ANNUAL REPORT FOR SEMP ECOLOGICAL INDICATORS PROJECT

PI: Virginia H. Dale, Oak Ridge National Laboratory (ORNL)

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Products

Presentations during this year:

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

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

Virginia Dale attended a workshop on "Climate Change and Species Survival: Implications for Conservation Strategies" on February 19-21, 2001 at the headquarters of The World Conservation Union (IUCN) in Gland, Switzerland. She gave a presentation on the "Use of indicators."

Virginia Dale attended the Fall Line Workshop on March 6-7, 2001 in Aiken, S.C. and gave on talk on "Lessons for Ecosystem Management."

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 Committtee, July 2001

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, August 6, 2001, Madison, WI.

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.

Papers:

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

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., Olsen, L. and Mann, L.K. In review. Contributions of federal lands to protection of endangered and threatened species. Natural Areas Journal.

Dale, V.H. , Beyeler, S.C., and Jackson, B. In review. Understory indicators of anthropogenic disturbance in longleaf pine forests. Ecological Indicators.

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. In review. Soil microbial biomass and community composition along an anthropogenic disturbance gradient within a longleaf pine habitat. Ecological Indicators.

Landscape Patterns as Indicators of Ecological Change

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This research seeks to identify indicators that signal ecological change in intensely and lightly used lands at Fort Benning, GA. Changes in fragmentation through time affect the biological integrity of terrestrial systems. Landscape patterns, therefore, are important indicators of the intensity of military use being enough to jeopardize ecological resources or areas at risk on military installations. The steps involved in landscape characterization include creation of a land-cover database, computation of landscape metrics, and evaluation of changes in those metrics over time. Identification of ecological indicators is an important component of building an effective environmental monitoring system.

Data Preparation

Historical

Historical land survey maps and field notes from the early 1800s were used to create a digital GIS model of the forests covering the Fort Benning area. Although Native Americans had been living in the area for thousands of years, the 1827 model is a reasonable representation of the forests in a pre-western agricultural environment. As such, the map provides baseline conditions for the area currently occupied by the base. Witness tree data, compiled by Thomas Foster, was used to create a continuous land cover map representing vegetation in 1827.

From witness tree locations (point data) to forest cover (continuous data)

Data points representing witness tree locations are often directly plotted to describe presettlement vegetation (Hong et al. 2000). A point coverage, however, does not adequately describe forest cover. To create a continuous vegetative surface, grids or polygon maps must be interpolated from the survey points (Hong et al. 2000, He & Ventura 1995, Brown 1998a & b, White & Mladenoff 1994). ARC INFO 7.2.1™, GRID™, and ArcView 3.2™ software was used to create the land cover map. Non-forest/cleared areas were added after the interpolation process was completed (Fig. 1). These areas represent large Native American settlements. The amount of non-forested land is probably underestimated on the map since the exact locations of smaller settlements are not known. The map shows that pine species dominated the landscape at Fort Benning. While this data is extremely generalized, this conclusion is supported by a separate analysis (Dale et al. in review), which indicates that over 95% of the soils at Fort Benning could support longleaf pine populations.

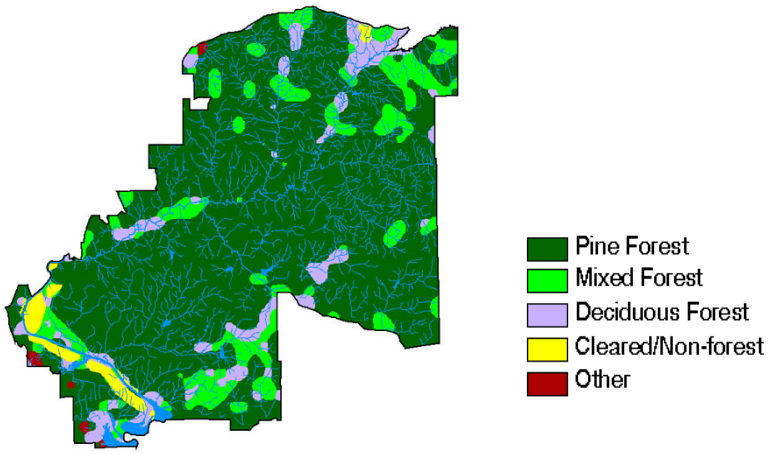

Figure 1. Forest Cover Map of Fort Benning, GA (1827)

Contemporary

Data and resource availability largely determined the time periods and methods chosen for this mapping effort. No aerial or supplemental remote sensing data were readily available to us for the 1827 to 1974 time period. Several data sources used were available for free via the internet or at minimal cost (cost of reproduction) from the United States Geological Survey (USGS). A combination of ARC INFO 7.2.1™, GRID™, ArcView 3.2™, and ERDAS IMAGINE 8.2™ software was used to derive land cover from satellite imagery.

