Prescott College Group, S=Savannah River Ecology Laboratory Group, O=Oak Ridge National Laboratory Group, FL=University of Florida Group. Numbers after the group designation are specific data set identifiers. For example Prescott College had five data sets P1-P5.

[2]Indicator denotes the type of ecological indicator. Indicator definition, units of measure and justification are defined in Appendix 1.

Table 3-3 Part A. Indicator selection scores for Land-Management Categories (LMCs) adequately represented by each research team.

[1]Data Set (LMC)	[2]Indicator	Regression			ANN	Tree		[4]Score
		Standard	Backward	Step		CHAID	C&RT	
P1 (UplFtI, RcwFtI, MilTrF)	Soil A Horizon Depth	[3]X	NA	NA	~	X	X	5
P2 (UplFtI, RcwFtI, MilTrF)	Soil Compaction	X	NA	NA	~	X	X	5
P3 (UplFtI, RcwFtI, MilTrF)	Soil Nitrate				X	X	X	3
P3	Soil Ammonium	X		X		X	X	4
P3	Soil Organic Matter	X	X	X	X	X	X	6
P4 (UplFtI, RcwFtI, MilTrF)	Bacteria Ttl Activity	X	X	X	~	~	~	3
P4	Bacteria Functional Diversity	X	X	X	~	~	~	3
P4	Fungi Functional Diversity	X	X	X	~	~	~	3
P5 (UplFtI, RcwFtI, MilTrF)	NL: nitrate			X	~	~	~	1
P5	NL: sulfate	X			~	~	~	1
S1 (UplWhI, UplTrI)	SoilDEPTH	X	X	X		X	X	5
S1	treesacre				X			1
S1	OrgLayerN	X	X	X	X			4
S1	NH3	X	X	X		X	X	5
S1	totalN	X	X	X	X	X	X	6
S2 (UplWhI, UplTrI)	NMINRATE	X	NA	NA	~	X	X	5
O1 (MilTrF, UplTrI, WetFtI)	O-HORgN/m2	X	X					2
O1	0-10g/cm3	X			X			2
O1	00-10[C]%	X	X				X	3
O1	O-HORgC/m2	X	X					2
O1	0-10gC/m2	X	X					2
O1	0-20gPOM-C/m2						X	1
O1	0-20gMOM-C/m2	X	X			X		3
O1	0-10[N]%		X					1
O1	O-HORC:N				X			1
O1	0-10C:N	X			X			2
O1	T0ugNH4N/g			X				1
O1	MOM[C]%	X						1
O1	MOM[N]%	X	X					2
O1	fPOM-C				X	X		2
O1	O-HORg/cm2	X						1
O1	NMINRATE	X	X		X			3

Table 3-3 Part B. Indicator selection scores for Land-Management Categories (LMCs) adequately represented by each research team.

[1]Data Set (LMC)	[2]Indicator	Regression			ANN	Tree		[4]Score
		Standard	Backward	Step		CHAID	C&RT	
O2 (Upl+,MilTrF,MilWhF,WldDrpI,UplFtF)	Cistaceae		~	~	X			1
O2	Compositae		~	~	X		X	2
O2	Ericacae		~	~			X	1
O2	Graminae	X	~	~	X			2
O2	Hypericaceae		~	~		X		1
O2	Leguminosae	X	~	~	X	X	X	4
O2	Loganiaceae		~	~	X			1
O2	Rosaceae	X	~	~	X			2
O3 (Upl+,MilTrF,MilWhF,WldDrpI,UplFtF)	BD		X	X	X			3
O3	SOIL-C			X				1
O3	SOIL-N	X	X	X				3
O3	C:N		X					1
O3	DepthA						X	1
O3	oldtree		X			X	X	3
O3	Ccover	X	X		X		X	4
O3	Ucover	X	X	X	X		X	5
O3	Urich	X	X					2
O3	Thero	X	X	X	X			4
O3	Cypto	X	X	X	X	X		5
O3	Hemic	X	X	X	X	X		5
O3	Chamae	X	X	X	X			4
O3	Phanero	X	X	X				3
O4 (Upl+,MilTrF,MilWhF,WldDrpI,UplFtF)	pmolgram	X	X	~			X	3
O4	Nsats			~	X			1
O4	TBSats			~	X		X	2
O4	Bmonos			~	X			1
O4	Monos	X	X	~	X		X	4
O4	Polys	X	X	~	X	X	X	5
FL1 (MilWhF, MilTrkF, UplFtI, WetTrkF, Wet+, Upl	TC	X	X	X	X	X		5
FL1	SoilResp	X	X	X	X	X	X	6
FL1	BetaGlActiv	X	X	X	X	X	X	6
FL2	A Horizon	X	N/A	N/A	~	~	~	1

[1] Data set: P=Prescott College Group, S=Savannah River Ecology Laboratory Group, O=Oak Ridge National Laboratory Group, FL=University of Florida Group. Numbers after the group designation are specific data set identifiers. Land Management Categories (LMCs): Upl+=Upland areas, MilTrF=Military Track Frequent, MilWhF=Military Wheeled Frequent, WldDrpI=Wilderness Drop Infrequent, UplFI=Upland Foot traffic Infrequent, UplFtF=Upland Foot traffic Frequent, RCWFtI=Red Cockaded Woodpecker Foot Traffic Infrequent, UplTrkI= Upland Track traffic Infrequent, UplWhI=Upland Wheel traffic Infrequent, UplTrI=Upland Track traffic Infrequent, WetFtI=Wet Foot traffic Infrequent, WetTrkF=Wet Track traffic Frequent, Wet+=Wetlands.

[2] Indicator denotes the type of ecological indicator. Indicator definition, units of measure and justification are defined in Appendix 1.

[3] X=selected indicator was significant in a significant model. ~ = selected model was not adequate. N/A=model was not applicable. A blank space means that indicator was not significant for that model.

[4] Score=The total number of significant models in which a given indicator was significant. The maximum score an indicator can receive is six.

Conclusions of SEMP Integration Project:
Principal Investigator: Virginia H. Dale
May 2006

The SEMP Integration project examined indicators for ecological changes at three levels of spatial resolution: the plot level, catchment or watershed, and landscape level. For the plots level study, a framework was developed that integrates data collected at Fort Benning by many researchers across the five teams. This approach first defined and mapped land-management categories and then considered if the plot-level indicators can separate between those categories. The retrospective analysis of the data collected by many research teams required a weight-of-evidence approach for the selection of indicators that best discriminated land-management categories. Although the data for this effort were not collected in a fashion commensurate with traditional statistical techniques, it was still possible to integrate the separate research efforts and score the results. The use of selection scores provided a straightforward comparison of each indicator and this was important in obtaining results

There were several major findings about how land management from this analysis. A collective vision for the land can be derived among resource managers with diverse objectives if care is taken to be sure that terms are communicated clearly and if all stakeholders have the opportunity to participate in discussions. Land-management categories can be developed based on management goal for each area, the use of the land, and the frequency of that use. These land management categories provide a meaningful way to resource managers to formalize their goals for the land given expected uses and to identify indicators that can be used to monitor if each goal is on track. Multivariate analysis supports our hypothesis that ecological indicators should come from a suite of spatial and temporal scales and environmental assets. Finally, maps can be created that depict land management categories that cover both ecological interests and military land uses.

1. Plot-level indicators

Key indicators at the plot levels include:

- Soil physical and chemical variables: soil "A" horizon depth, compaction, organic matter, organic layer N, NH_3, Total N, N mineralization rate, Total Carbon and % Carbon.
- Soil microbiological indicators: biomarkers for fungi, Gram-negative Eubacteria, soil microbial respiration and beta-glucosidase activity.
- Plant family and life form indicators: the Family Leguminosae, possibly Rosaceae, and the plant Life forms Therophyte, Cyptophyte, Hemicryptophyte and Chamaephyte as well as understory cover, overstory cover and tree stand characteristics.

