ERDC/CERL TR-07-12

US Army Corps
of Engineers®
Engineer Research and
Development Center

Strategic Environmental Research and Development Program

Development of a Site Comparison Index:

Southeast Upland Forests

Anthony J. Krzysik and Harold E. Balbach

May 2007

Construction Engineering
Research Laboratory

Strategic Environmental Research and
Development Program

ERDC/CERL TR-07-12
May 2007

Development of a Site Comparison Index:

Southeast Upland Forests

Anthony J. Krzysik

Prescott College
220 Grove Avenue
Prescott, AZ 86301

Harold E. Balbach

Construction Engineering Research Laboratory
U.S. Army Engineer Research and Development Center
2902 Newmark Drive
Champaign, IL 61822-1076

Final report

Prepared for Strategic Environmental Research and Development Program
901 North Stuart Street, Arlington, VA 22203

Under Work Unit SI-1114

Abstract: The SERDP Ecosystem Management Project (SEMP), a Defense research program hosted by Fort Benning, Georgia, is a set of related projects examining ecosystem management. Soils, vegetation, and military use aspects are part of a systematic study to assist military installation land managers to weigh demands for sustainable mission use and proactive stewardship. Adaptive management tools will be developed based on relating SEMP research findings to land management concerns and responsibilities. Different research teams, from many universities and U.S. Government laboratories, planned and chose their studies and sites with reference only to this goal. Each team ranked their sites on subjective Low, Medium, High disturbance scales. Later, when teams presented their results, it became clear that there was no consistent way to relate, for example, the different definitions of "medium" across the teams. To create a objective site comparison index (SCI), a combination of metrics: soil A-horizon depth, soil compaction, ground cover, canopy cover, basal area, remote sensed Normalized Difference Vegetation Index, and soil carbon and nitrogen, were evaluated in 2003 and 2004 across a broad disturbance gradient and forest community types at Fort Benning. The results support the application and utility of a SCI, at least in comparable environments.

Contents

NOTE: Citing specific suppliers or products does not constitute endorsement by SERDP, ERDC, or the U.S. Army Corps of Engineers.

Figures and Tables

Figures

Tables

Preface

This study was conducted for the Strategic Environmental Research and Development Program (SERDP) Office under SERDP Work Unit CS (later SI)-1114, “SERDP Ecosystem Management Project (SEMP).” The technical monitor at the time of the activities included in this report was Dr. Robert W. Holst, Program Manager, who has been succeeded in that position by Dr. John Hall. The Executive Director of SERDP is Mr. Bradley P. Smith.

The work was completed under the direction of the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL), Engineer Research and Development Center (ERDC). The SEMP Project Director through August 2005 was Mr. Bill Goran (now the ERDC-CERL Strategic Program Planner) who was succeeded by Mr. Lee Mulkey, of the University of Georgia. The CERL Principal Investigator was Dr. Harold E. Balbach. Alan B. Anderson was Chief, CEERD-CN-N, and John Bandy was Chief, CEERD-CN. The Director of CERL was Dr. Ilker Adiguzel. The associated Technical Director was Dr. William D. Severinghaus, CEERD-CV-T. Special thanks go to Elizabeth Keane, ERDC-CERL, who assisted significantly in the organization and preparation of this report.

Dr. Anthony Krzysik performed this study under cooperative agreement DACA42-02-2-0054, with Prescott College, Prescott, AZ. His research team included the following principals: Dr. John Graham, Berry College; Dr. D. Carl Freeman, Wayne State University; Dr. John Zak, Texas Tech University; Dr. David Kovacic, University of Illinois; and Dr. John Emlen and Mr. Jeff Duda, United States Geological Survey. Dr. Lawson Smith, ERDC Geotechnical and Structures Laboratory, deceased, was a member of the team from 2000 to 2003. These co-investigators, and the numerous students, field assistants, and laboratory assistants associated with their institutions were indispensable in the completion of the project.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Introduction

Background

There is growing and widespread interest in developing terrestrial metrics or indices that assess landscape condition or are capable of monitoring long-term ecological changes (Belnap 1998, Andreasen et al. 2001, Bryce et al. 2002, Lausch and Herzog 2002, Niemi and McDonald 2004). Terrestrial applications have proven difficult and lag far behind the two decades old stream-based IBI (Index of Biological Integrity) developed by Karr and his colleagues (Karr and Chu 1999). Interest was shown by research personnel at U.S. Army installations, the Strategic Environmental Research and Development Program (SERDP), the SERDP Ecosystem Management Project (SEMP), and the SEMP Technical Advisory Committee (TAC), to develop a standardized approach and methodology to analytically quantify “habitat disturbance,” for the purpose of objectively assessing and comparing “landscape condition” across a wide variety of landscapes, while minimizing subjective judgments and bias among field investigators.

The SEMP was organized between 1997 and 1999 to study important ecosystem components that were believed to be important indicators of system function, or to be thresholds indicating major turning points in system condition. Through the SERDP announcement process, five proposals were selected, three to seek to identify indicators, and two to look for thresholds. After selection, in each case, the project principals visited Fort Benning, GA, and selected study sites. Again, in each case, they were taken to the field by installation natural resources personnel to select possible study sites that would be used for the several years each study was to take for completion. This selection process was guided by the installation personnel, and each group selected sites which they characterized as having low, moderate, or high impact from training activities. Since sites were also selected so as not to physically interfere with or overlap those of other groups, an artifact of this process was that the investigators were not aware of the settings for the other projects.

The need to attempt to achieve a more uniform frame of reference became clear after the SEMP research teams involved in this study had been working for 1.5 to 2 years, about when they were reporting on the results of their first full year of research. It was agreed that the initial characterization of their study sites into areas of "low," "moderate," and "high" disturbance was too imprecise to allow cross-project comparisons of impact. Differentiating low impact and high impact sites was simple in comparison to determining the difference in intermediate sites. The "spacing" of different impact classes was very unclear, resulting in confusion and subjective opinions in data sets. An example from a manuscript describes the definitions of the different impacts:

- High impact sites were characterized by current landscape-scale training activities with mechanized infantry and supporting tactical elements.
- Medium sites had experienced past military activities, but current use was light, consisting mostly of foot traffic confined to existing roads and trails.
- Light sites had no evidence of military activities, but like the others were subjected to agricultural land-use prior to the 1940s. Some researchers termed this their "reference" site, i.e., the one to which other levels of disturbance were contrasted.

These definitions, although workable, were very ambiguous and did not solve the question of how to differentiate between different intermediate sites (Figure 1).

Figure 1. Difficulty in classifying sites.
These apparently similar sites were initially classified by different teams of researchers as falling in a wide range of different impact classes from "low" to "high."
This demonstrated the need to create a uniform site index.

Objective

The development of a Site Comparison Index (SCI) was based on the perceived need to interrelate the data obtained to develop Ecological Indicators to assist land managers in assessing and monitoring ecological processes and forest condition. This research was based on the SERDP project "Development of Ecological Indicator Guilds for Land Management", CS-1114B. The technical objectives and approach of this research were to develop Ecological Indicators based on disturbance gradients, ecosystem structure and processes, and unusual attention to analytical and statistical rigor.

Scope

The Ecological Indicators research was conducted at Fort Benning, in west-central Georgia. Fort Benning lies in the Fall-Line Sandhills, an ecologically complex transition zone between Piedmont and Coastal Plain physiographic provinces, and includes the introgression of Loamy Hills from the west. The installation was exposed to agricultural land use prior to its establishment, and also has a long history of timber extraction. The eastern portions were acquired in the 1940s, while the older, western, area was acquired in 1918. Landscape disturbance at Fort Benning reflects current mechanized infantry training activities and timber management, including active prescribed burning; and the historical template of agriculture and extensive timber cutting.

Approach

An Advisory Committee consisting of the different SEMP project Principal Investigators initially proposed candidate elements for the measurement of the quality of the site that would work across the full range of local landscapes, have clear biological relevance, and utilized actual values rather than the following subjective classes:

1. Vegetation structure (i.e., vertical layer, as well as horizontal distribution) and composition of communities by ecological group (as defined in Fort Benning's Integrated Natural Resources Management Plan [INRMP]).
2. Soil compaction (may correlate with changes in soil horizon profile).
3. Microfloral populations (applies to both terrestrial and aquatic systems).
4. Plant productivity (applies to both terrestrial and aquatic systems).
5. Soil and sediment carbon.

6. Plant (Raunkier) life form for communities.
7. Historical land use and current road/trail networks (both qualitative and quantitative).
8. Remotely-sensed surface cover by ecological group.

SEMP researchers reviewed proposed parameters and during Team Leader-Project Manager conference calls and spreadsheets with potential parameters, with added candidates—now 13 in all, were distributed. Researchers currently on SERDP projects at Fort Benning submitted and subsequently ranked habitat parameters they felt were ecologically important to assess landscape condition and disturbance. The Team Leaders ranked parameters on a scale of 1 to 5. The seven items which were ranked above 3.75 appeared to have some consensus as being of the highest value:

Element	**Score**
A-horizon Soil Depth	4.8
Soil/sediment Carbon	4.6
Soil Compaction (bulk density)	4.4
Vegetation Structure	4
Species Composition	4
Historical Land Use	3.8
Soil/Sediment Nitrogen	3.75
Plant Productivity	3.6
Surface cover (via RS)	3.2
Microflora	2.4
Nutrient Leakage	2.4
Ant Community Structure	2.333333
Raunkier Life Form	2.2

The final eight parameters were decided by a consensus, and all eight were already identified by the CS-1114B team to be statistically significant ecological indicators of landscape disturbance. An important advantage is that they are relatively easy to implement, but they do not characterize the full range of ecosystem responses to disturbance. The final set of elements suggested to develop an SCI consisted of:

1. Soil A-horizon Depth
2. Soil/Sediment Carbon
3. Soil Compaction
4. Vegetation Structure
5. Species Composition
6. Soil/Sediment Nitrogen

7. Surface Cover (via remote sensing), and
8. Canopy Cover.

This report investigates seven of these final elements for use in a composite SCI, emphasizing simplicity of data acquisition. A decision was made that species composition would not be included, because species identification requires a region-specific botanist, and even then an expert may not be able to accurately identify a plant that is not in its flowering stage. An important consideration for the design of a SCI is that it is easily derived without extremely specialized training, expertise, knowledge, or technical experience, including taxonomy; and that it can be derived throughout the growing season. Use of instrumentation was similarly restricted to relatively simple equipment which did not require elaborate setup for field use. This resulted in alternative measurements being used for some elements. Certain standard laboratory procedures which required only simple field sample collection were retained.

