2002 Annual Report on SEMP Ecological Indicators
PI: Virginia H. Dale, Oak Ridge National Laboratory (ORNL)
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Participants
•Jack Feminella and Kelly Maloney, Department of Biological Sciences, Auburn University — Stream macroinvertebrates
•Thomas Foster, Anthropology Department, Pennsylvania State University — Historical land cover
•Patrick Mulholland, Environmental Sciences Division, Oak Ridge National Laboratory — Aquatic ecology•Lisa Olsen, Environmental Sciences Division, Oak Ridge National Laboratory — Geographic information and landscape analysis
•David White, Aaron Peacock, and Sarah McNaughton, Center for Environmental Technology, University of Tennessee — Soil microbiology
•Virginia Dale, Environmental Sciences Division, Oak Ridge National Laboratory — Terrestrial and landscape indicators, integration

EXECUTIVE SUMMARY

The project is analyzing a suite of indicators that measure changes in ecological condition. The suite that we are examining includes measures of landscape patterns, soil microbial biomass and community composition, terrestrial understory and overstory, and stream conditions (both stream chemistry and aquatic biological integrity).

The landscape metrics for Fort Benning were calculated and analyzed, and an accuracy assessment was conducted. Metrics at the class and landscape level were compiled and analyzed to determine which were the best indicators of ecological change at Fort Benning. A suite of metrics was selected, based upon change through time or ability to differentiate between land cover classes. We found the most useful metrics for depicting changes in land cover and distinguishing between land cover classes at Fort Benning were percent cover, total edge (with border), number of patches, mean patch area, patch area range, CV of patch area, perimeter/area ratio, Euclidean nearest neighbor distance, and clumpiness. An accuracy assessment was performed of the 1999 land cover classification that was created using a July 1999 Landsat ETM image as compared to a 0.5 m digital color orthophoto of Fort Benning taken in 1999. The overall accuracy was found to be 85.6 for the 30 m resolution data. Results and methodology have been documented.

The potential aquatic indicators at Fort Benning have been narrowed to:

- Suspended sediment concentrations (both baseflow and storms) and baseflow (PO_4, DOC) and stormflow (NH_4, NO_3, and PO_4) nutrient concentrations
- Diurnal dissolved oxygen profiles (in-stream metabolism)
- Streambed organic matter content (habitat) and sediment movement dynamics
- Macroinvertebrate populations and communities, including EPT richness, Shannon diversity, Biotic indices, and Bray-Curtis similarity of disturbed and reference streams

The effects of historical land use / disturbance on macroinvertebrates are also being examined. Using remotely sensed imagery from 1974 and 1999 we used the GIS extension ATtILA to estimate areal percentage of 1) bare ground on slopes >3%, 2) successional stage of vegetation (early-regeneration forested land) on slopes >3%, and 3)

road density (km road/km^2 catchment) for each SEMP catchment. These three land use variables were then combined to derive a disturbance index (DI), which was used to rank and compare each catchment's historic and contemporary disturbance level. With these data we are examining the degree to which current measures of biotic water quality relate to historical vs. contemporary disturbance conditions. Preliminary analysis indicated that % silt in the streambed was positively correlated with levels of historical (1974) land use among the catchments. Moreover, relative abundance of macroinvertebrate functional feeding groups also was related to historical land use. These data suggest 1) a legacy of environmental disturbance in Ft. Benning catchments that spans at least 25 yr, and 2) that knowledge of historical land use conditions may be critical in interpreting present-day water quality conditions.

The analyses of our earlier data collected from sites at Fort Benning with five discrete land-use histories were published in two papers in *Ecological Indicators.* In the vegation study, high variability in species diversity and lack of distinctiveness of understory cover led us to consider life form and plant families as indicators of military use. Life form successfully distinguished between plots based on military use. For example, species that are phanerophytes (trees and shrubs) were the most frequent life form encountered in sites that experienced infantry foot traffic training. Analysis of soils collected from each transect revealed that depth of the A layer of soil was significantly higher in reference and infantry foot traffic training areas which may explain the life form distributions. In addition, the diversity of plant families and, in particular, the presence of grasses and composites were indicative of training and remediation history. These results are supported by prior analysis of life form distribution subsequent to other land uses and demonstrate the ability of life form and plant families to distinguish between military uses in longleaf pine forests.