2. Watershed indicators

We found that a number of physical, hydrological, chemical, and biological characteristics of streams were good indicators of watershed-scale disturbance at FBMI. Stream channel organic variables (i.e., BPOM, CWD) were highly related to disturbance and thus were good indicators. Additionally, the degree of hydrologic flashiness (as quantified by 4-hour storm flow recession constants) and bed stability were good indicators of watershed-scale disturbance. Among the stream chemistry variables, the concentrations of total and inorganic suspended sediments during baseflow and storm periods were excellent indicators of disturbance, increasing with increasing disturbance levels. In addition, baseflow concentrations of DOC and SRP were good disturbance indicators, declining with increasing disturbance levels. The magnitude of increases in SRP and possibly NO_3^- concentrations during storms also appeared to be good disturbance indicators. Among the biological variables, stream benthic macroinvertebrates also served as good indicators of watershed-scale disturbance. Traditional measures such as richness measures (e.g., number of EPT taxa and richness of Chironomidae) negatively corresponded with watershed disturbance; however, except for chironomid richness, all measures showed high variation among seasons and annually. A multimetric index previously designed for Georgia streams (GASCI) consistently indicated watershed disturbance and exhibited low seasonal and annual variation. Low diversity of fish precluded use of traditional measures (i.e., richness, diversity), however the proportional abundance of the two dominant populations (P. euryzonus and S. thoreauianus) were strongly but oppositely associated with disturbance, with P. euryzonus and S. thoreauianus being negatively and positively related to disturbance, respectively. Finally historic land use explained more variation in contemporary bed stability and longer-lived, low turnover taxa than contemporary land use suggesting a legacy effect on these stream measures. Prior to identification and use of potential indicators, we recommend that FBMI land managers consider land use history and the potential for legacy effects on contemporary conditions in streams.

3. Landscape indicators

Data collected for disparate purposes can be used to help develop an understanding of land-cover changes over time and are often necessary to further our knowledge of historic conditions on a given landscape. For the entire Fort Benning landscape, the values of landscape metrics for 1827 were very different from the values for recent decades. While the changes between 1827 and 1974 may be somewhat exaggerated due to data constraints, we can conclude that the nineteenth century landscape at Fort Benning was composed largely of uninterrupted pine forest with some deciduous forests found in riparian corridors and some open areas associated with Native American settlements. Land cover and land use in the 1970s were considerably different. Following decades of farming, military training activities had a pronounced effect upon the landscape. Heavy training activities resulted in areas of sparse land cover and bare ground. Interestingly, these areas have largely persisted on the landscape throughout the 1980s and 1990s. This result not only emphasizes the lasting footprint that military activities have on the landscape but also highlights the efforts made by management to confine heavy training exercises to certain sacrifice areas. Another interesting trend occurred in the 1990s. Pine forests have been on the rise as is reflected in both landscape composition and patch dynamics such as largest patch size, number of patches, and total edge. Management efforts at Fort Benning have focused upon managing for longleaf pine. These efforts appear to be decreasing hardwood invasion in favor of pine species in many areas on the installation.

Examining a suite of landscape metrics over time was useful for summarizing, describing, and assessing land-cover change at Fort Benning. The FRAGSTATS and ATtILA programs were relatively simple to use and provided information pertinent to understanding and managing the land. Therefore, we encourage resource managers to use landscape metrics to analyze changes in patterns of land cover over time to examine how human activities have affected an area.

Journal (in review): 3
Journal (to be submitted): 3
Proceedings: 1
Posters: 4
Presentations: 8
Dissertations: 1

Published

Dale, VH, AK Wolfe, and L Baskaran. Developing Ecological Indicators that are Useful to Decision Makers. 2005. Proceedings of the conference on Biodiversity: Science and Governance, Paris, France, January 24-28, 2005.

Paper in Review

Wolfe, A. K. and V. H. Dale. Using a Delphi Approach to Define Land-Management Categories and to Integrate Science and Practice. **J. of Environmental Management**.

Significance: This overview article summarizes the results from our use of a Delphi approach to identify a suite of land-use categories acceptable within and among two diverse groups of experts. These groups are SEMP ecological indicator/ecological threshold researchers and Fort Benning resource managers. The article's significance is two-fold: (a) it describes an approach that proved effective in achieving consensus, thereby helping to integrate the best available science into the practice of resource management; (b) it highlights the evolution of a land-management category matrix that identifies discrete land-management categories.

Submitted: July 2005 and revised January 2006

Wolfe, A. K., V. H. Dale, and T. Arthur. Science versus practice: Using a Delphi approach to reconcile world views. **Human Organization**.

Status Submitted June 2005 and requested revision was sent April 2006.

Significance: This article emphasizes the process we used to achieve consensus among and within groups. It will place our work in the context of other methods, approaches, and frameworks for considering the integration (or application) of science in decision making.

Dale, V.H., Peacock, A., C. Garten, and E. Sobek. Contributions of soil, microbial, and plant indicators to land management of Georgia pine forests. **Ecological Indicators**

Status: Submitted November 2005 and to be revised June 2006

Papers in Preparation:

Dale, V.H., Baskaran, L. and Wolfe, A. Developing and mapping land-management categories: A tool for resource stewardship in west central Georgia

Significance: The procedure for mapping land management categories is developed and applied.

Status: Draft paper is being revised

Peacock, A, Dale, V.H, Arthur, T. and others. Variable selection of indicators of land management.
Significance: Statistical methods used to determine indicators
Status Draft paper is in internal review.

Wolfe, A. K. and V. H. Dale. Tentative title: "Ecological indicators and land management: are they truly compatible?" Target journal: **Ecological Indicators**.

Significance This paper will focus on the substance of our findings, rather than on the Delphi approach. These findings bring into question the assumption that ecological indicators are valuable and useful to land managers. The context in which land managers like those at Fort Benning operate, precludes the use or usefulness of a number of indicators. The article will conclude by suggesting that ecological indicators be developed within the contexts they are intended to be used, and not simply "transferred" to target users.
*Status:*To be submitted June 2006

Dissertation:

Peacock, A. Ecological Indicator Development, Integration and Knowledge Mapping" Ph.D. Dissertation, The University of Tennessee Department of Biosystems Engineering.
Significance: Statistical analysis of the SEMP data
Status: Data compiled, statistical analysis completed, draft chapters in review by dissertation committee members.

Web site developed:

http://www.esd.ornl.gov/programs/SERDP/Integration/sip.html

SERDP Ecosystem Management Project's Integration Plan

Virginia Dale, Amy Wolfe, Latha Baskaran, & Taryn Arthur
Environmental Sciences Division, Oak Ridge National Laboratory

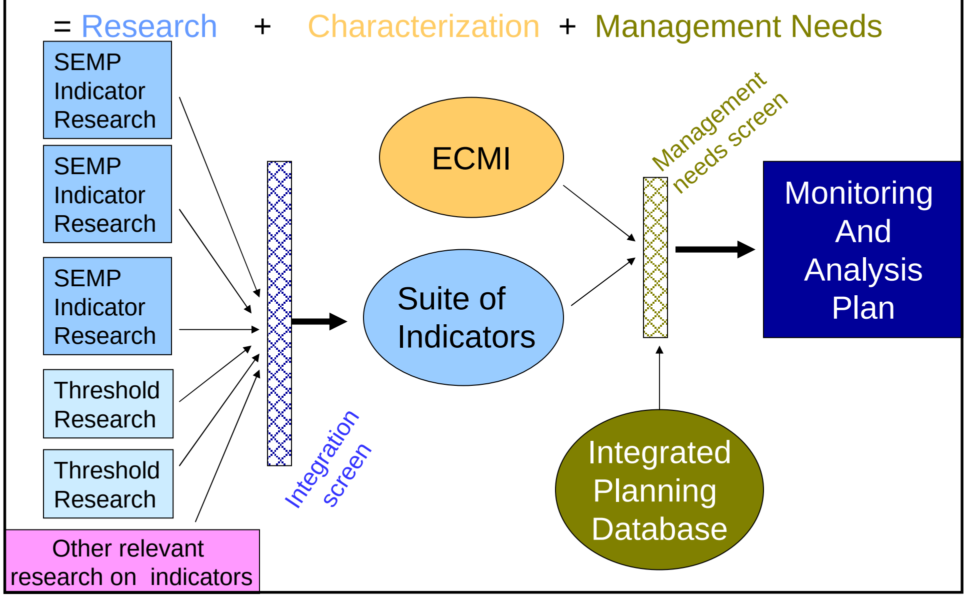
Aaron Peacock
Center for Biomarker Analysis, The University of Tennessee

May 2006

Focus of integration is on:

- Identifying indicators of ecological impacts of prior resource use or management
- Using data obtained by SEMP researchers
- Determining how these indicators can be an integral part of the monitoring and management program of Fort Benning
- Developing a procedure for integration (so the approach could be adopted by other DoD installations)