In practice, some potentially important elements resisted quantification. For example, past land use was unavailable on the scale needed and military use of the sites was known only as general patterns, not site-specific on the scale needed. As another example, present cover was so variable that no patterns were evident and vegetation structure and species composition were not immediately quantifiable in simple terms. And in still another example, measurement of compaction through use of the penetrometer was substituted for quantification of bulk density, which would require elaborate sample collection and laboratory analyses.

Forty sites were specifically selected to represent the widest range of landscape disturbance and upland forest community types found across Fort Benning. Each site was initially subjectively classified based on visual disturbance to vegetation and soils, primarily caused by military training activities. Relatively pristine sites were classified as Disturbance Class 1 (DC1); the most degraded sites were classified as DC10, before any field data were collected. The classification was based on the investigator's 20+ years of field experience with military training habitat disturbance. The research was done in two phases: Phase I evaluated uniform environments differing only in land-use conditions and Phase II evaluated many more sites and conditions in an effort to test the results found in Phase I.

Multivariate and univariate statistical methods were used to extract four levels of quantitative Ecological Indicator metrics: stand-alone variables, classes or groups of variables (e.g., Guilds), weighed combinations of variables, and multivariate vectors or variates. Statistical rigor was particularly stressed in three areas: (1) unbiased systematic-random sampling designs, (2) the minimization of Type I error, and (3) analyses with high statistical power. Analyses with high statistical power minimize Type II error, but require large sample sizes.

Mode of Technology Transfer

The information included in this report is one portion of the materials prepared by the Engineer Research and Development Center (ERDC) to assist installation natural resources program managers. The primary means of communicating the site index information will be through publication in the scientific literature, as well as through the availability of this report. The specific data presented are intended to be used in the preparation of monitoring and management plans related to planned Army actions where land managers need to make informed decisions on the comparability of different, apparently similar, sites. The data will be used for preparation of management plans, INRMPs, and in the preparation of ecological risk assessments involving training and other land-disturbing activities.

This report will be made accessible through the World Wide Web (WWW) at URL http://www.cecer.army.mil.

2 Methods

Phase I Studies

The research was conducted in two phases. Phase I research consisted of the evaluation of a very large number of potential Ecological Indicator systems in a reasonably uniform upland forest environment, differing only in current land use. This research took place on Fort Benning, GA, in 2000, 2001, and 2002 (2001-2002 for habitat characterization) in two adjacent watersheds: Bonham Creek and Sally Branch. These Sandhill watersheds consisted of mixed pine/hardwood forest with loam-sand to sand-loam soils, and experienced pre-1940s agricultural land use. Nine research sites were selected in these watersheds; three each in High, Medium, and Low disturbance classes. High sites experienced current mechanized-infantry training activities. Medium sites experienced past training activities and are close to High disturbance areas, but are impacted only by foot traffic. Medium areas can be considered “recovering” sites. Low sites have not experienced military tactical vehicle maneuvers, have minimal foot traffic, and are being managed for their conservation and wildlife values.

Phase II Studies

Phase II research was initiated in April and May 2003 to validate or test selected Ecological Indicators identified in Phase I that demonstrated high potential. Forty Phase II sites were selected to represent the widest range of landscape disturbance and upland forest community types present at Fort Benning. The 9 Phase I sites were included in the 40 sites (Figure 2), and the following data and criteria were used to select 40 research sites: eight GIS databases, Fort Benning’s “Unique Ecological Areas”, other SEMP research sites, and extensive final ground-truthing

Field Sampling Design

At each site center point, 4 perpendicular 100-m transects were established from a randomly determined coordinate between 0-359 degrees. The random coordinate was identified using a pair of dice. All field data collected by all research teams were referenced to these four transects. The site center point was identified with two fluorescent pink flags. Each transect was identified with four fluorescent pink flags, placed at intervals of 25, 50, 75, and 100 m. Each flag was marked with its respective bearing and distance from site center. Global Positioning System (GPS) center locations, transect bearings, and maps of all sites were provided to all research teams. Each site was classified (subjectively) based on visual disturbance to vegetation and soils, primarily caused by military training activities. Relatively pristine sites were classified as DC1, while the most degraded sites were classified as DC10. The individual doing the classification (author of this report, A. Krzysik) had two decades of field experience with military training habitat disturbance. The classification was conducted before any field data were collected.

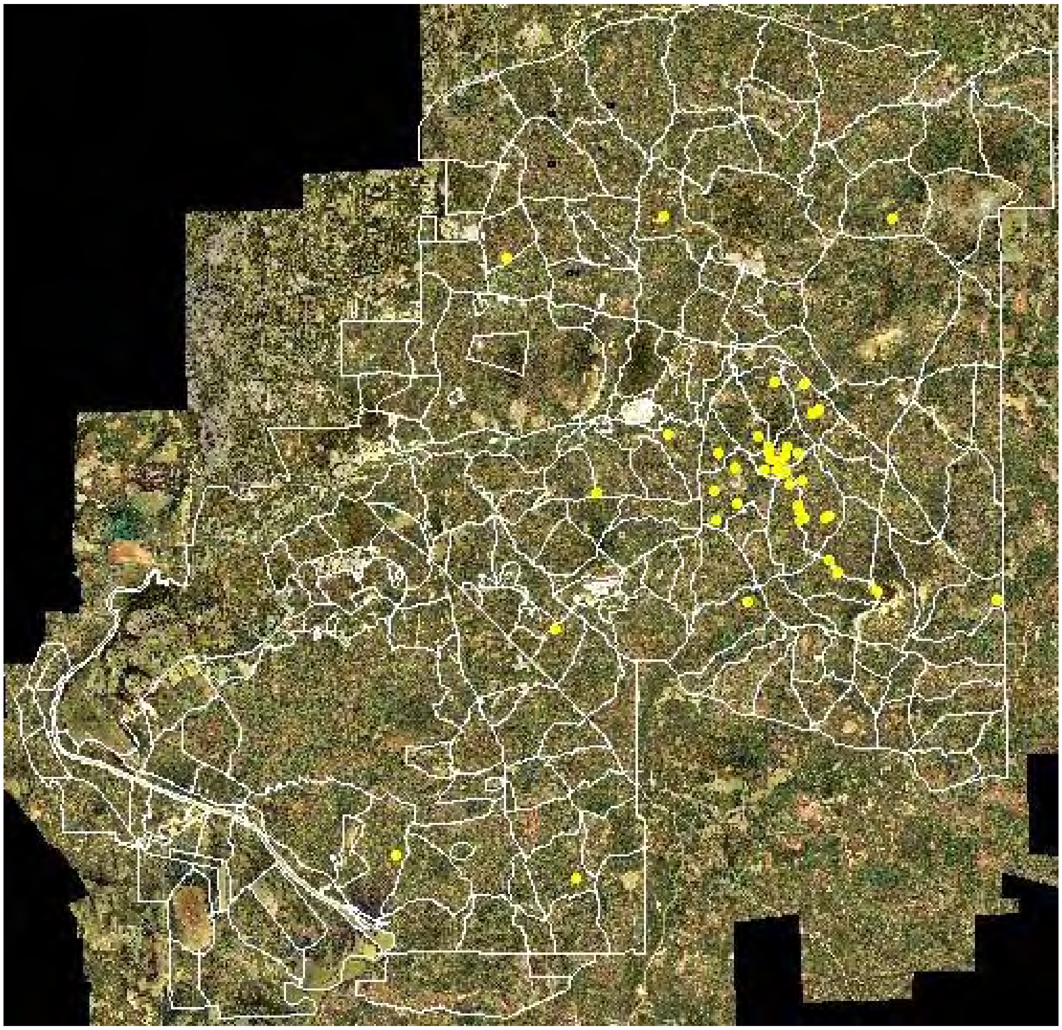

Figure 2. GIS map of Fort Benning, GA
The white lines designate the different training areas and the yellow points indicate the 40 sample sites used in the Phase II study. The background is color aerial photography acquired in February 1999.

Soil A-horizon Depth

A-horizon depth was systematic-randomly determined at 10 points along each transect from 10 to 100 m from the site's center, using a garden trowel and a 15-cm stainless steel metric ruler. Samples were taken in the identical quadrates that the ground cover samples were taken. See Ground Cover (page 9) for details of sampling locations. Because of the difficulty and subjectivity involved in locating the base of the A-horizon, estimates were always made by the same surveyor to 0.5 cm. Sample size per site was equal to 40.

Soil Compaction

Soil Compaction was determined systematically at 50 points along each transect from 2 to 100 m from the site's center using a Lang Penetrometer (Forestry Suppliers). Sampling was conducted approximately 1 to 2 m from alternating sides of the transect. Sample size per site was equal to 200.

Ground Cover (Includes Shrubs)

Ground Cover and Shrub Cover were sampled on the four perpendicular site transects. Ten quadrats were systematic-randomly sampled on each transect from 10 to 100 m from the site's center. Sampling points were determined as follows. A pair of dice was thrown on the ground. The left die determined the side of the transect for quadrat location (odd number = left side, even number = right side). The value on the second die indicated the number of meters to place the sampling quadrat. Quadrats were placed after moving this distance. Therefore, the quadrat centers were randomly located approximately 1.5 to 8 m from the site transects. The quadrat consisted of a "hula-hoop" 86 cm in diameter (0.58 m^2).

Percent cover was estimated for the following parameters:
Note that the sum of classes 1-3 = 100%

1. Bare Ground
2. Pine Litter
3. Deciduous Litter
4. Forbs (total)
5. Legumes (a sub-set of forbs)
6. Grass (total), includes sedge-like nongrasses
7. Ferns

8. Yucca
9. Cacti
10. Woody Plants (< 2 m high)
11. Identification and percent cover of each species or morpho-species.
    A morpho-species = an unknown taxa, but readily identified from other taxa. Most morpho-species were later identified in the lab by the use of herbarium specimens at the University of Illinois.