In the second paper we documented that the soil microbial community of a longleaf pine ecosystem at Fort Benning, Georgia responds to military traffic. Using the soil microbial biomass and community composition as ecological indicators, reproducible changes showed increasing traffic decreases soil viable biomass, biomarkers for microeukaryotes and Gram-negative bacteria, while increasing the proportions of aerobic Gram-positive bacterial and actinomycete biomarkers. Our results suggest that as a soil is remediated it does not escalate through states of succession in the same way as it descends following military use. We propose to explore this hysteresis between disturbance and recovery process as a predictor of the resilience of the microbial community to repeated disturbance/recovery cycles.

Building upon our first years' work, an experiment is being established in K-11 that is designed to examine how indicators change under experimental disturbances at the K-11 site. Data on of aquatic conditions, soil microbial biology, and understory indicators arfe being collected from the field experiment of disturbance impacts being conducted at K-11. Thinning and burning have been implemented to constitute a "light" land use. We are awaiting the implementation of the "heavy" land use.

Project Publications (those completed in 2002): 4 (2) Journal articles, national or international (published or in press) 1 (1) Journal articles, national or international (in review or submitted) 3 (3) Journal articles, other (in review or submitted) 2 Theses

Presentations: 20 (7) Professional meetings 7 (3) Other meetings

Data entered into the SEMP ECMI Data Repository

Metadata for two historical data sets
Historical witness tree data
Historical land cover GIS coverage.
Baseflow water chemistry data for each SEMP site

FULL REPORT

Our progress in examining each type of indicator is discussed in separate sections below.

Stream Studies

P. J. Mulholland, J. N. Houser, Oak Ridge National Laboratory
and
Jack W. Feminella and Kelly O. Maloney**,** Auburn University

Stream chemistry

Additional baseline sampling of the K11 planned experimental stream sites was conducted in anticipation of the thinning disturbance planned for autumn. This work consisted of baseflow and storm chemistry sampling and measurement of diurnal dissolved oxygen profiles. We began analysis of the stream chemistry and metabolism data collected to date to identify which measurements were most promising as indicators of disturbance effects. It appeared that baseflow and storm suspended sediment concentrations, baseflow phosphate concentrations, benthic organic matter content, and the maximum diurnal dissolved oxygen deficit were potentially useful indicators of disturbance effects at the catchment scale. A summary of these analyses was presented in a talk at the Ecological Society of America annual meeting in August in Tucson, AZ.

Macroinvertebrate Sampling

Collection of Hester-Dendy (HD) samplers for 9th sampling season (Summer 2002) was conducted. Water samples for nutrient, dissolved organic carbon, and ion analyses also were taken. Crest gauge levels were recorded at each site during the HD deployment and collection periods. Sediment cores for organic matter content analysis also were collected from all streams during HD retrieval.

To date, benthic macroinvertebrates from the first 8 seasons (November 1999 through May 2002) have been identified and enumerated, and resultant data files have been compiled into an Access database. The data suggest that many commonly used invertebrate metrics may not be indicative of landscape disturbance in these systems, but that some non-traditional measures may be sensitive enough to detect effects of sedimentation, One promising metric is stream-specific Bray-Curtis similarity to reference streams, which when plotted for all streams against disturbance intensity shows decreasing faunal similarity to the reference streams with increasing disturbance.

Historical Land Use / Disturbance

Using remotely sensed imagery from 1974 and 1999 we used the GIS extension ATtILA to estimate areal percentage of 1) bare ground on slopes >3%, 2) successional stage of vegetation (early-regeneration forested land) on slopes >3%, and 3) road density (km road/km^2 catchment) for each SEMP catchment. These three land use variables were then combined to derive a disturbance index (DI), which was used to rank and compare each catchment's historic and contemporary disturbance level. With these data we are examining the degree to which current measures of biotic water quality relate to historical vs. contemporary disturbance conditions.