Approach: SEMP Integration is developing plan for monitoring and analysis

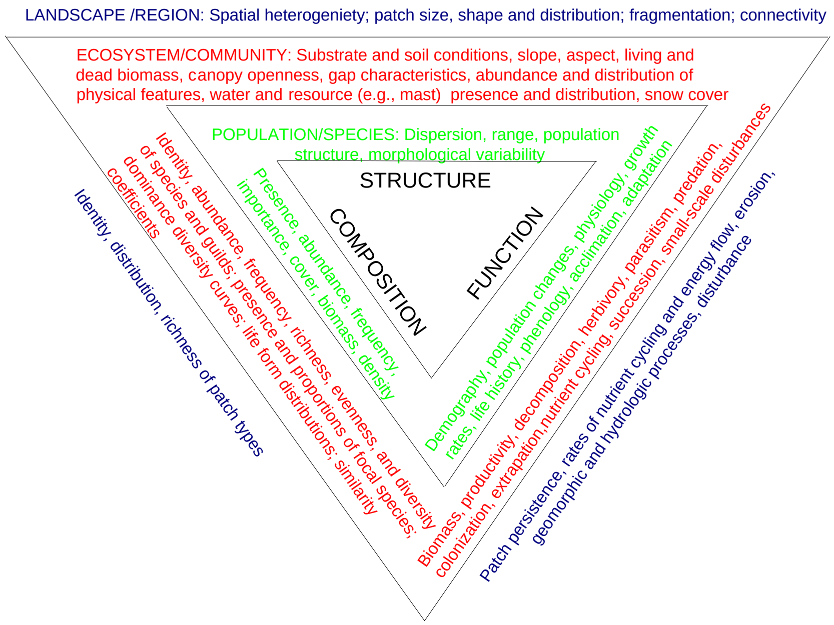


Criteria: Indicators should be technically effective and practically useful

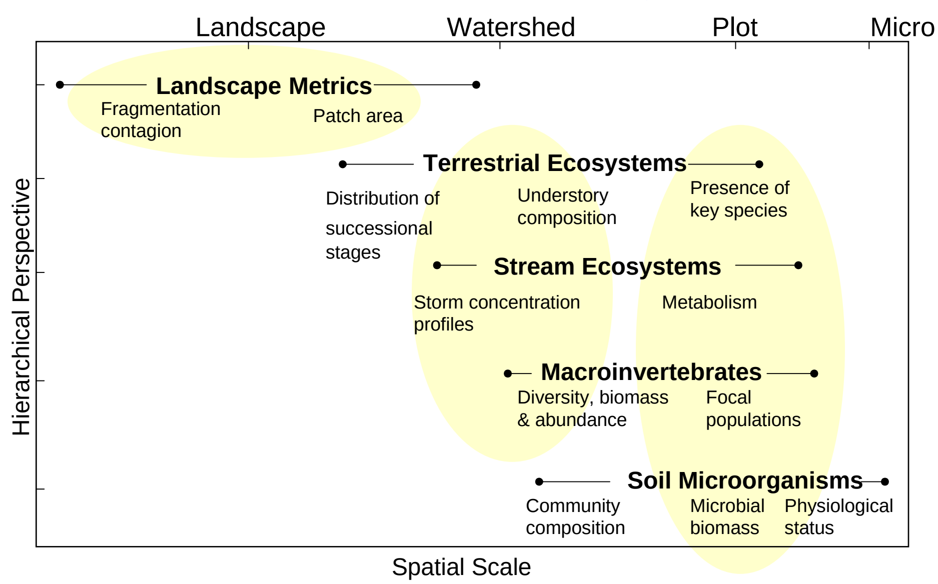
- Are easily measured
- Are sensitive to stresses on system
- Respond to stress in a predictable manner
- Are anticipatory: signify an impending change in the ecological system
- Predict changes that can be averted by management actions
- Have a known response to natural disturbances, anthropogenic stresses, and changes over time
- Have low variability in response
- Are integrative: the full suite of indicators provides a measure of coverage of the key gradients across the ecological systems
  - Are broadly applicable across the system of interest and to other systems
- Consider spatial and temporal context of measure

* Dale, V.H. and Beyeler, S.C. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1: 3-10.

Select among indicators of structure, function and composition



Hypothesis: There is a suite of ecological indicators



Dale, V H., Mulholland, P., Olsen, L. M., Feminella, J., Maloney, K., White, D. C., Peacock, A., Foster, T. 2004. "Selecting a Suite of Ecological Indicators for Resource Management," Pages 3-17 in *Landscape Ecology and Wildlife Habitat Evaluation: Critical Information for Ecological Risk Assessment, Land-Use Management Activities and Biodiversity Enhancement Practices,* ASTM STP 11813, L. A. Kapustka, H. Gilbraith, M. Luxon, and G. R. Biddinger, Eds., ASTM International, West Conshohocken, PA, 2004.

Challenge: selecting indicators that are technically effective and practically useful

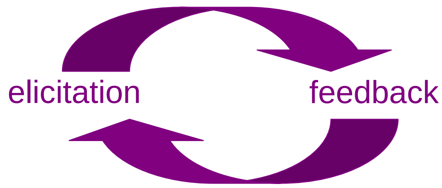
- Indicators
  - Defined, discrete
  - Targeted to Fort Benning
- Approach
  - May be applicable to Fall Line
  - Applicable to other installations
  - Can be used for prospective application, as well as retrospective application and test

Multiple steps lead to selection of plot-level indicators

- Identify discrete set of land-management categories
- Identify plot-level proposed indicators within land-management categories
- Make existing criteria operational; divide according to technical vs. practical utility
- Review comprehensive suite of proposed indicators
- Screen resulting proposed indicators for technical effectiveness (technical criteria)

Identified land-management categories via modified Delphi method

- Iterative process

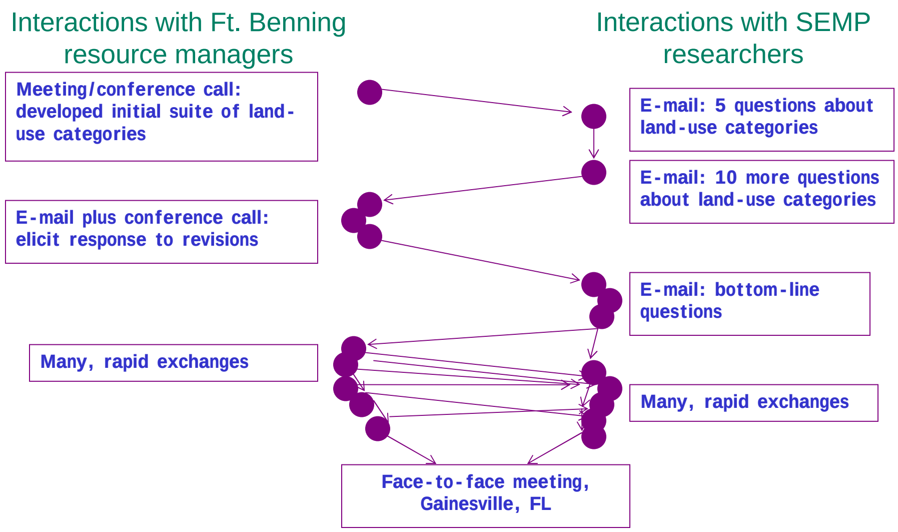


- Input from group of experts
- Achieve consensus

Sought consensus among experts

- **SEMP researchers**: 5 teams with different research objectives and approaches
- **Fort Benning resource managers**: different emphases
- Seeking consensus can be challenging
  - Within a diverse group
    - Researchers
    - Resource managers
  - Between two such groups
    - Perspectives and needs differ

Schematic view of the Delphi method, as implemented



Determined discrete land-management categories (LMCs) via the Delphi method

3-D Matrix of LMCs

	Cause of predominant ecological effect from ***military use*** of land
Land management ***goals***	Relative ***frequency*** of military use

- Discrete categories
  - Avoids multiple uses
- More informative than “land cover” or “land use” alone
  - Considers past and adjacent use
- Researchers can assign each plot to a LMC

Wolfe, A. K. and V. H. Dale. In review. Using a Delphi Approach to Define Land-Management Categories and to Integrate Science and Practice. J. of Environmental Management.

SERDP — Strategic Environmental Research and Development Program — Improving Mission Readiness Through Environmental Research

ornl — Oak Ridge National Laboratory

“Military uses of land” became “cause of predominant ecological effect from military use(s) of land”

- Change made in response to three major concerns raised during Delphi process, namely how to deal with
  - Multiple uses of land
  - Impacts on one parcel from adjacent activities
  - Historical…and future land uses

Land management categories as determined by military training and land management practices—final version

Key ‘0’ = *military uses* do NOT occur in areas managed in specified ways

‘I’ and ‘F’ = the relative frequency with which *military uses* occur in areas managed in specified ways (I = infrequent and F = frequent).