Sample size of number of quadrats per site was equal to 40.

Canopy Cover

Canopy Cover was determined systematically at 2 points along each transect, 33 and 67 m from the site's center using a Concave Spherical Densiometer, Model C (Forestry Suppliers). At each sampling point, 96 "canopy hits/misses" were determined at each of four 90-degree apart sighting positions. Therefore, there were 384 "canopy hits/misses" per sampling point, and 3072 per site. Sample size per site was equal to 8.

Basal Area

Basal Area was determined systematically at 3 points along each transect, 30, 60, and 90 m from the site's center using a Cruz-All Basal Area Factor (BAF) Gauge (Stock No. 59795, Forestry Suppliers). At each sampling point, BAFs of 40, 20, 10, and 5 were determined. In the database, the data were converted to m^2/ha, and the largest value of Basal Area from the four readings was used as the final point Basal Area estimate. Sample size per site was equal to 12.

Trees

Trees were sampled on four perpendicular 100-m x 10-m strip-transects, that coincided with the four site transects. Trees whose centerline fell within the strip-transect were identified and measured with a 5-m fiberglass DBH Tape (Forestry Suppliers Inc.; DBH = Diameter Breast High). DBH was recorded to 0.1 cm, and only individual trees with a DBH =/> 5 cm were tallied. Pine snags and deciduous snags were also measured. Forty-three tree species (plus Pine Snags and Deciduous Snags) representing 7031 individuals were identified at the 40 sites, ranging from 1433 Loblolly Pines to four species represented by only a single individual. Twenty-six species and snags (N=6903, 98.2 percent of all individuals) were used to develop an Upland Forest Classification for the 40 sites.

Trees with fewer than 18 sampled individuals were not included in this analysis. Six species of trees represented by small numbers (12 to 17 individuals), were not included in the tree database for classification analysis.

Tree species/snags were represented by their Basal Areas for forest classification. The tree data based on basal area was analyzed by Hierarchical Agglomerative Cluster Analysis using Ward's criterion (Ward 1963) with squared Euclidean distance as the similarity metric. Ward's method is a minimum variance clustering procedure that seeks to form N clusters under the criteria that the trace of matrix W is minimized, where W is the matrix obtained by summing within-cluster sums of squares and products matrices (i.e., variance-covariance matrices) over all N clusters. A large number of clustering algorithms were experimented with in these analyses, including Average Linkage, Single Linkage (Nearest Neighbor), Complete Linkage (Farthest Neighbor), Centroid, and Median methods. Ward's method gave very similar results to the Average Linkage (Unweighed Pair-Group Averages) method. The Average Linkage method is the most commonly used technique (Romesburg 1984), has desirable properties (Sneath and Sokal 1973), and was very effective with field data simulations (Krzysik 1987). However, Ward's method was most successful at developing a Tree Community classification that made the most ecological sense in tree species compositions. Both Ward's and Average Linkage methods are procedurally recommended (Romesburg 1984). All cluster analyses were performed with SPSS (2003). Ten upland forest communities were identified with cluster analysis (Table 1).

Independently, the tree community data based on basal areas was ordinated with Nonmetric Multidimensional Scaling (NMS) (McCune and Mefford 1999). The author has a great deal of experience with this method, and finds that it is robust and informative at uncovering underlying community patterns. Figure 3 shows the NMS ordination of the 40 sites, with 7 forest community types originally extracted with cluster analysis. Three pine-hardwood mixed forests (designated by "H") were closely clustered in NMS space. The first NMS axis represents a long gradient in basal area, clearly separating the highly disturbed sites (A) with low basal areas from the mature stands of Longleaf Pine Forests (F) on opposite ends of this gradient. The second axis is considered to represent a landscape moisture gradient, ranging from the Oak-Hickory Mesic Deciduous Forest (B) to Xeric Scrub Oak – Pine Savannas (G).

The pine-hardwood mixed forests (H) consisted of: (Ha) Loblolly/ Shortleaf – Hardwoods; (Hb) Mixed Pine – Oak – Hickory (Loblolly Dominant); (Hc) Mixed Pine – Southern Red Oak, two types, one pine dominant, the other hardwood dominant.

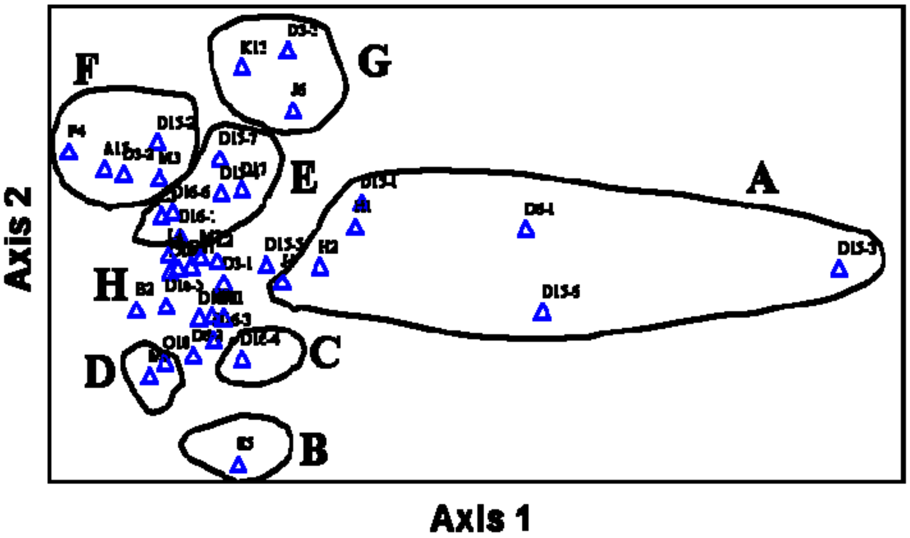

Figure 3. NMS Ordination of 40 sites.
Based on basal areas of 24 tree species (N=6903), pine and deciduous snags.

Table 1. Ten forest communities independently derived with cluster analysis.

Community Designation (from Figure 3)	Type	Number of Sites in the Class
A	Highly Disturbed Training Areas	7
B	Oak-Hickory Mesic Deciduous Forest	1
C	White/Southern Red/Post Oak - Shortleaf/Loblolly Forest	1
D	Piedmont Loblolly Pine Forests	2
E	Longleaf Pine – Oak Forests	6
F	Longleaf Pine Forests	5
G	Xeric Scrub Oak – Pine Savannas	3
H	Pine – Hardwoods Mixed Forests	
Ha	Loblolly/Shortleaf – Hardwoods	6
Hb	Mixed Pine – Oak – Hickory	7
Hc	Mixed Pine – Southern Red Oak	2

Statistical Analysis

Statistical comparisons of habitat metrics among disturbance classes were assessed with Tamhane's T2 multiple comparison test. This test is very conservative, therefore minimizing Type I error, and is the recommended procedure when variances are heterogeneous (Tamhane 1979). All statistical analyses were conducted with SPSS (SPSS 2003).

Site Comparison Index

Each variable that was used to calculate an SCI was first standardized by giving the specific variable a score of 100 at the site where this variable had its highest value, and then proportionately adjusting the values of that variable at each of the remaining 39 sites. Each habitat variable for this initial analysis was equally weighed. But in future analyses, variables could be assigned varying weights of importance. Therefore, for a given SCI, the sum of all variable scores comprising the index was divided by the number of variables to arrive at a "mean value" for the SCI. Thus, the potential maximum value for a SCI was 100. But in order to achieve this value, each habitat variable comprising a given SCI would have to achieve its highest value at a single site. This was not encountered during the study.

3 Results and Discussion

Ecological Indicator Foundations

Habitat variables (parameters) were collected at nine upland forests sites in the spring of 2001 and 2002. The spring field data collection took place from late April to early June, and was concentrated in May. The nine sites represented three sites in each of three land use disturbance classes, Low, Medium, High (see Methods section for details). Discriminant analysis was used to identify the habitat variables that most effectively characterized this “disjunct disturbance gradient”. In other words, discriminant analysis derived orthogonal (uncorrelated with each other) canonical vectors, which are weighed linear combinations of the original field variables, such that these vectors maximally distinguish among the three disturbance classes. Soil A-horizon depth, soil compaction, and both ground cover floristics and general classes of ground cover were effective discriminators of landscape disturbance.

The nine sites of Phase I were located in similar upland forests and soils in two adjacent watersheds: Bonham Creek and Sally Branch. The additional 31 sites of Phase II, were selected in spring 2003, and, with the original nine, represented the complete range of landscape disturbance and upland forest communities available at Fort Benning (see Methods section).

The Normalized Difference Vegetation Index (NDVI) has often been used to measure landscape net primary productivity (NPP), as it correlates strongly with LAI (leaf area index), FPAR (fraction of absorbed photosynthetically active radiation), NPP (measured net primary production), measures of chlorophyll, and albedo (Hobbs and Mooney 1990, Sellers 1994, Franklin 2001, Turner et al. 2001). NDVI was derived by Bob Lozar (ERDC-CERL) for each of the 40 sites employing a radius of 100 m. NDVI = (NIR – RED)/(NIR + RED), where NIR is near infra-red and RED is red spectral bands of Landsat TM imagery.

Table 2 shows the number of sites that were placed in each disturbance class. Figure 4 shows the NDVI values for the 40 sites relative to the 10 disturbance classes (DCs). NDVI was capable only of distinguishing between the most pristine sites and the higher disturbed sites. DCs 2 to 8 overlapped to a large extent. DC1 had the highest NDVI, but was highly variable because it included site E5, a mesic oak-hickory deciduous forest with the highest canopy cover, and site K13, a xeric scrub oak-longleaf pine savanna. DC8 contains highly disturbed sites, but canopy cover ranged from 14 to 41 percent.

Table 2. Number of sites that fell in each disturbance class.