Two Landsat 7 Enhanced Thematic Mapper (ETM) images dated July 24, 1999 and a series of North American Landscape Characterization (NALC) data were used in this analysis (Fig. 2). The NALC project is a component of the National Aeronautics and Space Administration (NASA) Landsat Pathfinder Program. The data are largely derived from Landsat Multispectral Scanner (MSS) imagery and were ordered from the Earth Resources Observation Systems (EROS) Data Center. The NALC data set covering the Fort Benning area is composed of two scenes of triplicates dated 1974, 1983/86, and 1991. Unsupervised classification, which creates a user-defined number of classes based upon spectral response, was utilized to create 45 spectral classes from the imagery. These 45 classes were then combined into six land cover classes using a 0.5 meter resolution digital color orthophoto (1999) and Land Cover Trend Analysis (LCTA) point data (1991) as reference data. The six classes include: water, pine forest, mixed forest (deciduous and pine, areas of sparse forest cover, or areas of transition between forest and non-forest), deciduous forest, non-forest (cleared of forest vegetation but does have some ground cover, may include grassy and transitional areas), and barren/developed. LCTA data was used to evaluate the classes. Results varied due to inconsistencies in scale, definitions of cover types, and the sampling dates of the field data. The ability of this classification to differentiate between forest classes is questionable. Errors of omission in the pine and deciduous classes and of comission in the mixed classes are expected. Specifically, the "mixed forest" class may contain pixels of deciduous forest and pine forest resulting in an underestimation of these classes. Appropriate data were not available to perform a rigorous accuracy assessment. A high level of uncertainty is associated with the classification. The goal of this project, however, is to develop a cost

and time effective tool for land managers at military installations, and not to create a map product. The quality of the classification is open to improvement if more resources become available.

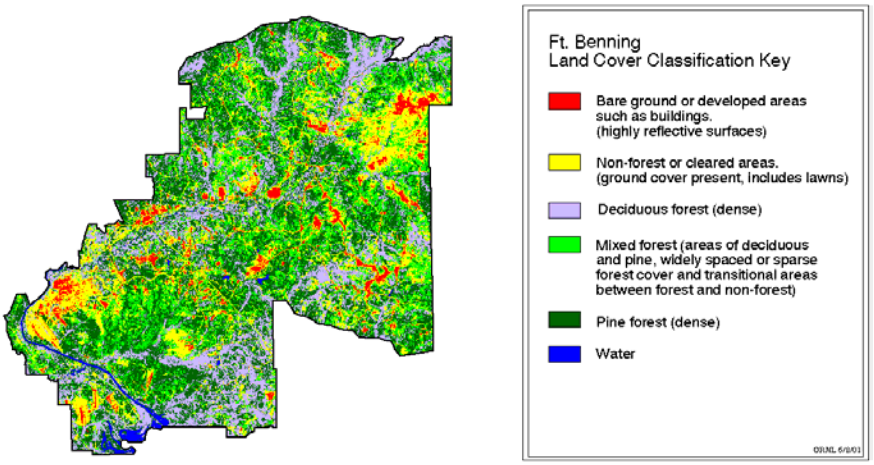

Figure 2. Six Class Land Cover Classification of Fort Benning, GA derived from a July 1999 ETM image

Analysis

Landscape Indicators

Indicators of fragmentation were examined to understand land cover changes at the landscape level. Candidate landscape metrics that describe a diversity of land use types and how they may affect land management activities have been selected for analysis. Examples of landscape characteristics that are typically important include: edge density, contagion, mean nearest neighbor distance, mean proximity index, and perimeter area fractal dimension (O'Neill et al. 1988, Hargis et al. 1998). These metrics largely describe the size, shape, and distribution of relatively homogenous "patches" of vegetation or land cover. Together, these metrics cover a diversity of features describing landscape patterns that can relate to how changes in fragmentation affect the biological integrity of terrestrial systems (e.g., Fahrig and Jonsen 1998). The estimates of landscape metrics uses the 1827 land cover map to provide baseline conditions. Classifications derived from remotely sensed data were assessed to identify changes through time.