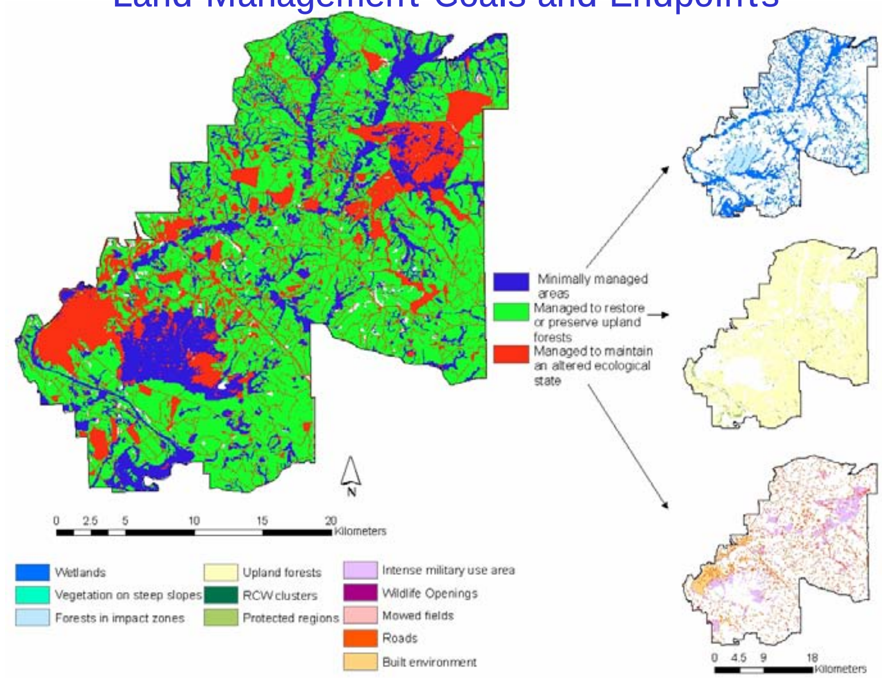
‘+’ = *land management* options in areas not used by the military

Land management goals and endpoints	Cause of predominant ecological effect from military use(s) of land								
	Tracked vehicles	**Wheeled vehicles**	**Foot traffic**	**Designated bivouac areas**	**Firing ranges**	**Impact areas**	**Drop or landing zones**	**No military effect**	**Administrative use**
1. Minimally managed areas									
1.1 Wetlands	I,F	I, F	I	0	0	0	0	+	0
1.2 Vegetation on steep slopes	I, F	I, F	I	0	0	0	0	+	0
1.3 Forests in impact zones	0	0	0	0	0	I,F	0	+	0
2. Managed to restore and preserve upland forest									
2.1 Upland forests 2.1.a Long leaf dominance 2.1.b Mixed pine 2.1.c Scrub oak pine mix	I	I,F	I, F	0	0	0	0	+	0
2.2 RCW mgmt clusters	I	I	I,F	0	0	0	0	+	0
2.3 Sensitive area designated by signs	0	0	I,F	0	0	0	0	+	0
3. Managed to maintain an altered ecological state									
3.1 Intensive military use areas	F	F	0	I,F	F	0	0	0	0
3.2 Wildlife openings	0	I	I	0	0	0	I	+	0
3.3 Mowed fields	0	I	I,F	0	I,F	0	I,F	+	0
3.4 Roads (paved and unpaved)	I, F	I, F	I, F	0	0	0	0	+	0
3.5 Built environment	0	0	0	0	0	0	0	0	+

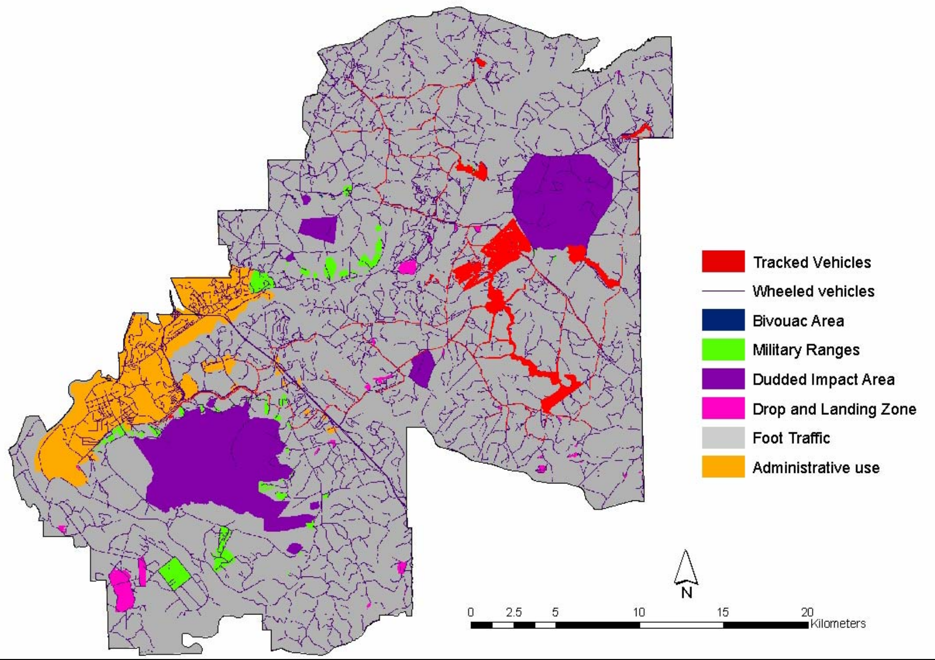
Map of LMCs being developed for Fort Benning

- Map developed
  - Based on existing data layers
  - With input from
    - Fort Benning resource managers
    - Nature Conservancy staff at Fort Benning
- Maps consists of two layers
  - The *land management goals and endpoints* (headers in the far left column of LMC matrix)
  - The *cause of the predominant ecological effects from military use(s) of the land* (the header row at the top of LMC matrix)

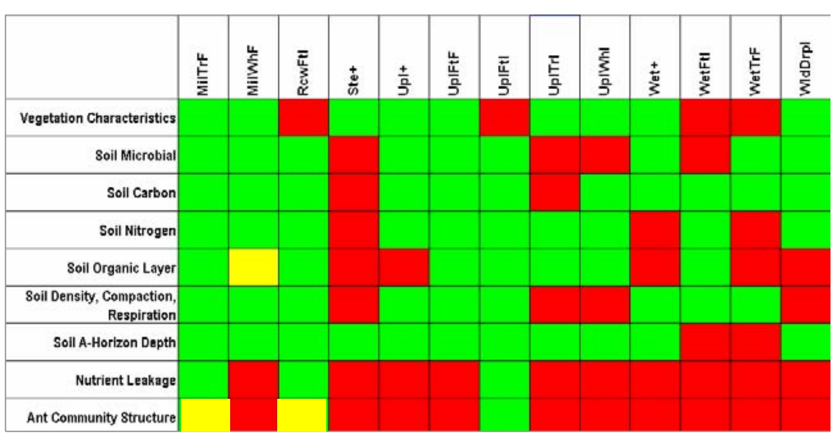
Land Management Goals and Endpoints



Military Use of Land



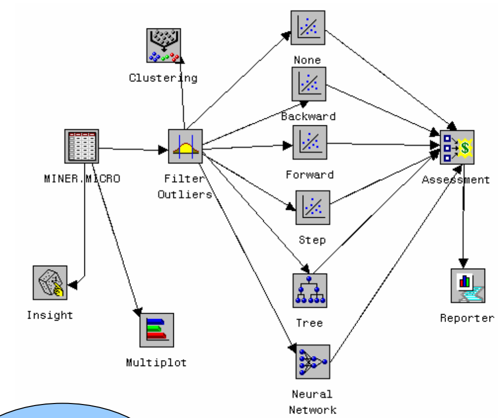
Groups of indicators by LMCs



= no data = insufficient data for analysis = sufficient data for analysis

Assessing ability of indicators to differentiate among LMCs

- Multivariate analysis of proposed indicators
  - GOAL
    Define a set of indicators that provide robust information about the LMCs

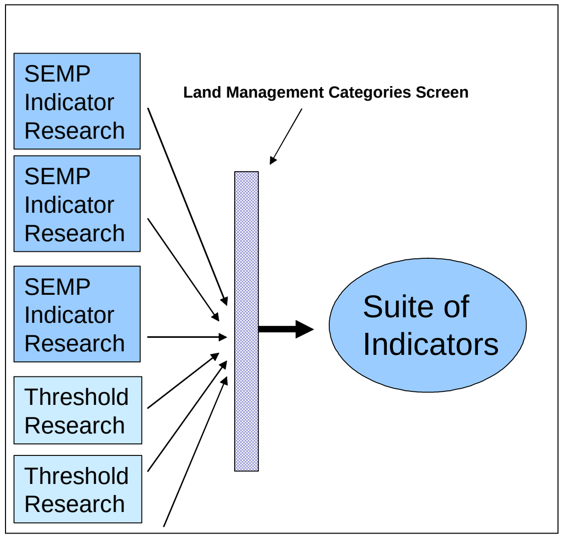


Indicator Data → Indicators that Differentiate LMCs → Quantifiable Targets

Indicator Data (Some Stats)