Disturbance Class:	1	2	3	4	5	6	7	8	9	10
Number of sites:	3	3	5	7	6	4	3	3	3	3

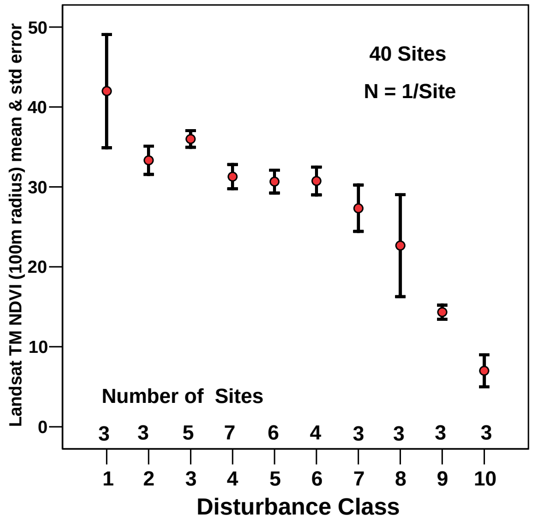

Figure 4. NDVI (mean and standard error) at the 40 sites based on disturbance class.

Figure 5 shows soil A-horizon depth for the 40 sites relative to the 10 DCs. The numbers in the figure represent statistically different A-horizon depths. A-horizon depth characterizes the disturbance gradient extremely well for several important reasons. There is a consistent, smooth, linear, monotonic decrease of the A-horizon with increasing disturbance. DC3 was the single exception, but it was not significantly different from either DC4 or DC2. DC3 contains sites L2 and L3, which were definitely exposed to agricultural activity, and the two “Piedmont” sites M8 and O10, which appear in good condition. However, Piedmont sites are known to have experienced extensive agricultural and timbering activities. The consistent pattern in this figure is analytically verified by the pairing of adjacent DCs, resulting in five statistically significant disturbance classes based on A-horizon depth.

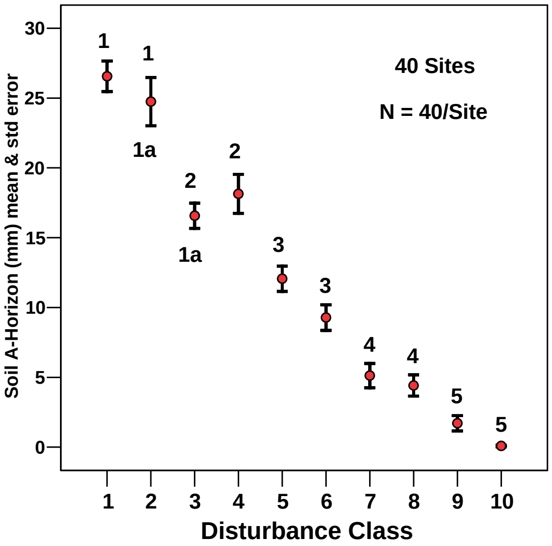

Figure 5. Soil A-horizon depth (mean and standard error) at the 40 sites based on disturbance class.
See Table 2 for number of sites in each disturbance class.
Numbers represent statistically similar disturbance classes.

Figure 6 shows soil compaction for the 40 sites relative to the 10 DCs. The numbers in the figure represent statistically different soil compaction classes. The pattern is not as smooth and linear as with A-horizon depth, but seven statistically significant disturbance classes are evident. The most pristine and most disturbed sites are dramatically separated from the other classes. DC4 and DC5 are similar, as are DC6, DC7, and DC8. But these “groupings” are not exactly the same as displayed by the A-horizon groups. DC2 contains the site with the highest clay content (A15, 13.6 percent). Soils with a higher clay content typically demonstrate higher levels of soil compaction.

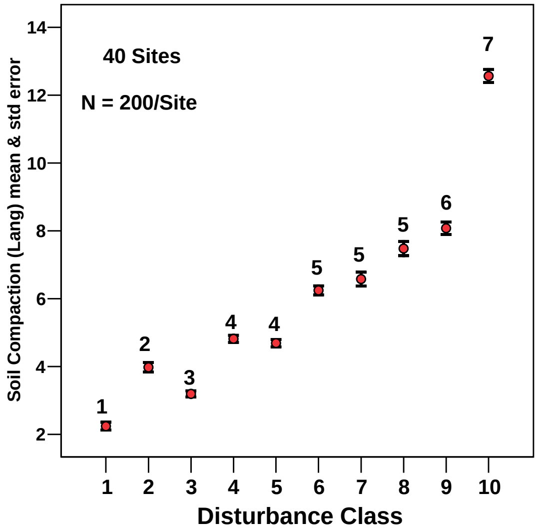

Figure 6. Soil compaction (mean and standard error) at the 40 sites based on disturbance class.

See Table 2 for number of sites in each disturbance class.
Numbers represent statistically similar disturbance classes.

The ability of general ground cover parameters to distinguish among the 10 DCs were tested with discriminant analysis. The eight ground cover parameters (in %) were: bare ground (=100-litter), woody, forbs, grass, ferns, pine seedlings, legumes (also included in forbs), and total ground cover. Figure 7 shows Discriminant Function (DF) 1 for the 40 sites relative to the 10 disturbance classes (DCs). The numbers in the figure represent statistically different values of DF1. DF1 has a correlation of 0.95 with bare ground. Although DF1 was clearly related to the disturbance gradient, it was not as consistent and smooth as A-horizon depth. DC1 and DC3 had the least bare ground, while DC10 had the most. DC7, DC8, and DC9 were similar to each other, while DC2 with the mid-disturbance classes DC4, DC5, and DC6 were similar to each other. The general pattern of bare ground suggests four classes: DC1-DC3; DC2-DC4-DC5-DC6; DC7-DC8-DC9, and DC10. The pattern is monotonic, with only DC3 and DC5 having less bare ground then expected.

Figure 8 with DF2 is informative. DF2 correlates with total ground cover (0.81), forb cover (0.73), and woody cover (0.66). This figure demonstrates that the intermediate disturbance classes have the highest values of ground cover. This is not unexpected. The more disturbed sites, of course, possess less ground cover, while the less disturbed sites have a higher canopy cover and more severe competition for nutrients and water from trees.

The intermediate disturbance sites exhibit more canopy and soil disturbance patchiness, leading to more ground cover.

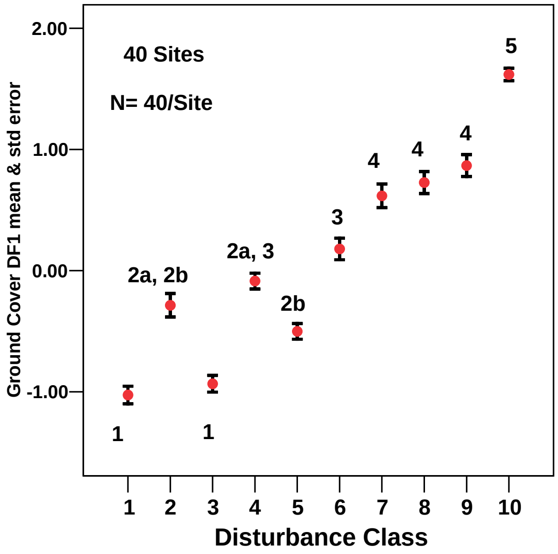

Figure 7. Ground cover DF1 scores (mean and standard error) at the 40 sites based on disturbance class.
See Table 2 for number of sites in each disturbance class.
Numbers represent statistically similar disturbance classes.

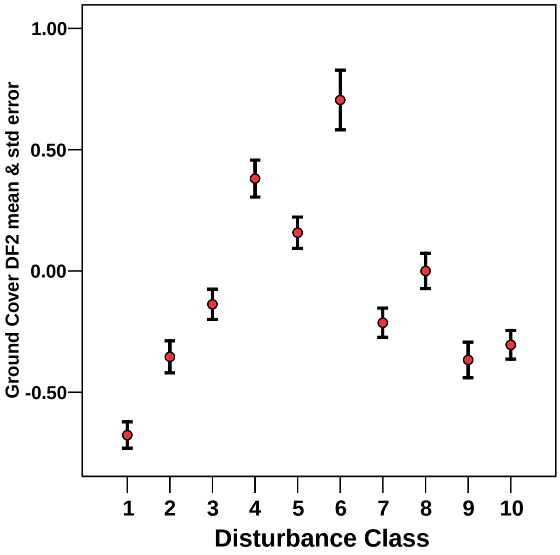

Figure 8. Ground cover DF2 scores (mean and standard error) at the 40 sites based on disturbance class.
See Table 2 for number of sites in each disturbance class.

Figure 9 shows DF3, which was correlated with fern cover (-0.87). Ferns readily establish after a fire, and also appear to be associated with mature pine stands. Therefore, DF3 may be an important parameter for quantifying fire history.

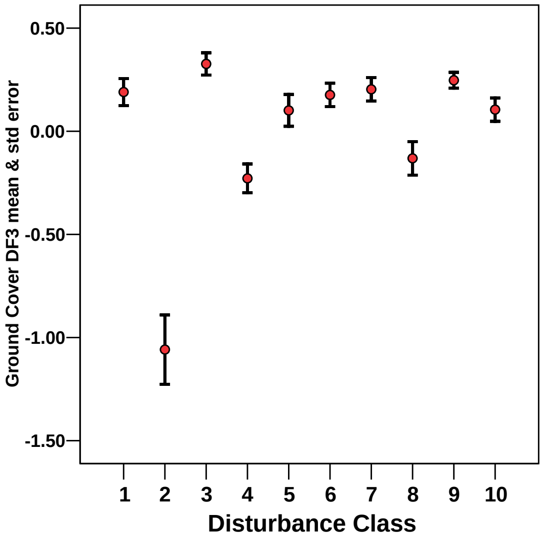

Figure 9. Ground cover DF3 scores (mean and standard error) at the 40 sites based on disturbance class.

See Table 2 for number of sites in each disturbance class.

Figure 10 shows DF4, which was correlated with grass cover (0.73). A very interesting pattern is evident, but it is unknown if it is coincidental or real. The three highest disturbed sites (DC10) clearly possess the highest grass cover. This was as expected, because many grasses grow well in nutrient poor and highly disturbed soils in an open canopy. The interesting feature of this graph was that the 10 disturbance classes form a clumped-pattern of Low – Medium – High subgroups, with DF4 scores (grass cover) increasing ***within*** each Low – Medium – High subgroup. The single exception was DC9. It is important to recall that DF4, although primarily and strongly correlated with grass cover, also consists of a weighed linear combination of the other seven ground cover variables, with the constraint that all derived discriminant functions are uncorrelated. Grass cover alone does not exhibit this pattern. It can be difficult to completely interpret discriminant analysis patterns.