Two programs were used to evaluate the land cover maps and calculate landscape metrics. The first is a relatively new suite of tools available in an ArcView extension. The Analytical Tools Interface for Landscape Assessments (ATtILA) was created through a cooperative effort between the Environmental Protection Agency (EPA) and the Tennessee Valley Authority (TVA) (Ebert et al. 2001)., Additional metrics were calculated for each land cover map using the raster version of FRAGSTATS.

<u>Preliminary Results</u>

Presented below are some initial observations taken from a comparison of landscape characteristic output from ATtILA and FRAGSTATS. It is important to note that we cannot conclusively determine which metrics are most valuable as indicators of change and military land use at Fort Benning without a better understanding of the level of

uncertainty associated with the land cover classifications. Errors in the classification may falsely indicate change that is not occurring and may also mask real changes to the landscape.

Land Cover Composition

Fort Benning has experienced a gradual decrease in forest populations coupled with an increase in non-forest vegetation (Table 1). The percentage of non-forest vegetation found on steep slopes (greater than 3%) is also on the rise. Areas of pine forest appear to be increasing, although the magnitude of this increase may be underestimated due to the misclassification of pine pixels into the mixed forest class. Areas of deciduous forest appear to be decreasing; however, caution must be exercised in interpreting these results due to uncertainty associated with the "mixed forest" class. The statistical significance of these numbers is related to uncertainty associated with the classification process.

Table 1. Percentage Land Cover Composition, Fort Benning, GA

Date	Forest %	Pine %	Mixed %	Deciduous %	Barren %	Non-Forest %	Non-forest on steep slopes %
1999	76.231	34.065	21.5371	20.629	4.6059	19.1631	13.9975
1991	77.9872	29.0650	22.9136	25.9187	3.8312	18.2716	13.344
1983/86	80.4795	27.4658	29.8621	23.1516	4.1953	15.3252	11.1388
1974	82.9005	23.9859	23.3856	35.529	3.2056	13.8939	9.3257
1827	97.4475	78.1853	11.7355	11.7355	NA	2.5525	0.5983

The trends in riparian areas are similar (Table 2). ATtILA calculated land cover composition within a 1 pixel buffer zone of streams. Notably, the percentage of forest in riparian zones appears to have decreased between 1974 and 1999, with the rate of change possibly decreasing in the 1990s. The percentage of non-forest and barren cover types in this buffer has increased with a slight decrease of barren areas in the 1990s. These numbers can possibly be related to changes in management practices at Fort Benning in the last decade.

Table 2. Land Cover Distribution in Riparian Areas (60 m buffer of streams)

Date	Forest	Pine	Mixed	Deciduous	Barren	Non-Forest
1999	85.8149	38.4712	16.8006	30.5431	1.7338	12.4513
1991	86.1888	32.0574	22.4120	31.7195	1.9144	11.8967
1983/86	89.3779	27.4933	30.4007	31.4839	1.7922	8.8298
1974	90.6792	27.0853	23.4212	40.1728	1.3079	8.0128

Forest Patch Metrics- ATtILA

When computing patch metrics, the ATtILA software treats all forest classes as a single patch type. Diversity indices such as the Shannon-Weiner index and the Simpson diversity index did not change significantly during between image dates. The number of forest patches present, using one 60 m pixel as the minimum patch size recognized, has been increasing, and the rate of change has increased in the 1990s (Table 3). Average patch size has been decreasing throughout the period of measure. The proportion of largest forest patch to total forest area decreased between 1827 and 1974 and has been slowly increasing in the ensuing decades with a greater increase occurring in the 1990s. Metrics associated with forest fragmentation including pixels identified as patch, transitional, edge, perforated and interior, have changed by orders of magnitude in the

1990s. More exploration of the data and the influence of scale on these metrics needs to be conducted before further conclusions can be drawn. The affect of uncertainty associated with the land cover classifications on these metrics is unknown.