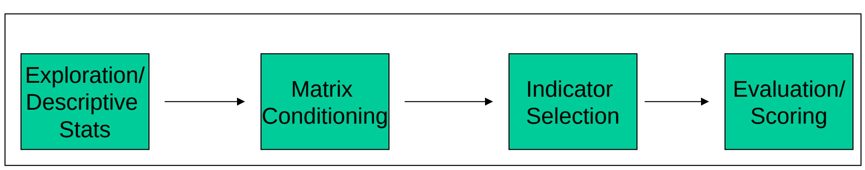
- 5 Research Teams
- 12 Land Management Categories*
- 13 Data Sets
- 112 Candidate Indicators
- 4283 Observations

***Contained Data**



Screening Approach

Land Management Categories Screen



Results (page 1)

			Regression		ANN	Tree		Score
Data Set (LMC)	Indicator	Standard	Backward	Step		CHAID	C&RT	
P1 (UplFtI, RcwFtI, MilTrF)	Soil A Horizon Depth	X	NA	NA	~	X	X	5
P2 (UplFtI, RcwFtI, MilTrF)	Soil Compaction	X	NA	NA	~	X	X	5
P3 (UplFtI, RcwFtI, MilTrF)	Soil Nitrate				X	X	X	3
P3	Soil Ammonium	X		X		X	X	4
P3	Soil Organic Matter	X	X	X	X	X	X	6
P4 (UplFtI, RcwFtI, MilTrF)	Bacteria Ttl Activity	X	X	X	~	~	~	3
P4	Bacteria Functional Diversity	X	X	X	~	~	~	3
P4	Fungi Functional Diversity	X	X	X	~	~	~	3
P5 (UplFtI, RcwFtI, MilTrF)	NL: nitrate			X	~	~	~	1
P5	NL: sulfate	X			~	~	~	1
S1 (UplWhI, UplTrI)	SoilDEPTH	X	X	X		X	X	5
S1	treesacre				X			1
S1	OrgLayerN	X	X	X	X			4
S1	NH3	X	X	X		X	X	5
S1	totalN	X	X	X	X	X	X	6
S2 (UplWhI, UplTrI)	NMINRATE	X	NA	NA	~	X	X	5
O1 (MilTrF, UplTrI, WetFtI)	O-HORgN/m2	X	X					2
O1	0-10g/cm3	X			X			2
O1	00-10[C]%	X	X				X	3
O1	O-HORgC/m2	X	X					2
O1	0-10gC/m2	X	X					2
O1	0-20gPOM-C/m2						X	1
O1	0-20gMOM-C/m2	X	X			X		3
O1	0-10[N]%		X					1
O1	O-HORC:N				X			1
O1	0-10C:N	X			X			2
O1	T0ugNH4N/g			X				1
O1	MOM[C]%	X						1
O1	MOM[N]%	X	X					2
O1	fPOM-C				X	X		2
O1	O-HORg/cm2	X						1
O1	NMINRATE	X	X		X			3

Results (page 2)

			Regression		ANN	Tree		Score
Data Set (LMC)	Indicator	Standard	Backward	Step		CHAID	C&RT	
O2 (Upl+,MilTrF,MilWhF,WldDrpI,UplFtF)	Cistaceae		~	~	X			1
O2	Compositae		~	~	X		X	2
O2	Ericacae		~	~			X	1
O2	Graminae	X	~	~	X			2
O2	Hypericaceae		~	~		X		1
O2	Leguminosae	X	~	~	X	X	X	4
O2	Loganiaceae		~	~	X			1
O2	Rosaceae	X	~	~	X			2
O3 (Upl+,MilTrF,MilWhF,WldDrpI,UplFtF)	BD		X	X	X			3
O3	SOIL-C			X				1
O3	SOIL-N	X	X	X				3
O3	C:N		X					1
O3	DepthA						X	1
O3	oldtree		X			X	X	3
O3	Ccover	X	X		X		X	4
O3	Ucover	X	X	X	X		X	5
O3	Urich	X	X					2
O3	Thero	X	X	X	X			4
O3	Cypto	X	X	X	X	X		5
O3	Hemic	X	X	X	X	X		5
O3	Chamae	X	X	X	X			4
O3	Phanero	X	X	X				3
O4 (Upl+,MilTrF,MilWhF,WldDrpI,UplFtF)	pmolgram	X	X	~			X	3
O4	Nsats			~	X			1
O4	TBSats			~	X		X	2
O4	Bmonos			~	X			1
O4	Monos	X	X	~	X		X	4
O4	Polys	X	X	~	X	X	X	5
FL1 (MilWhF, MilTrkF, UplFtI, WetTrkF, Wet+, Upl	TC	X	X	X	X	X		5
FL1	SoilResp	X	X	X	X	X	X	6
FL1	BetaGlActiv	X	X	X	X	X	X	6
FL2	A Horizon	X	N/A	N/A	~	~	~	1

Compiled Results

- Soil A Horizon Depth
- Soil Compaction
- Soil Nitrogen*
- Soil Carbon*
- Soil N Min. Rate
- Soil Respiration
- Beta Glucosidase Activity
- Soil Microbial Composition*
- Family Leguminosae
- Canopy Cover
- Understory Cover
- Plant Life Form Analysis
- Oldest Tree

***Some Form of Measure**

Overlap of indicator measures that made it through the integration screen

Indicator	Krzysik	SREL	Research Team ORNL (Garten)	ORNL (Dale)	UF
Soil A Horizon Depth	X	X	X	X	X
Soil Compaction/Density	X		X		
Soil Nitrogen measures	X	X	X	X	
Soil Carbon measures	X		X	X	X
Tree age/Density		X		X	
Plant understory cover by family				X	
Overstory cover				X	
Soil Microbial composition/Activity				X	X

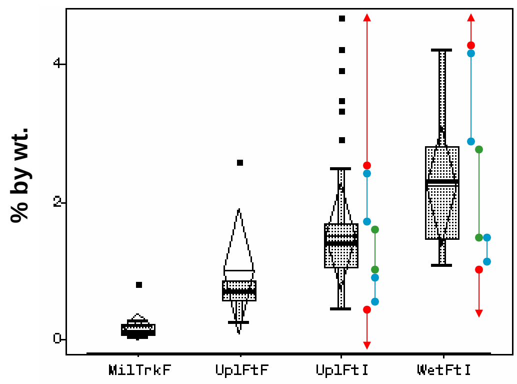
Indicator Parameters

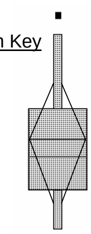
- Research teams measured several unique indicators and several redundant indicators
- Research teams used different plots at different times of year or different years
- Correlation of indicator results among teams enhances confidence in the indicator

Final step

- Define what type of method to use as the measure of the indicator.
- Define quantitative targets for selected indicators within land management categories.

Distribution and conceptual quantitative target level for % soil carbon





Desired value

Marginal value

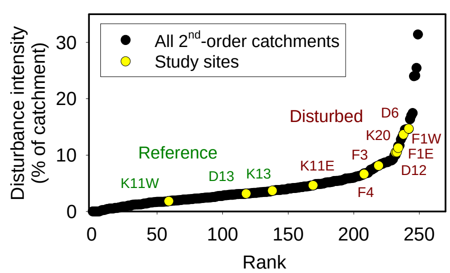
Undesired value

Catchment level indicators

Disturbance intensity defined as the sum of:

% bare ground on slopes > 3%

% road coverage

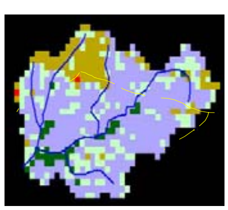


Disturbance classes:

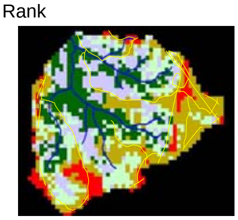
Ref. – K11W, D13, K13 (1.8 – 3.7%)

Low – K11E, F4, F3 (4.6 – 8.1%)

High – D12, F1E, K20, F1W, D6 (10.5 – 14.7%)



Low Intensity



High Intensity

Bare Ground/Urban
Transitional/Sparse Veg
Deciduous
Mixed Forest
Pine Forest
Water

Catchment-Scale Indicators

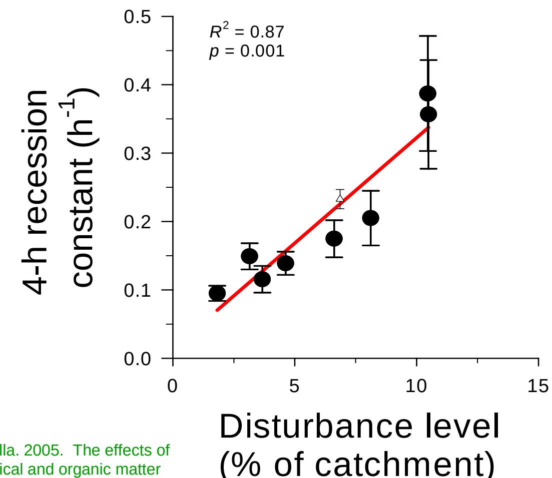
(Summary of applicable stream measurements)

- Hydrological
  - Storm flow recession coefficients
- Chemical
  - Suspended sediment concentrations (baseflow, storm)
  - Baseflow PO_4 and DOC concentrations
  - Storm increases in NO_3 and PO_4 concentrations
  - Diurnal changes in dissolved oxygen concentrations
- Biological Habitat
  - Streambed stability
  - Coarse woody debris
  - Benthic particulate organic matter
  - Sediment particle size
- Biota
  - Macroinvertebrate assemblage
  - Fish assemblage

Catchment-Scale Indicators

Hydrological – Storm flow recession coefficients

- Stream flashiness increased with increasing catchment disturbance
- Indicates the potential for increased transport of material during storm events
- Suggests reduced stability and associated suitable habitat



Maloney, K. O, P.J. Mulholland, and J.W. Feminella. 2005. The effects of catchment-scale military land use on stream physical and organic matter variables in small Southeastern Plains catchments (USA). Environmental Management 35(5): 677-691.