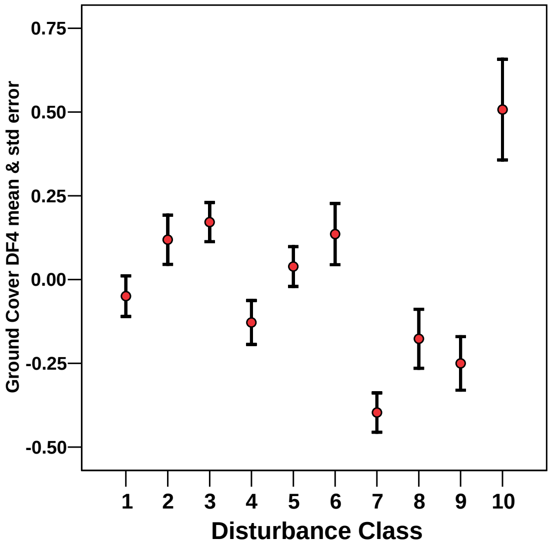

Figure 10. Ground cover DF4 scores (mean and standard error) at the 40 sites based on disturbance class.

See Table 2 for number of sites in each disturbance class.

Developing a Site Comparison Index (SCI)

Three habitat variables show potential for characterizing a broad landscape disturbance gradient based on the analysis of data from the 40 Ecological Indicator research sites. The promising variables are: A-horizon Depth, Soil Compaction, and Bare Ground. Bare Ground is exactly related to Litter Cover; based on our field methods, Litter Cover = 100 – Bare Ground. Litter Cover will be used in this analysis because of its positive relationship with A-horizon Depth. Canopy Cover and Basal Area will also be evaluated in SCI development, because they are important parameters, directly reflecting Southeast forest condition – canopy continuity and tree size.

Figure 11 shows A-horizon depth on a relative scale. Note that the pattern of the means is identical to Figure 4, but the scales are different, Figure 10 reflecting the SCI design, and the standard errors are very different. Figure 4 standard errors are based on 40 samples per site. This translates to at least N=120 for DCs with 3 sites, and N=280 for DC4 (7 sites). This is required for the multiple comparisons analysis. However, for the SCI analyses, N varies from 3 to 7, depending on the number of sites within specific DCs, because SCIs are based on comparing individual sites. An important observation in this figure was that the lowest DC mean (DC1) had less than half the maximum possible score of 100, and that DC2 and DC4 are highly variable in their A-horizon. The deepest soils were found at site J6 (a scrub oak - pine savanna), and although moderately disturbed (DC4), it was the only site that apparently was never plowed.

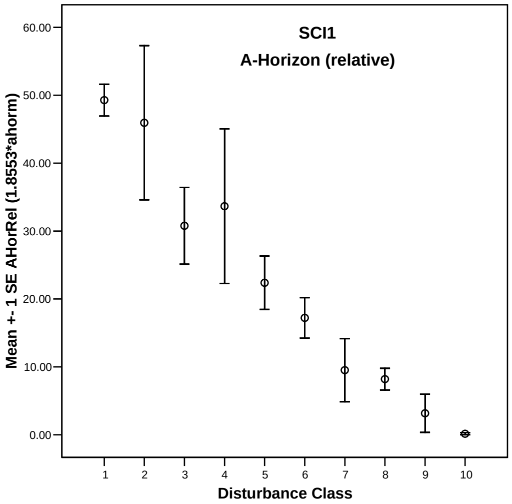

Figure 11. Site Comparison Index (SCI1) based on A-horizon depth (mean and standard error) at the 10 disturbance classes.

Note that the ordinate is a relative scale where 100 is the maximum possible value.
See Table 2 for number of sites in each disturbance class.

Figure 12 shows the SCI based on two variables: A-horizon and soil compaction. Although there is a great deal of overlap among the disturbance classes, note that there is a complete monotonic decrease in the SCI with increasing DCs.

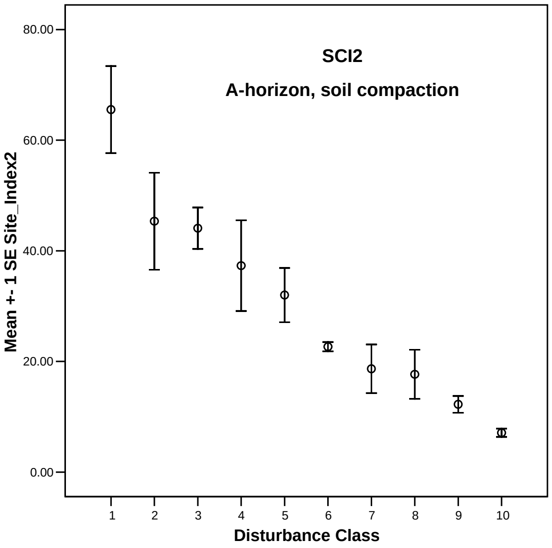

Figure 12. Site Comparison Index (SCI2) based on A-horizon depth and soil compaction (mean and standard error) at the 10 disturbance classes.

Note that the ordinate is a relative scale where 100 is the maximum possible value.
See Table 2 for number of sites in each disturbance class.

Figure 13 shows the SCI based on three variables: A-horizon, soil compaction, and litter cover (litter cover is exactly inversely related to bare ground). Note that DC3 and DC5 increase in their SCI values. This parallels the results for groundcover as shown in Figure 7.

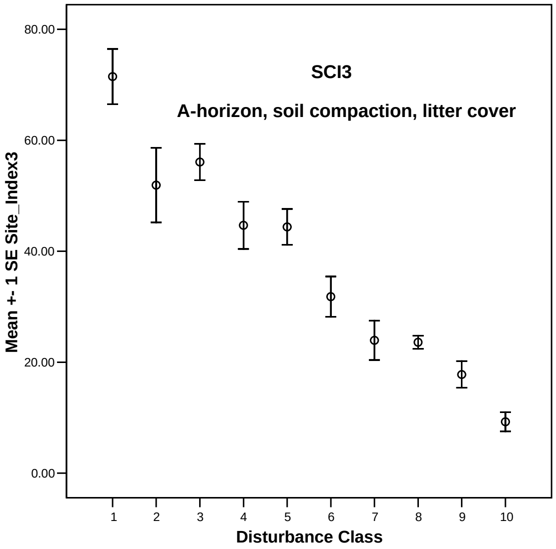

Figure 13. Site Comparison Index (SCI3) based on A-horizon depth, soil compaction, and litter cover (mean and standard error) at the 10 disturbance classes.
Note that the ordinate is a relative scale where 100 is the maximum possible value.
See Table 2 for number of sites in each disturbance class.

Figure 14 shows the SCI based on five variables: A-horizon, soil compaction, litter cover, canopy cover, and basal area. The addition of variables quantifying canopy integrity and tree size or dominance results in a smooth decrease in SCI values from moderate to severe disturbance (i.e., DC5 to DC10). The addition of NDVI to the 5-variable SCI had no effect on the index (Figure 15).

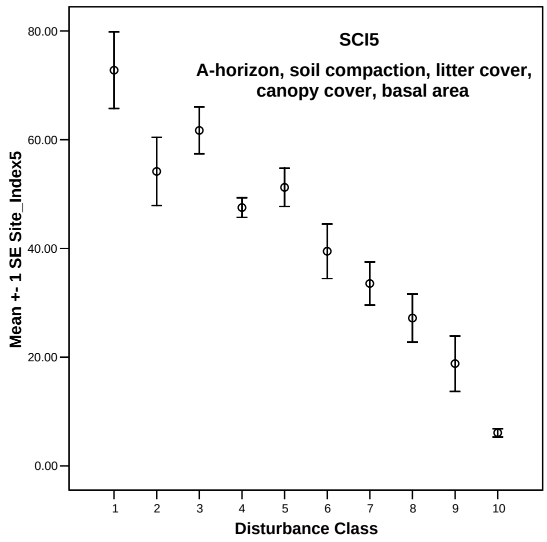

Figure 14. Site Comparison Index (SCI5) based on A-horizon depth, soil compaction, litter cover, canopy cover, and basal area (mean and standard error) at the 10 disturbance classes.

Note that the ordinate is a relative scale where 100 is the maximum possible value.
See Table 2 for number of sites in each disturbance class.

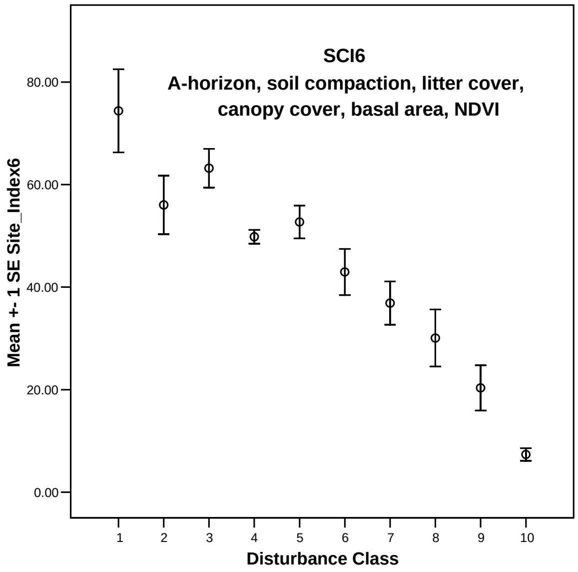

Figure 15. Site Comparison Index (SCI6) based on A-horizon depth, soil compaction, litter cover, canopy cover, basal area, and NDVI (mean and standard error) at the 10 disturbance classes.

Note that the ordinate is a relative scale where 100 is the maximum possible value.
See Table 2 for number of sites in each disturbance class.