Four of the study catchments (streams in compartments D13, K13, K11E, K20) showed an increase in DI from 1974 to 1999, whereas the remaining 4 catchments (streams in compartments F2/3, D12/13, D6, K11W) showed no change. Preliminary analysis indicated that % silt in the streambed was positively correlated with levels of historical (1974) land use among the catchments. Moreover, relative abundance of macroinvertebrate functional feeding groups also was related to historical land use (i.e., lower %'s of shredders and higher collector-gatherers in historically disturbed catchments). These data suggest 1) a legacy of environmental disturbance in Ft. Benning catchments that spans at least 25 yr, and 2) that knowledge of historical land use conditions may be critical in interpreting present-day water quality conditions.

Landscape Indicators - Landscape Analysis

Lisa Olsen and Virginia Dale, Oak Ridge National Laboratory

Metadata were created following SEMP standards for two historical data sets and submitted the historical witness tree data and the continuous historical land cover GIS coverages into the SEMP ECMI Data Repository. Data and documentation are available under the "Land Status" data category.

An accuracy assessment was performed of the 1999 land cover classification that was created using a July 1999 Landsat ETM image. The assessment quantified the overall accuracy of the classification by comparing the classified image with a 0.5 m digital color orthophoto of Fort Benning taken in 1999. Approximately fifty points per land cover class were examined. The overall accuracy was found to be 85.6 for the 30 m resolution data.

New landscape metrics were computed using the latest release of FRAGSTATS and AtTILA. Metrics at the class and landscape level were compiled and analyzed to determine which were the best indicators of ecological change at Fort Benning. A suite of metrics was selected, based upon change through time or ability to differentiate between land cover classes. We found the most useful metrics for depicting changes in land cover and distinguishing between land cover classes at Fort Benning were percent cover, total edge (with border), number of patches, mean patch area, patch area range, CV of patch area, perimeter/area ratio, Euclidean nearest neighbor distance, and clumpiness. Results and methodology have been documented in a manuscript delivered to SEMP and that will be submitted to *Landscape Ecology* after review by two independent landscape ecologists and the Benning staff.

Vegetation Indicators

Virginia Dale, Oak Ridge National Laboratory

The analyses of our earlier data collected from sites at Fort Benning with five discrete land-use histories were published in *Ecological Indicators.* A total of 137 plant species occurred in these transects with the highest diversity (95 species) in infantry foot traffic training areas and the lowest (16 species) in plots with tracked vehicle training. Forty-seven species were observed in only one of the five disturbance categories. The variability in understory vegetation cover among disturbance types was trimodal ranging from less than 5% cover for areas with regular tracked vehicle use to 67% cover for reference, infantry foot traffic, and remediated areas. High variability in species diversity and lack of distinctiveness of understory cover led us to consider life form and plant families as indicators of military use. Life form successfully distinguished between plots based on military use. Species that are phanerophytes (trees and shrubs) were the most frequent life form encountered in sites that experienced infantry foot traffic training. Therophytes (annuals) were the least common life form in reference and foot traffic training areas. Chamaephytes (plants with their buds slightly above ground) were the least frequent life form in remediation sites. Sites with regular tracked vehicle use supported no chamaephytes or hemicryptophtes (plants with dormant buds at ground level). The tracked vehicle, remediated, and reference sites were all dominated by cryptophytes (plants with underground buds) possibly because of their ability to withstand both military use and ground fires (the natural disturbance of longleaf pine forests). Analysis of soils collected from each transect revealed that depth of the A layer of soil was significantly higher in reference and infantry foot traffic areas which may explain the life form distributions. In addition, the diversity of plant families and, in particular, the presence of grasses and composites were indicative of training and remediation history. These results are supported by prior analysis of life form distribution subsequent to other land uses and demonstrate the ability of life form and plant families to distinguish between military use in longleaf pine forests.