Catchment-Scale Indicators

Hydrological – Storm flow recession coefficients

Management implications

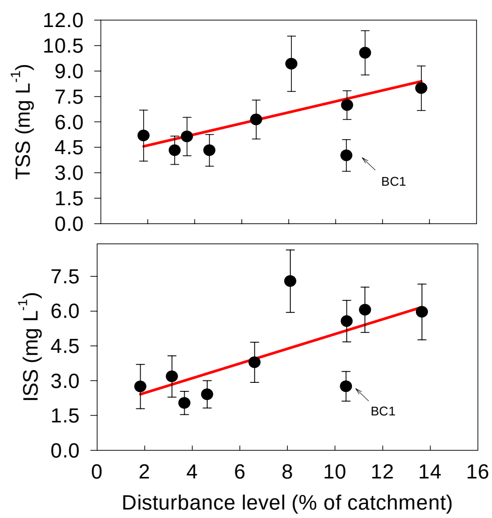
→ Coefficients consistently > 0.2 hr^{-1} (1^{st} and 2^{nd} order streams) are found only in highly disturbed catchments (>10% as bare ground and unpaved roads)

→ High coefficients indicate disruption of catchment hydrology producing "flashy" storm hydrographs which tend to produce more sediment transport and stream channel instability

Catchment-Scale Indicators

Chemical – Stream suspended sediment concentrations (baseflow)

- Both stream water total suspended solids (TSS) and inorganic suspended solids (ISS) increased with increasing disturbance
- Indicates increased erosion and sediment transport with increasing disturbance



Houser, J.N., Mulholland, P.J., and K. Maloney. In press. Stream chemistry indicators of disturbance on military reservations. Journal of Environmental Quality

Catchment-Scale Indicators

Chemical – Stream suspended sediment concentrations (baseflow)

Management implications

→ Stream TSS > 6 mg/L and ISS concentrations > 4 mg/L were only consistently observed in highly disturbed catchments

→ Disturbance levels > 8% of catchment as bare ground and unpaved roads appeared to be a disturbance threshold, above which stream TSS and ISS concentrations at baseflow are considerably higher.

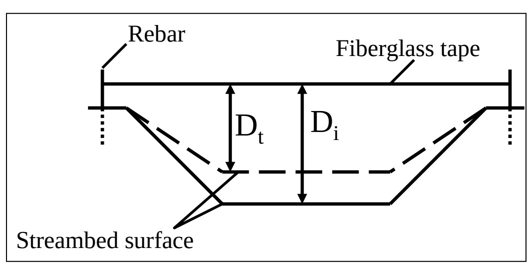
→ Increased erosion and sediment transport from disturbance is evident even during baseflow, indicating disturbance produces highly unstable stream channels which will have significant negative effects on biota and biotic habitat.

Streambed Stability

Stability transects, leveled at deployment dates, measures taken every ~ 2 months. Stability calculated as

$$\frac{\sum_{1}^{n}\sum_{1}^{z}|D_{zi} - D_{zt}|}{n}$$

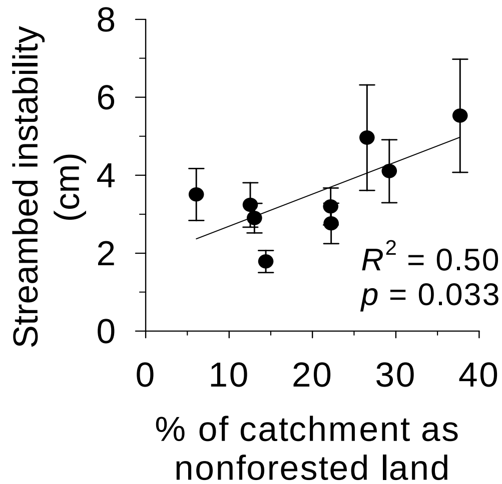
where z is the distance along the transect, n is the number of transects in a stream and D is depth at time i and t.



Catchment-Scale Indicators

Biotic habitat – streambed stability

- Bed instability increased with increasing disturbance intensity (as % of non-forested land).
- Suggests higher rates of erosion and subsequent sedimentation of stream within higher disturbed catchments
- Indicates reduced available habitat in more highly disturbed catchment



Catchment-Scale Indicators

Biotic habitat – streambed stability

Management implications

⟶ A increase in bed instability indicates more movement of sediment as well as a reduction in available habitat for aquatic biota

⟶ Unrelated to bare ground and unpaved roads however significant positive relationship with non-forested land on slopes > 3%. The proportion of non-forested land includes fields and early successional vegetation, which may include historically disturbed areas. The inverse relationship between stability and non-forested land may indicate a land use legacy.

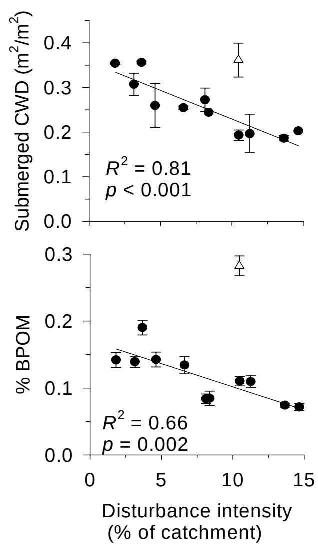
SERDP

Coarse woody debris, benthic particulate organic matter, and bed particle size

Catchment-Scale Indicators

Biotic habitat – coarse woody debris (CWD) and benthic particulate organic matter (BPOM)

- Both CWD and BPOM decreased with catchment disturbance
- Suggests that with increasing disturbance a reduction in available habitat and base food resources occurs



Maloney, K. O, P.J. Mulholland, and J.W. Feminella. In press. The effects of catchment-scale military land use on stream physical and organic matter variables in small Southeastern Plains catchments (USA). Environmental Management 35(5) 677-691.

Catchment-Scale Indicators

Biotic habitat – coarse woody debris and benthic particulate organic matter

Management implications

⟶ A reduction in coarse woody debris and benthic organic matter signals a reduction in available habitat and basal food resources in these streams.

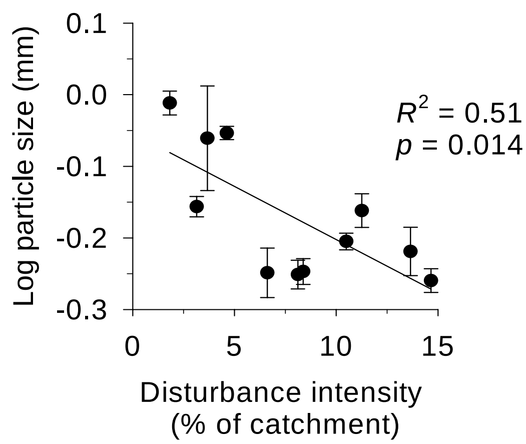
⟶ Reduction in organic inputs as well as greater burial and transport downstream are likely explanations accounting for the lower CWD and BPOM levels in more disturbed catchments.

⟶ Disturbance levels > 8-10% of catchment as bare ground and unpaved roads appeared to be a disturbance threshold for CWD and BPOM (consistent with that observed for several chemical patterns).