The upland forests at Fort Benning represent a broad range of tree communities, although most are representative of “Mixed Pine/Hardwoods”. The use of cluster analysis and nonmetric multidimensional scaling (NMS) ordination based on tree species basal areas identified 10 upland forest communities that could be represented on two axes; Axis 1: magnitude of basal area, Axis 2: a moisture gradient. Based on these results the 40 sites were placed into four Forest Moisture Classes (Table 3). Most of the forests were mixed pine/hardwoods. In order to assess the effect of forest physiognomy or structure on the SCI, analyses were separately conducted on each of the four forest moisture classes using the five-variable SCI. The highest forest moisture class consisting of a high deciduous forest component and Piedmont Loblolly/hardwoods exhibited a very clear pattern (Figure 16). The mixed pine/hardwoods comprised the majority of sites and included representation from all 10 DCs. The pattern was excellent with only DC4 and DC5 being very similar (Figure 17). Note the small but important improvement over Figure 13. The longleaf pine forests did not exhibit a consistent pattern on the disturbance gradient (Figure 18). The SCI for DC5 was similar to DC2, with the trend in the wrong direction, but sample size was small. There were only three scrub oak – pine savanna sites, but the exhibited pattern was correct (Figure 19).

Table 3. Upland forest community classification into four classes based on available soil moisture.

(Class 1 = mesic forests, Class 4 = xeric forests). The original 10 forest community classes were determined by cluster analysis, and forest moisture gradients were derived from nonmetric multidimensional scaling (NMS).

Forest Moisture Class	N =	Forest Community Classes	Training Area and Site Number	Dominant Cover Type
1 (highest available soil moisture)	4	B, C, D,	E5	Oak-Hickory
			D16-4	White/Southern Red/Post Oak – Shortleaf/Loblolly
			M8, 010	Loblolly – Hardwoods (Piedmont)
2	28	A, E, Ha, Hb, Hc	D15-1, D15-3, D15-6, D6-1, H1, H2, J4	Mixed Pines-Oak, very low basal area
			D15-4, D15-7, D16-1, D16-6, D17, L3	Mixed Pines-Oak Longleaf Dominant
			D16-2, D16-3, D16-5, D6-2, H3, L1	Loblolly/Shortleaf-Hardwoods
			D11, D15-5, D16-7, D3-1, L2, M1, M2	Mixed Pines-Oak-Hickory: Loblolly Dominant
			B2, F1	Mixed Pines-Southern Red Oak
3	5	F	A15, D15-2, D3-2, F4, M3	Longleaf Pine
4	3	G	D3-3, J6, K13	Scrub Oak-Pine Savannah

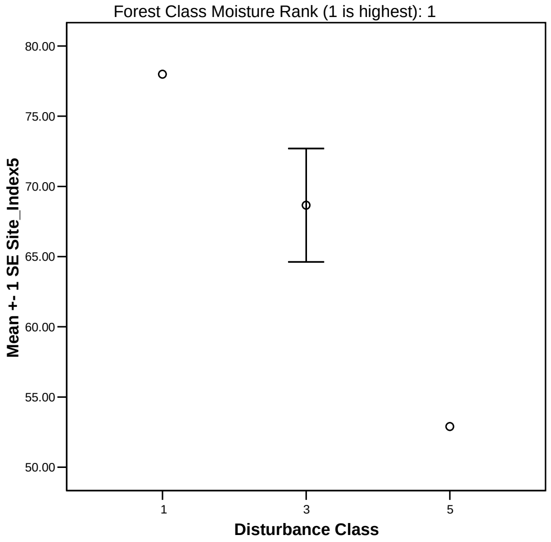

Figure 16. Site Comparison Index (SCI5) for Forest Class Moisture 1.
See Table 3. Based on A-horizon depth, soil compaction, litter cover, canopy cover, and basal area (mean and standard error) at the three available disturbance classes.
Note that the ordinate is a relative scale where 100 is the maximum possible value.

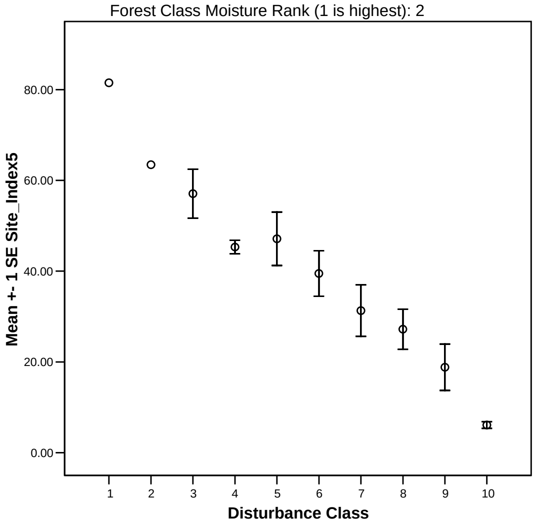

Figure 17. Site Comparison Index (SCI5) for Forest Class Moisture 2.
See Table 3. Based on A-horizon depth, soil compaction, litter cover, canopy cover, and basal area (mean and standard error) at all 10 disturbance classes.
Note that the ordinate is a relative scale where 100 is the maximum possible value.

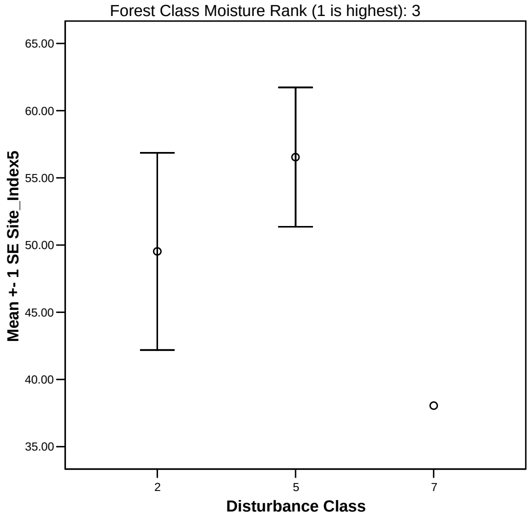

Figure 18. Site Comparison Index (SCI5) for Forest Class Moisture 3.
See Table 3. Based on A-horizon depth, soil compaction, litter cover, canopy cover, and basal area (mean and standard error) at the three available disturbance classes.
Note that the ordinate is a relative scale where 100 is the maximum possible value.

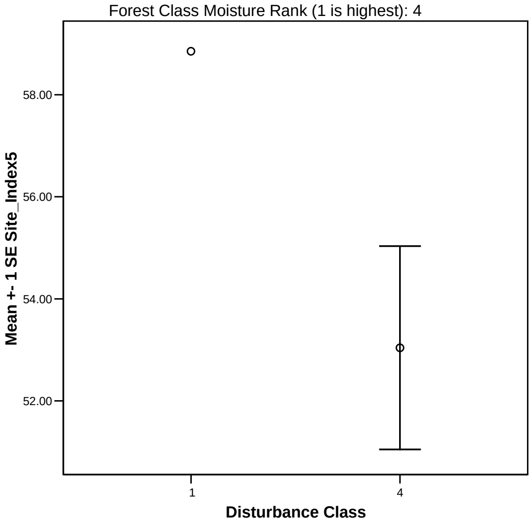

Figure 19. Site Comparison Index (SCI5) for Forest Class Moisture 4.
See Table 3. Based on A-horizon depth, soil compaction, litter cover, canopy cover, and basal area (mean and standard error) at the two available disturbance classes.
Note that the ordinate is a relative scale where 100 is the maximum possible value.

Despite the broad range of forest community types and habitat disturbance represented by the 40 sites, soil textures were surprisingly similar when soil textures were assessed over scales of 4 hectares. Ten sites had sandy loam soils, 27 had loamy sand soils, while 3 sites had sand textures. The latter two texture classes were combined into a “sandy” class. The SCI analysis was repeated for these two soil texture classes. The sand loam textures had higher clay contents than the sandy sites. Sand loam sites exhibited a relatively consistent pattern, with DC4 and DC5 being similar (Figure 20). The sandy sites, consisting of three-fourths of the total sample, not surprisingly, gave similar results as the 40-site data set; compare Figure 21 with Figure 14.

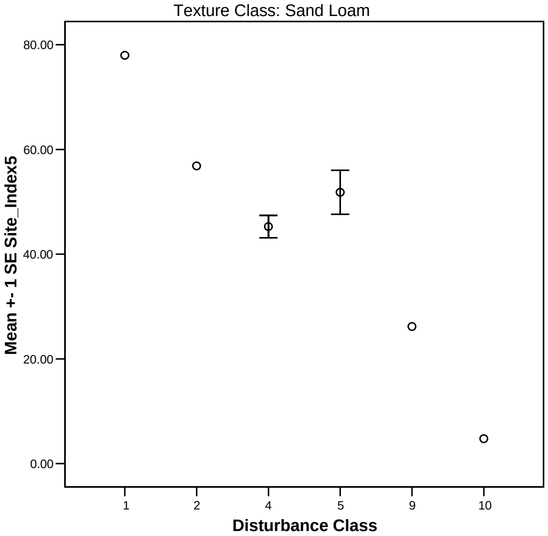

Figure 20. Site Comparison Index (SCI5) for Soil Texture Sand Loam.
N=10 sites. Based on A-horizon depth, soil compaction, litter cover, canopy cover, and basal area (mean and standard error) at the six available disturbance classes.
Note that the ordinate is a relative scale where 100 is the maximum possible value.

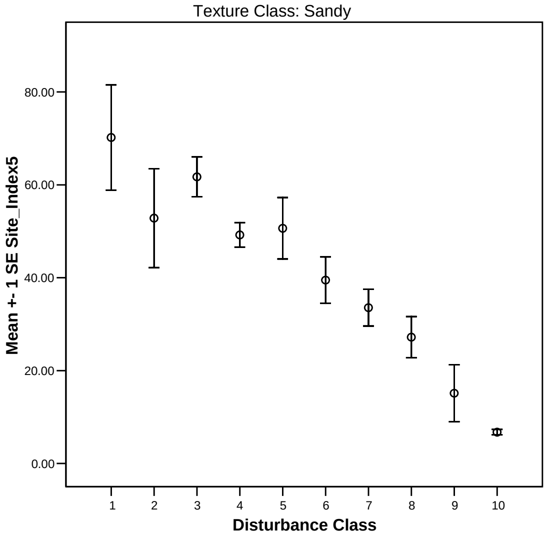

Figure 21. Site Comparison Index (SCI5) for Soil Texture Sandy.
N=30 sites. Based on A-horizon depth, soil compaction, litter cover, canopy cover, and basal area (mean and standard error) at all 10 disturbance classes.
Note that the ordinate is a relative scale where 100 is the maximum possible value.