Table 3. Selected Forest Patch Metrics from ATtILA

Metric	1827	1974	1983/1986	1991	1999
# Patches	3	202	238	248	395
Largest patch size	719348400	563396400	541213200	525078000	546213600
Mean Patch Size (ha)	239833200	3000403	2467845.4	2291530.6	1408557
Shannon-Weiner Diversity Index	0.7439	1.4747	1.5203	1.5274	1.6566
Simpson's Diversity Index	0.6312	0.254	0.2381	0.2338	0.22

Landscape metrics- FRAGSTATS

While ATtILA calculated forest metrics without differentiating between forest types, FRAGSTATS used each of the six land cover types as a valid patch class. Inconsistency within the mixed forest class may have skewed the output statistics in the 1980s. Thus, we only include the results for the pine forest and non-forest patch types (Tables 4 & 5). Several landscape level measures showed no statistical difference between maps during the period of analysis. Further research regarding the accuracy of the classifications and the sensitivity of the metric calculations needs to be completed before these measures can be fully evaluated.

Table 4. Selected Class Metrics, Non-Forest Class (from FRAGSTATS)

Metric (NON-FOREST)	**1974**	**1983/86**	**1991**	**1999**
Percent of landscape	13.761	15.152	18.065	18.948
# Patches	1638	1713	2175	3751
Mean Patch Size	6.201	6.529	6.129	3.729
Largest Patch Index %	1.937	2.566	3.431	2.580
Patch Density (#/100ha)	2.219	2.321	2.948	5.082
Total Edge (m)	2520660	2830740	3179940	4080960
Mean Patch Fractal	1.049	1.051	1.044	1.042
Double Log Fractal	1.558	1.561	1.537	1.592
Area-Weighted Mean Fractal	1.210	1.219	1.228	1.214
Interspersion/Juxtaposition %	76.690	70.712	76.062	80.117

Table 5. Selected Class Metrics, Pine Class (from FRAGSTATS)

Metric (PINE FOREST)	**1974**	**1983/86**	**1991**	**1999**
Percent of landscape	23.757	27.155	28.737	33.682
# Patches	3080	5048	3904	3494
Mean Patch Size	5.693	3.971	5.431	7.116
Largest Patch Index %	1.169	3.337	4.261	5.212
Patch Density (#/100ha)	4.173	6.839	5.291	4.733
Total Edge (m)	4290840	5753400	6083280	6464760
Mean Patch Fractal	1.047	1.047	1.051	1.045
Double Log Fractal	1.516	1.581	1.465	1.600
Area-Weighted Mean Fractal	1.186	1.206	1.216	1.266
Interspersion/Juxtaposition %	55.479	51.170	59.625	68.972

The metrics suggest that altered management practices in the 1990s may have resulted in changes to the landscape at Fort Benning, GA. Several trends, such as an increase in non-forested and barren lands in riparian buffers were slowed or reversed in the last

decade. Pine forest, on the other hand, appears to have been increasing in the last ten years. Improved monitoring techniques coupled with an aggressive management strategy for perpetuating pine forest at Fort Benning may have resulted in an increase in pine populations and a decrease in hardwood invasion. This management strategy includes harvesting timber and burning to establish and maintain viable pine communities. While it appears that the percentage of non-forest land has been slowly increasing, the number of non-forest patches has increased tremendously in the last decade. Consequently, the size of these patches has decreased significantly. Altered management has constrained certain land uses to smaller geographic areas. The next step in this process will be to correlate land use and management with the metrics described in this paper.

Summary-Future Research

Once a complete set of metrics have been calculated and evaluated at different scales and with different input parameters, results can be compared and reviewed for change. After examples of significant ecological change have been identified, the investigation of possible causes begins. If connections between landscape change and land use or management can be easily determined, that metric can be used as an ecological indicator to aid land mangers in decision making. Due to the level of uncertainty associated with the land cover classifications, however, these metrics should be interpreted with caution.