Catchment-Scale Indicators

Biotic habitat – sediment particle size

- Average bed particle size decreased with increasing catchment disturbance
- Suggests streams in higher disturbed catchment may have less available habitat for biota likely a result of increased sedimentation from the higher erosion rates associated with high disturbance



Catchment-Scale Indicators

Biotic habitat – sediment particle size

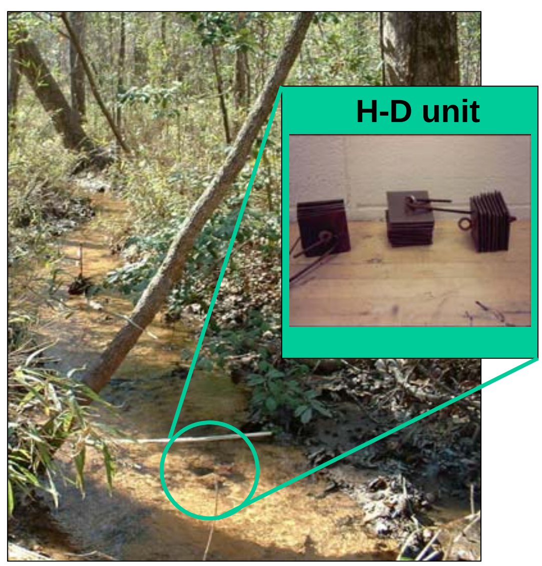
Management implications

⟶ A reduction in bed stability indicates more movement of sediment as well as a reduction in available habitat for aquatic biota.

⟶ Reduction in average particle size likely a function of the greater proportion of smaller, on-average, particles from eroded areas associated with catchment disturbance.

⟶ Disturbance levels > 6.5% of catchment as bare ground and unpaved roads appeared to be a disturbance threshold for bed particle size (consistent with that observed for several chemical patterns).

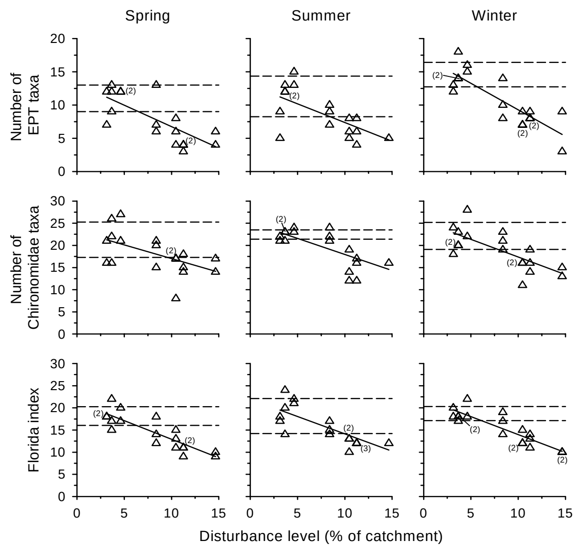
Macroinvertebrate assemblage



Catchment-Scale Indicators

Biota - Macroinvertebrates

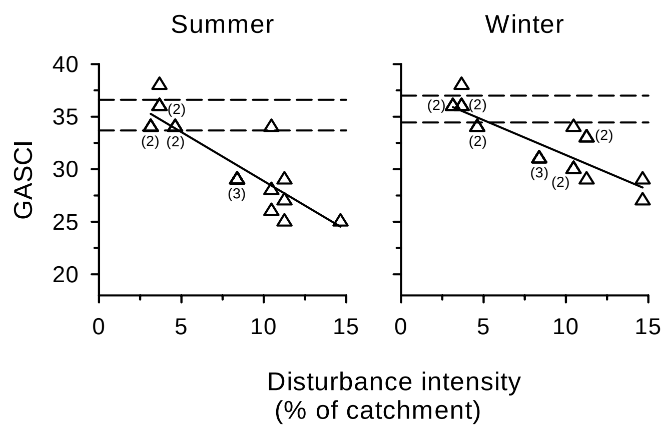
- Negative relationships between sensitive taxa (EPT), Number of Chironomidae taxa, and a regional defined tolerance index (Florida Index) with catchment disturbance level
- Suggests that with increasing disturbance benthic integrity decreases



Catchment-Scale Indicators

Biota – Macroinvertebrates (GASCI)

- Negative relationship between the GASCI with catchment disturbance level
- Suggests with increasing disturbance a reduction in biotic integrity occurs



Maloney, K.O., and J.W. Feminella In press. Evaluation of single- and multi-metric benthic macroinvertebrate indicators of catchment disturbance at the Fort Benning Military Installation, Georgia, USA. Ecological Indicators.

Catchment-Scale Indicators

Biota - Macroinvertebrates

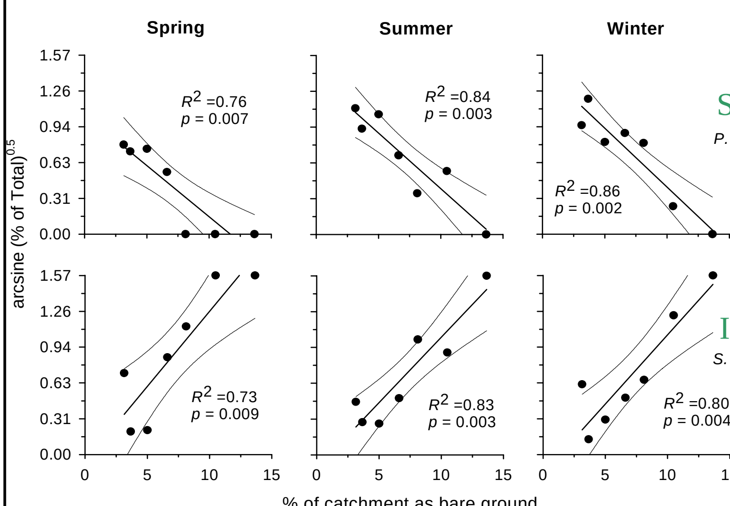
Management implications

→ A reduction in sensitive taxa and lower tolerance index and multimetric scores with increasing catchment disturbance indicates a reduction in stream integrity with military training intensity. However even most disturbed sites were classified as "Good" using the multimetric index.

→ The reduction in sensitive taxa and lower tolerance index and multimetric scores with increasing catchment disturbance are likely a result of the altered water chemistry, increased flashiness, and reduced available habitat in the more disturbed catchments.

→ Disturbance levels > 8% of catchment as bare ground and unpaved roads appeared to be a disturbance threshold for reduced benthic macroinvertebrate integrity (consistent with that observed for several chemical patterns).

Fish as indicators

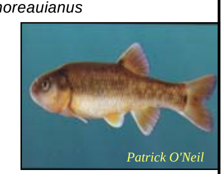


Sensitive fish

P. euryzonus

Insensitive fish

S. thoreauianus



Maloney, K.O., Richard M. Mitchell and J.W. Feminella. In press. Influence of catchment disturbance from military training on fish assemblages in small southeastern headwater streams. Southeastern Naturalist.

Catchment-Scale Indicators

Biota - Fish

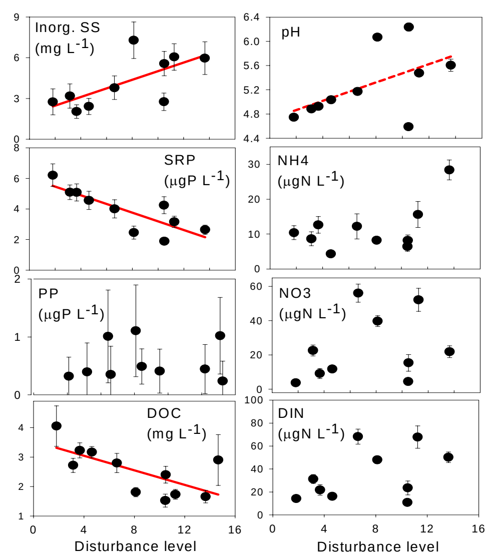
Management implications

⟶ A reduction in sensitive taxa and increase in tolerant taxa with increasing catchment disturbance indicates a reduction in stream integrity with military training intensity. In fact, in the most disturbed catchment the sensitive taxa was not collected.

⟶ The opposite relationships with catchment disturbance are likely a result of different life history traits. *P. euryzonus* prefers deep flowing water with abundant CWD, are selective drift feeders, and require vegetation for spawning, whereas *S. thoreauianus* are omnivorous and deposit eggs into sediment. The culmination of increased SS, reduced CWD and bed stability associuated with catchment disturbance likely affected *P. euryzonus* to a greater degree than *S. thoreauianus*.

⟶ Disturbance levels > 8% of catchment as bare ground and unpaved roads appeared to be a disturbance threshold for stream integrity using fish (consistent with that observed for several chemical patterns and macroinvertebrates).