The analysis of our earlier data collected from sites at Fort Benning with five discrete land-use histories was published in *Ecological Indicators.* Building upon that work, the K-11 experiment is designed to examine how these vegetation indicators change under experimental disturbances at the K-11 site.

Understory and overstory plant data, depth of A horizon, and data on changes in soil erosion pins were collected from the K-11 experimental plots in October 2002. These plots were previously sampled in the October 2001 and burned in May 2002. Thinning of the plots occurred in October 2002. A larger military disturbance for half of the plots is also being planned, and then the plots will be resampled in the fall of 2003.

Methods

Four transects were set up in the K11 section of Fort Benning, Georgia. Each transect had a number of plots placed along it at fifteen-meter intervals between each plot's center. Each plot had a five meter radius, based upon the equilibrium of a species area curve developed for an undisturbed long leaf pine forest at Fort Benning.

Within each plot, a number of measurements were recorded. The soil's A horizon depth was recorded to the nearest millimeter. To measure the canopy cover of the plot, a concave densiometer was used on four corners of the circular plot, approximately at right angles to each other. The four readings were recorded, and their average derived. A tree corer was used to determine the approximate age of the stand, based on the number of rings of the largest trees in the plot. Each tree larger than 5 cm in the plot was measured at Diameter Breast Height (DBH) for circumference. To record any erosion of the soil, pieces of re-bar were driven into the boundary of several quadrats, and measured from their top to the soil. Erosion or sedimentation of soil will be noted in the next measurement.

Current results

Site A will be subjected to "light" disturbance and site B will have "heavy" disturbance so it is important to know the differences between these sites. When the data for each plot is compared as a whole, one can see that the understory vegetation in the A1 and A2 plot were dominated by chameaphytes (over 50%), whereas the vegetation in the B1 and B2 plots have phanaerophytes as their dominant life form. In all four plots, however, the hemicryptophytes were the least populous (by percent of the current vegetation's cover).

As for the plant families, holly was the largest group in terms of overall cover for three of the four stands. A1 had 69% of understory vegetation cover in Aquifoliaceae, B2 had 37% (but with Graminae a close second at 32%), and A2 had 34%. Hamamelidaceae, or sweetgum, dominated the B1 plot by 25%.

All four stands had a larger cover of litter than they did of bare ground or vegetation. Stands A1 and A2 had a slightly higher level of total vegetation than bare ground, and B1 and B2 had a much higher level of vegetation than bare ground. Since Aquifoliaceae dominated A1 and A2, it stands to reason that the non-deciduous foliage would help keep the ground free from leaf litter in the autumn.

When one takes the overall highest categories into account, one can make a rough overview of the Ft. Benning K11 area. Most often chameaphytes and phanaerophytes were the dominant life form. Few to no annuals were present. The main understory plant families were Aquifoliaceae or Hamamelidaceae (holly and sweetgum), and the ground was mostly covered in leaf litter. The canopy cover was around 26%, and the soil's depth to the A horizon averaged 16 mm deep. The average age of the trees recorded was about 45 years, and their average girth was 22.9cm at diameter breast height. Thus, the average tree ring change per year is 5.09mm.

Soil Microbiology

David C. White and Aaron Peacock,
The University of Tennessee Center for Biomarker Analysis