Soil Microbial Biomass and Community Composition Along an Anthropogenic Disturbance Gradient Within a Longleaf Pine Habitat

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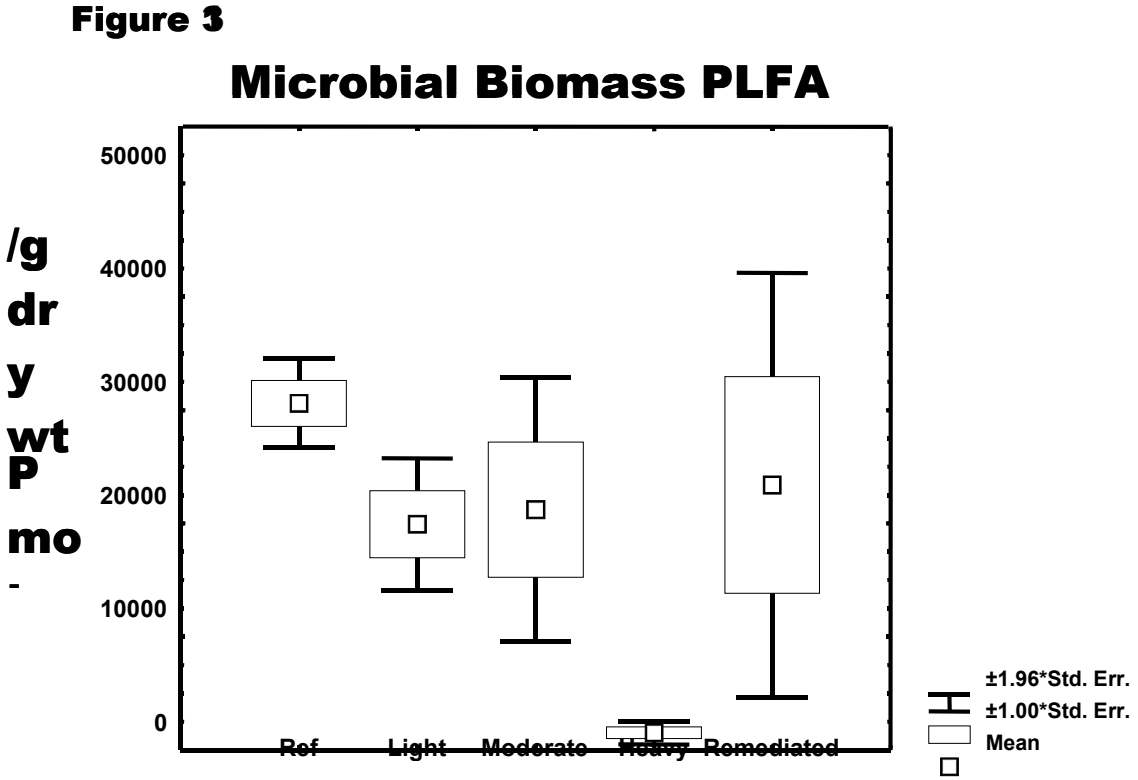
Some of the finest surviving natural habitat in the United States is on military reservations where land has been protected from development. However, responsibilities of military training often require disturbance of that habitat. We have demonstrated that soil microbial community of a longleaf pine ecosystem at Fort Benning, Georgia responds to military traffic disturbances. Using the soil microbial biomass and community composition as ecological indicators, reproducible changes showed increasing traffic disturbance decreases soil viable biomass, biomarkers for microeukaryotes and Gram-negative bacteria, while increasing the proportions of aerobic Gram-positive bacterial and *actinomycete* biomarkers. Soil samples were obtained from four levels of military traffic (reference, light, moderate, and heavy) with an additional set of samples taken from previously damaged areas that were remediated via planting of trees and ground cover. Utilizing 17 phosphlipid fatty acid (PLFA) variables that differed significantly with land usage (Fig. 3), a linear discriminant analysis with cross-validation classified the four groups. Wilks' Lambda for the model was 0.032 ($P<0.001$). Overall, the correct classifications of 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. Non-linear Artificial Neural Network

(ANN) discriminant analysis was performed using the biomass estimates and all of the 61 PLFA variables. The resulting optimal 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 (not impacted), two as moderate, and four as heavily trafficked. Although the ANN included more comprehensive data, it classified eight of the ten remediated transects at the usage extremes (reference or heavy 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 as a soil is remediated it does not escalate through states of succession in the same way as it descends following disturbance. 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.