A Survey of Other Potential SCI Variables

Figure 22 shows tree density at the 40 sites ranked in order of site A-horizon depth. The rank of A-horizon depth closely parallels site quality (Figure 5). The three most degraded sites completely lacked an A-horizon (Figure 5), so tree density ranks for these in Figure 22 is undefined. Although the overall general pattern is a decrease of tree density as A-horizon decreases, there is a great deal of variability. Note that sites ranked closely together and therefore having similar A-horizon depths, may have dramatically different tree densities. Importantly, this can be the case along the entire disturbance gradient, from relative pristine sites, to moderately impacted areas, and to highly disturbed sites. Tree density would provide conflicting information in an SCI, is highly correlated with canopy cover and basal area, and adds no additional “habitat information” than already provided by canopy cover and basal area, variables that are already in the SCI.

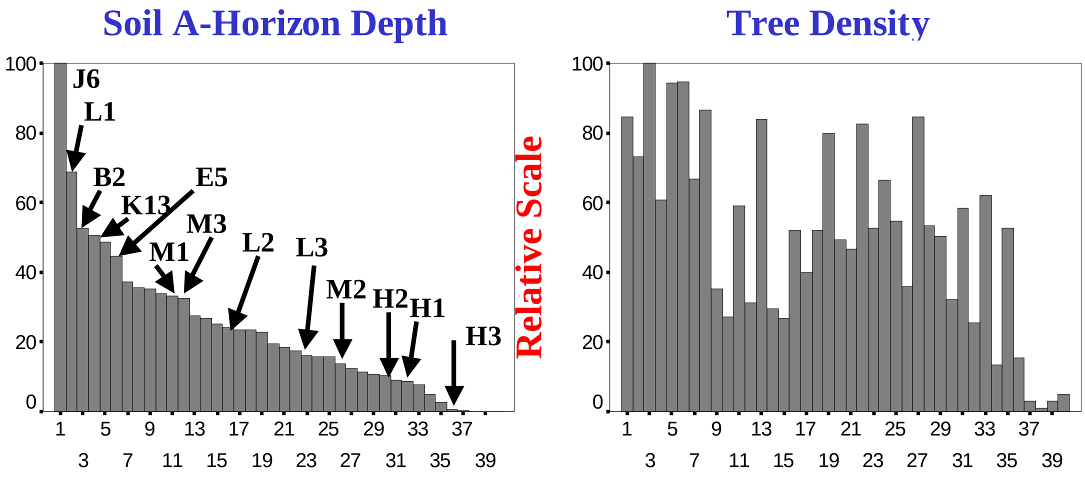

Figure 22. Tree density at the 40 sites, ranked by soil A-horizon depth.
Note that the ordinate is a relative scale where 100 is the maximum possible value.

Figure 23 shows soil nitrate (NO3-) at the 40 sites ranked in order of site A-horizon depth. Despite the large differences among the 40 sites in habitat disturbance and forest composition, soil nitrate was relatively similar along the entire disturbance gradient, with the exception of three large anomalies and three smaller ones. The sites with high nitrate represent dramatically different communities: scrub oak – pine savanna (J6), oak-hickory deciduous forest (E5), Loblolly/Shortleaf – Hardwoods (D6-2). However, site D6-2 contains a section with a network of ravines with very large sweet gum and tulip trees.

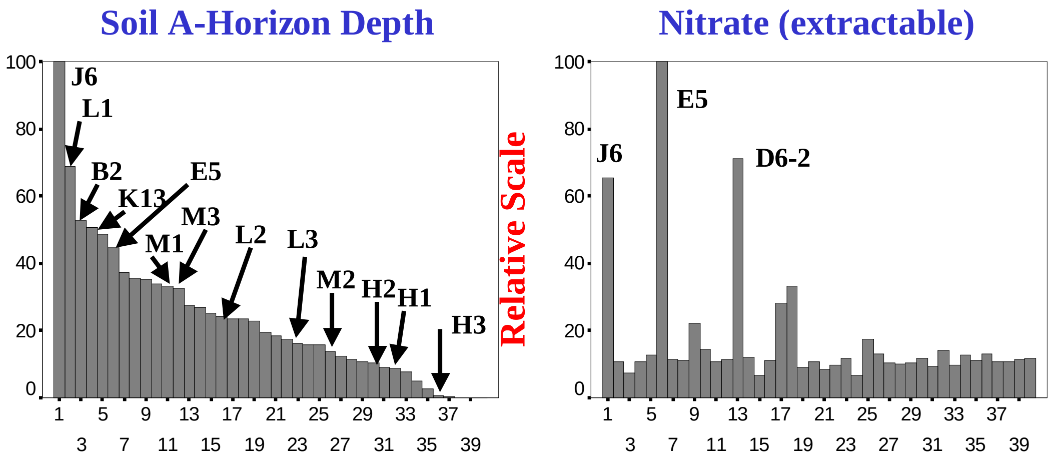

Figure 23. Soil nitrate (NO$_3$-) at the 40 sites, ranked by soil A-horizon depth.
Note that the ordinate is a relative scale where 100 is the maximum possible value.

Figure 24 shows soil ammonium (NH4+) at the 40 sites ranked in order of site A-horizon depth. Unlike the general uniformity of soil nitrate, soil ammonium shows a general pattern of increasing along the disturbance gradient. The oak-hickory forest site (E5), as in the case of nitrate, again demonstrated the highest ammonium value. Nitrogen dynamics in Southeast forests appear to be very complex (Kovacic et al. 2004). The interrelationships of nitrate and ammonium to each other, forest disturbance, forest community types, microbial activity, soil carbon, ecosystem nutrient leakage, and seasonal and weather influences are currently under analysis, and undoubtedly will require additional research in both detail and in a broader range of Southeast landscapes.

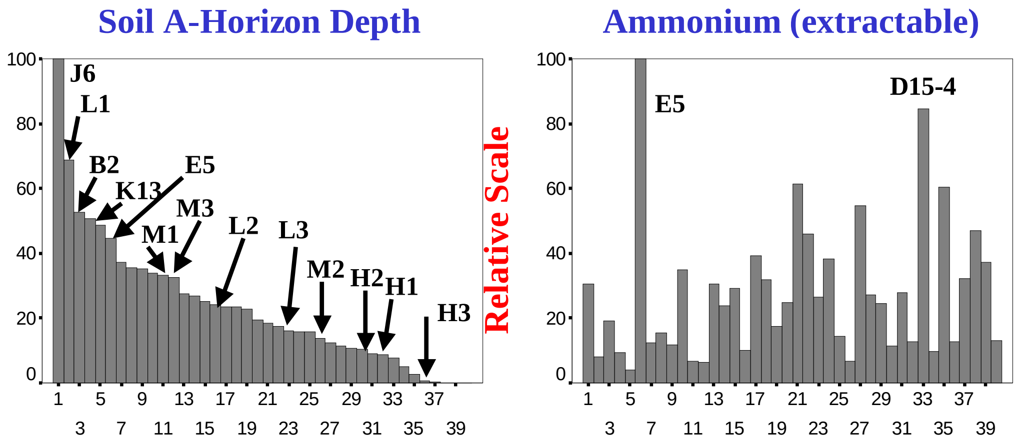

Figure 24. Soil ammonium (NH$_4$+) at the 40 sites, ranked by soil A-horizon depth.
Note that the ordinate is a relative scale where 100 is the maximum possible value.

Figure 25 shows microbial carbon biomass (MCB) at the 40 sites ranked in order of site A-horizon depth. MCB is closely associated with available soil carbon, and therefore should closely track organic matter in the ecosystem. There is a general pattern of decreasing MCB with decreasing A-horizon depth and increasing disturbance. However, inter-site variability is high, even among sites possessing similar A-horizon depths. The four sites with the deepest A-horizons demonstrate moderate to low MCB. Sites J6 (DC4) and K13 (DC1) are scrub oak – pine savannas, site L1 (DC2) is loblolly/shortleaf-hardwoods, and site B2 (DC1) is southern red oak – mixed pine (71 percent deciduous). The common theme in these four sites is a high percentage of deciduous trees and low disturbance. Although J6 is a DC4, it had the deepest A-horizon and was probably the only site that was never plowed. More analyses are being conducted on the soil carbon of our sites and relationships to microbial and nitrogen dynamics.

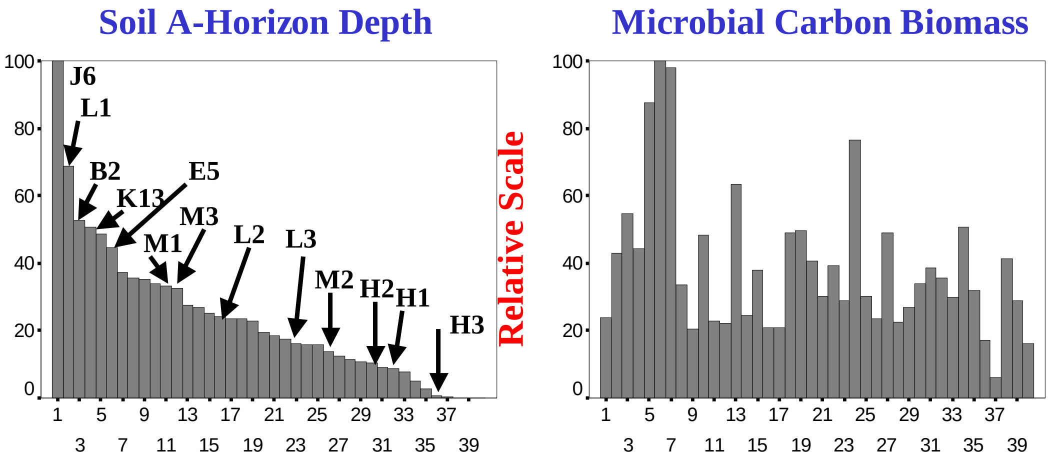

Figure 25. Microbial carbon biomass at the 40 sites, ranked by soil A-horizon depth. Note that the ordinate is a relative scale where 100 is the maximum possible value.