Military activity causes loss of soil structure and organic carbon, reducing microbial and enzymatic activities. We documented that the soil microbial community of a longleaf pine ecosystem at Fort Benning, Georgia responds to military traffic. Using the soil microbial biomass and community composition as ecological indicators, reproducible changes showed increasing traffic decreases soil viable biomass, biomarkers for microeukaryotes and Gram-negative bacteria, while increasing the proportions of aerobic Gram-positive bacterial and actinomycete biomarkers. Utilizing 17 PLFA variables that differed significantly with land usage, a discriminant analysis with cross-validation classified the four groups. Wilks' Lambda for the model was .032 ($P<.001$). Overall, the correct classifications of the profiles was 66% (compared to the chance that 25% would be correctly classified). Using this model, ten observations taken from the remediated transects were classified. One observation was classified as a reference, three as light trafficked, and six as moderately trafficked. A non-linear Artificial Neural Network analysis (ANN) was performed using the biomass estimates and all of the 61 PLFA variables. The resulting ANN included five hidden nodes and resulted in an r^2 of 0.97. The prediction rate of profiles for this model was again 66%, and the ten observations taken from the remediated transects were classified with four as reference, two as occasional tracked vehicle use, and four as regular tracked vehicle traffic. Although the ANN included more comprehensive data, it classified eight of the ten remediated transects at the usage extremes (reference or tracked vehicle traffic). Inspection of the novelty indexes from the prediction outputs showed that the input vectors from the remediated transects were very different from the data used to train the ANN. This difference suggests that as a soil is remediated it does not escalate through states of succession in the same way as it descends following military usee. We propose to explore this hysteresis between disturbance and recovery process as a predictor of the resilience of the microbial community to repeated disturbance/recovery cycles.

Samples that were collected during the previous trip to Ft. Benning have been extracted and fractionated into neutral, glyco, and polar lipid fractions. As with the first set of samples the polar lipid will be transesterified and analyzed via GC. Recently this laboratory has optimized the analysis of quinones via LC/MS/MS and the neutral lipid from the Ft. Benning samples will be analyzed for quinones. The quinone analysis should provide insights into the community structure and dominant terminal electron accepting status of the soil microbes. Selected samples from this set have been set aside for T-RFLP analysis to ascertain if genetic data will correlate with that generated from the lipids from the transects.

Samples were collected during October 2002 from plots established in the K-11 experimental site. These soils are in cold storage pending their extraction and fractionation into neutral, glyco, and polar lipid fractions. These data will be compared to the earlier samples in order to asssess how the fire has affected community structure and dominant terminal electron accepting status of the soil microbes. Selected samples are being set aside for T-RFLP analysis to ascertain if genetic data will correlate with that generated from the lipids from the transects.

Products of SERDP "Ecological Indicators" Project

<u>Papers:</u>

Beyeler, S.C. 2000. Ecological indicators. Master's thesis. University of Miami in Ohio.

Black, B.A., H. T. Foster, and M.D. Abrams. In press. Combining environmentally dependent and independent analysis of witness tree data in east-central Alabama. Canadian Journal of Forest Research.

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

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.

Foster, H.T., II. 2001. Long term average rate maximization of Creek Indian residential mobility a test of the marginal value theorem. Ph.D. dissertation, Department of Anthropology, Pennsylvania State University.

Foster, H.T., II and Abrams, M.D. In review. Physiographic analysis of the pre-European settlement forests in east-central Alabama. Canadian Journal of Forest Research.

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

Posters:

Dale, V.H. and Beyeler, S.C. Ecological indicators: Tools for ecosystem management. SERDP Symposium, Dec. 1999, Washington, DC

Dale, V.H. Ecological indicators. Workshop on Ecological Models for Resource Management. Oct. 2000, Oak Ridge TN.

Dale, V.H., Feminella, J., Foster, T., Mulholland, P., Olsen, L., Peacock, A., White, D. "Ecological indicators for land management. Ecological Society of America Annual Meeting, Aug. 2001, Madison, WI.

Dale, V.H., Feminella, J., Foster, T., Mulholland, P., Olsen, L. Selecting a suite of ecological indicators for land management. SERDP Symposium, Dec. 2001, Washington, DC

Maloney, K.O., J.W. Feminella, and P.J. Mulholland. Effects of watershed disturbance on macroinvertebrate communities in small streams at Fort Benning, GA. 2002 North American Benthological Society, Pittsburgh, PA.

Dale, V.H., Feminella, J., Maloney, K., Mulholland, P., Olsen, L, Peacock, A., and White, D. Tools for resource management. SERDP Symposium, Dec. 2002, Washington, DC

Presentations (in addition to the many presentation made at internal SEMP meetings)

Dale, V.H. Views from the Ridge: Considerations for Planning at the Landscape Scale, sponsored by the Pacific Northwest Research Station, USDA Forest Service, Vancouver, Washington, Nov. 2-4, 1999.