Figure 3. Microbial biomass PLFA of samples from the four disturbance categories and samples undergoing remediation. The reference samples contain the highest microbial biomass followed by light and moderate disturbance and finally heavy disturbance.



Understory Indicators of Anthropogenic Disturbance in Longleaf Pine Forests

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Environmental indicators for longleaf pine (*Pinus palustris*) ecosystems need to include some measure of understory vegetation because of its responsiveness to disturbance and management practices. To examine the characteristics of understory species that distinguish between disturbances induced by military traffic, we randomly established transects in four training intensity categories (reference, light, moderate, and heavy) and in an area that had been remediated following intense disturbance at Fort Benning, Georgia. A total of 137 plant species occurred in these transects with the highest diversity (95 species) in light training areas and the lowest (16 species) in heavily disturbed plots. 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 heavily disturbed areas to 67% cover for reference, light, 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 disturbance. Life form successfully distinguished between plots based on military disturbances (Fig. 4). Species that are phanerophytes (trees and shrubs) were the most frequent life form encountered in sites that experienced light infantry training. Therophytes (annuals) were the least common life form in reference and light training areas. Chamaephytes (plants with their buds slightly above ground) were the least frequent life form in or moderate and remediation sites. Heavy training sites supported no chamaephytes or hemicryptophtes (plants with dormant buds at ground level). The heavy, moderate, remediated, and reference sites were all dominated by cryptophytes (plants with underground buds) possibly because of their ability to withstand both military disturbance 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 light 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 disturbances and demonstrate the ability of life form and plant families to distinguish between military disturbances in longleaf pine forests.

Stream Indicators

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Stream Chemistry Studies

Two years of data have been collected and analyzed to evaluate whether stream chemistry patterns are useful indicators of disturbances resulting from military training and land management at Fort Benning, Georgia. We are focusing primarily on 1st and 2nd order streams because small headwater streams are usually most strongly influenced by characteristics of the catchments they drain. The field sampling has been confined to the period December through March because it is believed that stream chemistry would be most sensitive to disturbances during the winter and early spring periods when stream discharge is most responsive to rainfall events. Further, stream metabolism and consequently, diurnal dissolved oxygen profiles, were believed to be most responsive to disturbances during the months of February and March prior to emergence of leaves in the deciduous riparian vegetation when light levels reaching streams are highest. The following is a preliminary analysis of results of these studies to date.

Nine streams have been studied to date. Two of these are considered to be reference streams with little apparent disturbance in their catchments (K13, K11W). The other seven streams cover a range of disturbance levels, based on inspection of maps and aerial photos and ground observations. At present we believe that five of these streams (D13, D12, K11E O13, K20) can be considered to have low to moderate levels of disturbance, whereas two streams (F2, D6) appear to have severely disturbed catchments. We have located two sampling locations on the K11E stream to collect the baseline data prior to performing a disturbance experiment in the catchment. We hope to improve our disturbance classification scheme by quantifying land condition in the catchments of each stream based on work currently being performed by the SEMP ECMI group. We anticipate that mapping of several land use categories related to disturbance (e.g., lands denuded of forest vegetation, bare ground, etc) will be available from the ECMI group within several months and these will be used as the basis for deriving quantitative disturbance metrics for each of our catchments.

Baseflow Chemistry Patterns

Baseflow concentrations of suspended sediments, ammonium, nitrate, phosphate, and sulfate were evaluated as disturbance indicators. High suspended sediment concentrations in streams often result from high rates of catchment erosion, and during baseflow are an indication of very unstable stream bottoms prone to sediment resuspension. Ammonium, nitrate, and phosphate are important biological nutrients and concentrations can be elevated as a result of disturbances in catchments. This is particularly true for nitrate concentrations which have been shown to increase sharply in streams with disturbances to terrestrial vegetation. Concentrations of sulfate were thought to be a possible indicator of changes in the dominant hydrologic flowpath. Previous work has suggested that sulfate concentrations may increase when water flow shifts from deeper to more shallow paths as a result of disturbance to the soil surface reducing infiltration rates.