Stream Chemistry (baseflow)

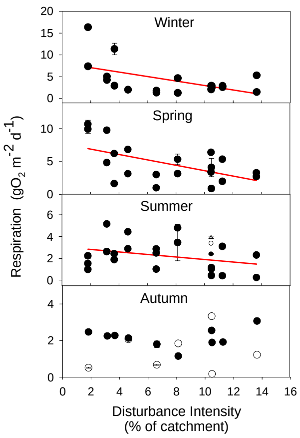


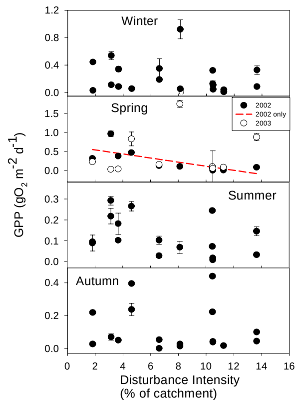
With increasing disturbance level:

- **Inorganic suspended sediment concentrations increase**
- **pH increases**
- **Soluble reactive P and DOC decline**
- **Some evidence that NH_4 and NO_3 concentrations increase**

Maloney, K.O., P.J. Mulholland, J.W. Feminella. 2005. Influence of catchment-scale military land use on physicochemical conditions in small Southeastern Plains streams (USA). Environmental Management. 35:677-691.

Ecosystem process: Stream Metabolism



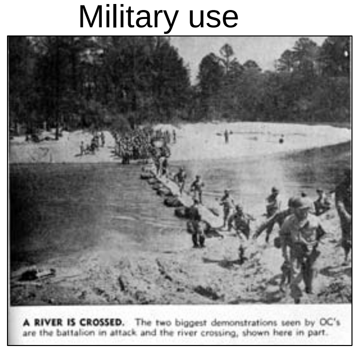


- Respiration rates decline with increasing disturbance level
- GPP rates are very low and show little effect of disturbance

Mulholland, P. J., J. N. Houser, and K. O. Maloney. 2005. Stream diurnal dissolved oxygen profiles as indicators of in-stream metabolism and disturbance effects: Fort Benning as a case study. Ecological Indicators 5:243-252.

Historic land use (pre-1942)

Military use

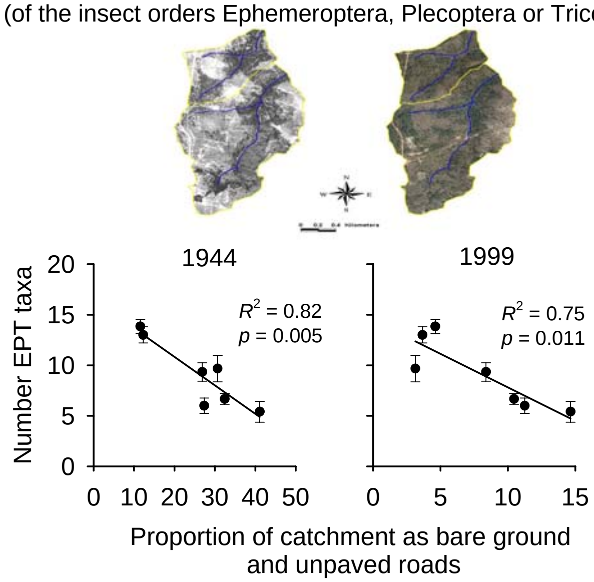


Contemporary land use

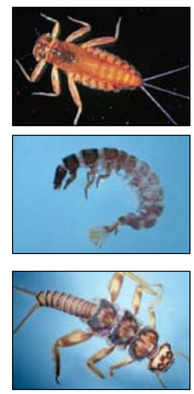
Example use of indicator to show change over time:

Number of taxa of EPT

(of the insect orders Ephemeroptera, Plecoptera or Tricoptera)



Indices based on macroinvertebrates



Summary of Watershed Indicators

- Disturbance intensity
  - % bare area on slopes > 3%
  - % road coverage
- Dissolved Organic Carbon and pH
  - weak indicators
  - best explained by contemporary land use
- Stream physical habitat
  - **CWD, BPOM, Flashiness**: good indicators and best explained by contemporary land use
  - **Stability**: weak indicator, explained by historic land use*
- Macroinvertebrates
  - **EPT**: good indicator, explained by historic land use
  - **Chironomidae richness** and **GASCI**: strong indicators and no legacy effect
- Fish
  - **Assemblage metrics**: poor indicators, related to historic land use.
  - **Population metrics**: good indicators, both sensitive and tolerant populations related to contemporary land use

What metrics best describe changes in patterns for the entire Fort Benning area?

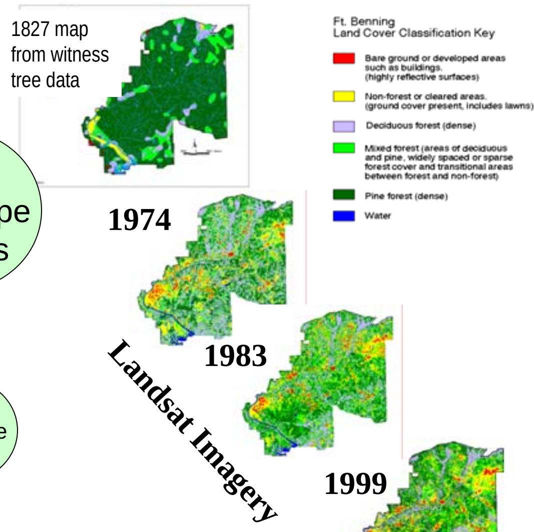
- Percent cover of cover types
- Total edge (with border)
- Number of patches
- Mean patch area
- Patch area range
- CV of patch area
- Perimeter area ratio
- Euclidean nearest neighbor distance
- Clumpiness

>70 landscape metrics

↓

9 landscape metrics

[Choice of metric depends on question]

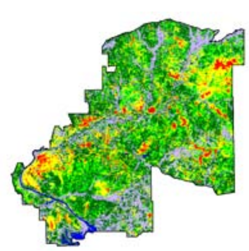


Olsen, L.M., Dale, V.H., and H.T. Foster. In press. Landscape patterns as indicators of ecological change at Fort Benning, GA. Land Use and Urban Planning

Return to criteria to select final indicators

Recognizing that base cost of obtaining indicators differs by scale

- Plot
  - Getting to plots
  - Creation of map of land management categories
- Watershed
  - Getting to watershed
  - Aerial photos or maps to define context of watershed
- Landscape
  - Aerial/satellite imagery



How might Fort Benning resource managers use indicators?

Their responses:

- Planning budgets
- Provide a "heads up" regarding compliance
  - Heading toward non-compliance?
- Signal whether on right path toward achieving longer term goals
- Signal whether on right path to achieve shorter term objectives
- Suggest need for targeted research
  - The "holy cow" scenario

Wolfe, A. K. and V. H. Dale. In review. Science versus practice: Using a Delphi approach to reconcile world views. **Human Organization**.

Measures of practical utility, suggested by Fort Benning resource managers

- Provide feedback — are current ecological conditions consistent with achieving goals
  - Longer term
  - Shorter term
- Indicator values are meaningful—quantifiable and able to signal "red flags"

Measures of practical utility, suggested by Fort Benning resource managers (continued)

- Help anticipate potential noncompliance
  - Existing obligations (Endangered Species Act)
  - Potential obligations (gopher tortoise)
  - Early warning signal
- Maximize the ratio of sampling effort exerted to information yielded (biggest bang for buck)
  - Proportionate to need
  - Cost-effective*
  - Comprehensive*
    - Provide information about a large area, more than one resource, etc.

Resource managers noted that some criteria are conditional

- "Cheaper is better, but more expensive might be ok"

  If associated with
  - Critical training needs
  - Endangered Species Act
  - Isolated populations ("lucrative targets")
- Broad applicability is better, but narrow applicability might be ok

Resource managers' perspectives are essential

- In developing appropriate weights for indicator selection via statistical model
- In developing a suite of indicators that are meaningful and useful in resource management

Future directions

- Applying process to other installations
- Possibilities
  - A scientists' guide to developing ecological indicators that meet resource managers' needs
  - A guide to developing technically robust, practically useful ecological indicators for resource management

Next steps for analysis

- Knowledge maps
  - How do selected indicators interact?
  - What do indicators reveal about ecological interactions?
- Verification
  - Fort Benning?
  - Fort Bragg?
  - Camp Lejeune (DCERP proposal)

Conclusions

- **The Delphi approach can delineate land-use categories in a complex landscape**
- **Integration of ecological research for natural resource management should involve both researchers and resource managers.**
- **Land-use categories provide a common theme by which projects designed for different purposes can relate.**
- **Defining land-use categories by both *land management goals* and *causes of predominant ecological impact***
  - Allows the categories to be used for forward-thinking environmental management
  - Takes into account past activities on the land.
- **Indicators arise from a suite of environmental metrics**
  - Plot
    - Soil conditions
    - Tree density, age, and cover and understory cover and family
    - Soil microbial activity / composition
  - Watershed
    - Disturbance intensity
    - Dissolved organic carbon and pH
    - Stream physical habitat
    - Marcoinvertebrates and fish
  - Region: landscape metrics of pattern