Dale, V. H. Symposium on "Urban landscape ecology" at the 15th Annual US Landscape Ecology Symposium, Fort Lauderdale, Fl., April 15-19, 2000.

Dale. V.H. EcoSummit 2000: Integrating the Science. Halifax, Nova Scotia, Canada, June 18-22, 2000.

Dale, V.H. Using indicators for restoration and management. Ohio State University. November 2, 2000.

Dale, V.H. Lessons for Ecosystem Management. Fall Line Workshop. March 6-7, 2001, Aiken, S.C.

Dale, V.H. Use of indicators. Workshop on "Climate Change and Species Survival: Implications for Conservation Strategies," February 19-21, 2001, The World Conservation Union (IUCN) in Gland, Switzerland.

Dale, V.H. "Top Ten Issues in Landscape Ecology" session at the 16th Annual Symposium on Landscape Ecology, Tempe Arizona, April 2001

Dale, V.H. Virginia Polytechnic Institute, Blacksburg, Virginia, April 2001

Dale, V.H. University of Illinois in Chicago, April 2001

Dale, V.H. SERDP SAB, Washington, DC, June 2001

Dale, V.H. SEMP Technical Advisory Committee, Washington, DC, July 2001

Dale, V.H. Workshop on "Community-based Stewardship of Natural Lands" held at the Ecological Society of America Annual Meeting, Madison, WI, August 6, 2001.

Dale, V.H. SEMP Research Coordination Meeting, Columbus, GA, Nov. 2001

Dale, V.H. SEMP Technical Advisory Committee, Washington, DC, April 2002.

Dale, V.H. SEMP Technical Advisory Committee, Columbus, GA October, April 2002.

Dale, V.H. Pardee Symposium on "Geologic and Ecologic Responses to Landscape Disturbances" at the Geological Society of America, October 29, 2002 in Denver, Colorado.

Dale, V.H. Botany Department, University of Tennessee, November 2002.

Dale, V., L.Olsen, and T. Foster. Landscape Patterns as Indicators of Ecological Change at Fort Benning, GA. US International Association for Landscape Ecology 17th annual symposium in Lincoln, Nebraska, April 2002.

Foster, T. "Evolutionary Ecology of Creek Residential Mobility," Southeastern Archaeological Conference, Macon, Georgia, November 2000.

Foster, T. " Witness tree analysis of Native American influences on the distribution of forest trees An example among the Creek Indians of the Southeastern U.S. Society of American Archaeology, Denver, CO, March 20, 2002.

Maloney, K.O., J.W. Feminella, P.J. Mulholland, V. H. Dale and L. M. Olsen. Effects of past and present land use practices on small streams at Fort Benning, Georgia. Ecological Society of America. Tucson, AR, August 2002.

Maloney, K. O., J. W. Feminella, and P. J. Mulholland. Effects of watershed disturbance on macroinvertebrate communities in small streams at Fort Benning, GA. North American Benthological Society, May 29-June 1, 2002, Pittsburg, PA.

Mulholland, P. J., J. N. Houser, J. W. Feminella, and K. O. Maloney. Stream indicators of ecological impacts from military training at Fort Benning, GA. Ecological Society of America, Aug. 4-8, 2002, Tucson, AZ.

Olsen, Lisa M., Virginia Dale, and Thomas Foster. Landscape Patterns as Indicators of Ecological Change at Fort Benning, GA. ESRI User Conference, July 9-13, 2001, San Diego, CA.

White, D.C., Peacock, A.D., S. J. Macnaughton, J. M. Cantu, V. H. Dale. Ninth International Symposium on Microbial Ecology Interactions in the Microbial World, Amsterdam, The Netherlands. "Changes in soil viable microbial biomass and composition reflect disturbance impacts and may serve as quantitative end points for reversibility" (Mo.O59); August 27, 2001.