Site Comparison Index – A Caveat

The dilemma in developing a multi-metric "Site Comparison Index" is directly analogous to another "index of environmental quality," the diversity index. When one contrasts a reasonably large set of samples, both indices clearly reveal a significant correlation with disturbance or environmental impacts, and high quality sites are easily distinguished from poor quality sites. However, when trying to compare any two or several sites that are close together on a disturbance gradient, a significantly more important comparison than the extremes or a general overall trend, these multi-metric indices usually fail to elucidate innate important differences. This is because the index consists of a composite of metrics, where the relative contributions of individual metrics are obscured, confounded, and unknown, unless separately identified. For species diversity, this is the relative contribution of species richness and equitability (relative abundances of species). In other words, two sites can have the same species diversity, but innately possess two different patterns of community structure; high species richness with some dominance in one case, and lower species richness but more consistent relative species abundances in the other case. Similarly, a "Site Comparison Index" composed of A-horizon depth, soil compaction, canopy cover, basal area, and litter cover (or bare ground), would mask individual contributions by each of these metrics; even though each of these are highly and statistically significantly correlated with each other and with disturbance along a broad disturbance gradient. There are also interesting relationships among the habitat metrics. For example, at the Phase II 40 sites, high canopy cover can be achieved by either high tree density or high basal area or some intermediate combination. A-horizon depth and soil compaction can be attributed to historical, recent past, and current specific habitat impacts. Therefore, teasing apart the relative contributions of temporal-based disturbances would most likely be masked by the substitution of a single composite index for A-horizon depth, soil compaction, and other habitat metrics.

4 Summary and Conclusions

A Site Comparison Index (SCI) was developed using one to six parameters:

SCI	Parameters
SCI1	soil A-horizon depth
SCI2	soil A-horizon depth, soil compaction
SCI3	soil A-horizon depth, soil compaction, litter cover (=100 - bare ground)
SCI5	soil A-horizon depth, soil compaction, litter cover, canopy cover, basal area
SCI6	soil A-horizon depth, soil compaction, litter cover, canopy cover, basal area, NDVI.

Soil A-horizon depth alone was very effective at assessing the landscape disturbance gradient based on 10 disturbance classes (Figure 11). The addition of soil compaction to the index (SCI2) improved the index by reducing within-disturbance class variability and producing a better monotonic fit to the disturbance gradient (Figure 12). The addition of litter cover (or bare ground) (SCI3) not only did not improve the SCI, but degraded the interpretation of lower disturbance classes (Figure 13). The addition of canopy cover and basal area (SCI5) dramatically improved the monotonic relationship among moderately to highly disturbed sites, DC5 to DC10 (Figure 14). The addition of NDVI (SCI6) had no effect, and did not change this index compared to SCI5 (Figure 15).

The 40 sites varied a great deal in forest community composition, reflecting local physiographic and edaphic environments, especially available soil moisture. This was originally assessed with cluster analysis and non-metric multidimensional scaling. Therefore, the 40 sites were classified into 4 forest classes reflecting the NMS derived moisture gradient, from mesic to xeric forests: deciduous forests and Piedmont loblolly/hardwoods, mixed pine/hardwoods, longleaf pine, and scrub oak – pine savannas. Most sites were mixed pine/hardwoods (N=28). This classification significantly improved the interpretation of the 5 parameter based SCI (SCI5). The mixed pine/hardwoods class possessed a consistent and smooth relationship between SCI5 and the disturbance gradient (Figure 17). Although there were only a small number of sites available, and therefore, the disturbance gradient was limited for the mesic deciduous sites and the xeric savannas; SCI5 provided a clear assessment of site conditions in both of these classes (Figure 16 and Figure 19, respectively). However, the longleaf pine sites did not produce a clear interpretation, DC5 sites had a larger SDI5 than DC2 sites, but a DC7 site had a low value (Figure 18).

Despite the large variety of forest community types among the 40 sites, soil texture did not vary appreciably: 27 sites were loamy sand, 10 were sandy loam, and 3 were sand. An SCI5 analysis on the separation of sites into sandy and sandy loam was not informative (Figure 20 and Figure 21).

The best fit between a SCI and the 10 disturbance classes was based on only two parameters, A-horizon depth and soil compaction. However, the SCI based on five parameters (SCI5) provided the best “overall general assessment” of site disturbance condition. A-horizon depth as a stand-alone parameter was very effective at portraying the disturbance gradient, and this metric appeared to be the foundation for developing multi-metric SCIs for assessing landscape disturbance classes. The effectiveness of the SCI to assess disturbance classes was significantly improved by first classifying the upland forest communities into “forest moisture classes,” instead of applying it to all combined forest community types. The forest moisture classes were derived from cluster analysis and non-metric multidimensional scaling ordination of sites based on tree species basal areas.

These initial results in developing a Site Comparison Index from a very broad, complete, and essentially continuous disturbance gradient; and a wide variety of upland forest communities at Fort Benning are encouraging, and a great deal has been learned in this analysis. Nevertheless, the Fort Benning upland forests represent only a small portion of the Southeast landscape, and most of the sites are mixed pine/hardwoods on sandy soils. This is, however, an extremely common general forest setting across the region, and it would be desirable to examine mixed pine/hardwoods forests in other geographical contexts in the Southeast. Although the results in more mesic and more xeric forests are based on small samples and narrower disturbance gradients, the general results paralleled those in mixed pine/hardwoods forests. Nevertheless, additional data is required to validate these initial conclusions. However, the longleaf pine forest sites produced anomalous results, possibly because of small sample size. Clearly, additional samples are required for this important, but rapidly disappearing Southeast community type. In order to develop an optimal SCI, it is necessary to acquire additional data on a greater variety of forest communities throughout the entire geographic range of Southeast forests. There is also the need for assessing the SCI in different soil textures, especially clayey soils.

References

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

Belnap, J. 1998. Choosing indicators of natural resource condition: A case study in Arches National Park, Utah, USA. Environmental Management 22:635-642.

Bryce, S.A., R.M. Hughes, and P.R. Kaufmann. 2002. Development of a bird integrity index: Using bird assemblages as indicators of riparian condition. Environmental Management 30:294-310.

Ellis, S., and A. Mellor. 1995. Soils and Environment. Routledge, New York, NY. 364pp

Franklin, S.E. 2001. Remote Sensing for Sustainable Forest Management. Lewis publishers, Boca Raton, FL. 407pp

Hobbs, R.J., and H.A. Mooney, eds. 1990. Remote Sensing of Biosphere Functioning. Springer-Verlag, New York, NY. 312pp

Karr, J.R., and E.W. Chu. 1999. Restoring Life in Running Waters: Better Biological Monitoring. Island Press, Washington D.C. 206pp.

Kovacic, D.A., A.J. Krzysik, M.P. Wallace, J.C. Zak, D.C. Freeman, J.H. Graham, H.E. Balbach, J.J. Duda, and J.M. Emlen. 2004. Soil mineralization potential as an ecological indicator of forest disturbance. In review.

Krzysik, A.J. 1987. Environmental Gradient Analysis, Ordination, and Classification in Environmental Impact Assessments. USA-CERL Technical Report N-87/19. 121pp

Lausch, A., and F. Herzog. 2002. Applicability of landscape metrics for the monitoring of landscape change: Issues of scale, resolution and interpretability. Ecological Indicators 2:3-15.

McCune, B., and M.J. Mefford. 1999. PC-ORD. Multivariate Analysis of Ecological Data, Version 4.25. MjM Software Design, Gleneden Beach, OR.

Niemi, G.J., and M.E. McDonald. 2004. Application of ecological indicators. Annual Review of Ecology, Evolution, and Systematics 35:89-111.

Romesburg, H.C. 1984. Cluster Analysis for Researchers. Wadsworth, London.

Sellers, P.J. 1994. A global 1-degrees-by-1-degrees NDVI data set for climate studies. 2. The generation of global fields of terrestrial biophysical parameters from the NDVI. International Journal of Remote Sensing 15:3519-3545.

Sneath, P.H.A., and R.R. Sokal. 1973. Numerical Taxonomy: The Principles and Practice of Numerical Classification. Freeman, San Francisco, CA. 573pp

SPSS. 2003. SPSS software, version 12.0.1. SPSS, Inc., Chicago, IL.

Tamhane, A.C. 1979. A comparison of procedures for multiple comparisons of means with unequal variances. Journal of the American Statistical Association 74:471-480.

Turner, M.G., R.H. Gardner, and R.V. O'Neill. 2001. Landscape Ecology in Theory and Practice: Pattern and Process. Springer-Verlag, New York, NY. 416 pp.

Ward, J.H. 1963. Hierarchical grouping to optimize an objective function. Journal of the American Statistical Association 58:236-244.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY) 05-2007	**2. REPORT TYPE** Final	**3. DATES COVERED (From - To)**

4. TITLE AND SUBTITLE
Development of a Site Comparison Index:
Southeast Upland Forests

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Anthony J. Krzysik and Harold E. Balbach

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
PO Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CERL TR-07-12

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Strategic Environmental Research and Development Program
901 North Stuart Street,
Arlington, VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

14. ABSTRACT

The SERDP Ecosystem Management Project (SEMP), a Defense research program hosted by Fort Benning, GA, is a set of related projects examining ecosystem management. Soils, vegetation, and military use aspects are part of a systematic study to assist military installation land managers to weigh demands for sustainable mission use and proactive stewardship. Adaptive management tools will be developed based on relating SEMP research findings to land management concerns and responsibilities. Different research teams, from many universities and U.S. Government laboratories, planned and chose their studies and sites with reference only to this goal. Each team ranked their sites on subjective Low, Medium, High disturbance scales. Later, when teams presented their results, it became clear that there was no consistent way to relate, for example, the different definitions of "medium" across the teams. To create a objective site comparison index (SCI), a combination of metrics: soil A-horizon depth, soil compaction, ground cover, canopy cover, basal area, remote sensed Normalized Difference Vegetation Index, and soil carbon and nitrogen, were evaluated in 2003 and 2004 across a broad disturbance gradient and forest community types at Fort Benning. The results support the application and utility of a SCI, at least in comparable environments.

15. SUBJECT TERMS
Strategic Environmental Research and Development Program (SERDP) ecosystem management land management
range management training lands

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Hal Balbach
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	SAR	45	**19b. TELEPHONE NUMBER (include area code)** (217) 352-6511, ext 6785

NSN 7540-01-280-5500

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18