<u>Papers in preparation:</u>

Foster, H.T., Black, B., and Abrams, M.D. In preparation. Catchment Analysis of Indian-Forest Interaction in central Georgia and Alabama

Black, B., Foster, H.T., II and Abrams, M.D. In preparation. A comparison of techniques for interpreting witness tree data in western Georgia.

Olsen, L.M., V.H. Dale and H.T. Foster. In preparation. Landscape patterns as indicators of ecological change at Fort Benning, GA

Indirect products of SERDP project

<u>Books:</u>

Dale, V.H. and Haeuber, R.A. (editors). 2001. Applying Ecological Principles to Land Management. Springer-Verlag: New York.

Dale, V.H. (editor) 2003. Ecological Modeling for Resource Management. New York: Springer-Verlag.

Forman, RT.,D. Sperling, J. Bissonette, A. Clevenger, C. Cutshall, V.H. Dale, L. Fahrig, R. France, C. Goldman, K. Heanue, J. Jones, F. Swanson, T. Turrentine, and T. Winter. 2002. Road Ecology: Science and Solutions. Island Press.

Chapters:

Dale,V.H.,S. Brown, R. A. Haeuber, N. T. Hobbs, N. Huntly, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone. 2001. Ecological Guidelines for Land Use and Management. Pages 3-36 In (V. H. Dale and R. A. Haeuber, editors). Applying Ecological Principles to Land Management. Springer Verlag: New York.

Dale, V.H. 2001. Applying Ecological Guidelines for Land Management to Farming in the Brazilian Amazon. Pages 213-215 In (V. H. Dale and R. A. Haeuber, editors). Applying Ecological Principles to Land Management. Springer Verlag: New York.

Dale, V. 2003. New directions in ecological modeling for resource management. In Dale, V.H. (editor) Ecological Modeling for Resource Management. New York: Springer-Verlag.

Dale, V. 2003. The value of ecological modeling for resource management. In Dale, V.H. (editor) Ecological Modeling for Resource Management. New York: Springer-Verlag.

Dale, V. H., Fortes, D. T., and Ashwood, T. L. 2002. A landscape transition matrix approach for land management. Pages 265-293 In (J. Liu and W. Taylor, ed.) Integrating Landscape Ecology into Natural Resource Management. Cambridge University Press.

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Hohler, D., T. Ashwood, J. Richardson, L. Olsen, N. Hendrix, and A. Williams. 2003. Effective ecological modeling for use in management decisions: Data Issues. In Dale, V.H. (editor) Ecological Modeling for Resource Management. New York: Springer-Verlag.

King, W.C. and V. Dale. 2003. What in the World Is worth fighting for? Using models for environmental security, In Dale, V.H. (editor) Ecological Modeling for Resource Management. New York: Springer-Verlag.

Noon, B.R. and V.H. Dale. 2002. Broad scale ecological science and its applications. Pages 34-52 In (K. Gutzwiller, ed.) Applying Landscape Ecology in Biological Conservation. New York: Springer-Verlag.

Papers:

Russell, C., Dale, V., Lee, J., Jensen, M.H., Kane, M., Gregory, R. 2001. Experimenting with multi-attribute utility survey methods in a multidimensional valuation problem. Ecological Economics 36: 87-108.

Schiller, A., C. T. Hunsaker, M. A. Kane, A. K. Wolfe, V. H. Dale, G. W. Suter, C.S. Russell, G. Pion, M. Hadley, and V. C. Konar. In press. Communicating ecological indicators to decision-makers and the public. Conservation Ecology.

Harwell, M.A., W. Adams, S.M. Bartell, K.W. Cummins, V. Dale, C. Johnston, F.K. Pfaender, W.H. Smith, T.P. Young, and S. Sanzone. In review. Assessing relative risks to ecological systems. Environmental Management.

Report:

U.S. EPA. 2002. An Science Advisory Board Report: A Framework for Assessing and Reporting on Ecological Condition. Report EPA-SAB-EPEC.