Baseflow suspended sediment concentrations are generally higher in streams draining disturbed catchments, particularly those that are highly disturbed (Fig. 5). However, our data on baseflow nutrient chemistry shows no obvious effect of disturbance (Figs. 6 and 7). Concentrations of ammonium, phosphate, and sulfate were similar between reference and disturbed streams. Concentrations of nitrate (Fig. 6, bottom panel) appeared to be somewhat higher in some of the disturbed streams compared with reference streams, although this effect was not consistent.

Storm chemistry patterns

There was some evidence that storm hydrographs in streams draining disturbed catchments were somewhat more flashy than streams draining reference catchments, particularly for larger rainfall events (Fig. 8). Disturbed catchment streams also had higher peak concentrations of suspended sediments, with the differences between reference and disturbed streams being greater for inorganic sediments that total sediments (Fig. 9). The effect of disturbance on storm sediment concentrations is magnified when sediment concentrations are normalized for fractional maximum discharge increases during storms, particularly in the case of inorganic sediments (Fig. 10). This normalization takes into account the positive effect of storm size on peak sediment concentrations, with higher sediment concentrations increases during the larger storms than during smaller storms in all streams. There is some evidence that peak ammonium and nitrate concentrations during storms are somewhat higher in streams draining disturbed catchments relative to those draining reference catchments (Fig. 11), although very little evidence of an effect of catchment disturbance on maximum storm phosphate and sulfate concentrations (Fig. 12).

Diurnal dissolved oxygen patterns

Diurnal dissolved oxygen profiles can be used as an indicator of rates of metabolism within stream ecosystems, including respiration and gross primary production. After converting dissolved oxygen concentrations to oxygen deficits, the amplitude of diurnal dissolved oxygen deficit profiles may be a good indicator of primary production in streams. In addition, the absolute value of dissolved oxygen deficits may be an indicator of total respiration in streams. We expect that impairment of stream ecological communities as a result of catchment disturbances would have negative effects on stream metabolism. These negative effects should be most pronounced during the late winter and early spring when rates of primary productivity are highest in forested streams and the effects of storms are more pronounced.

A comparison of diurnal dissolved oxygen profiles in a reference stream (K13) and a highly disturbed stream (F2) suggests that these may be a useful disturbance indicator. The absolute value of oxygen saturation deficits and the amplitude of the diurnal deficit profile is considerably lower for the disturbed stream compared with the reference stream (Fig. 13). Analysis of data across our study sites confirms this finding, with lower diurnal amplitudes of changes in oxygen deficit for the disturbed streams relative to the reference streams (Fig. 14). The diurnal amplitude of dissolved oxygen deficits is particularly low for the most highly disturbed streams, F2 and D6.

Stream Macroinvertebrate Studies

Beginning in November 1999, benthic macroinvertebrates and their habitats were quantified from 9 catchments (compartments A17, K11E, K11W, K13, K20, D6, D12, D12/13, F2/3), to assess the degree to which landscape alteration from military training activities affects stream biodiversity and habitat structure. Over this period benthic invertebrate sampling has been conducted approximately seasonally (3 times per year), during January (winter), May (spring), and September (summer-fall). Two methods have been used to quantify invertebrates: 1) Hester-Dendy multiplate samplers collected from 4 stations per stream; and 2) semi-quantitative sweep net samples collected from the upstream and downstream ends of study reaches of each stream. Preliminary analyses indicate that each sampling method contributes unique and useful ecological information about invertebrate assemblages in Ft. Benning streams. Multiplates provide a standardized substrate area that allows estimation of benthic density (e.g., no. of invertebrates per m^2), and thus enables direct density comparisons among sites. In contrast, sweep nets more efficiently capture larger-bodied and/or rarer species occurring within a variety of stream microhabitats, which facilitate comparisons of stream invertebrate assemblage structure (e.g., as total stream richness, dominance, relative abundance) among sites. Taken together, both sampling methods provide a robust means to assess 1) the relationship between sediment disturbance and stream biological communities and, in turn, 2) the efficacy of using benthic macroinvertebrates as ecological indicators of landscape disturbance from military training.

We exchanged sampling of stream sites in compartments A17 and D13, sampled in 2000, with sites in K11E, K11W, and D6 in 2001. Streams in all remaining compartments (i.e., K13, K20, F2/3, D12/13) were sampled both years. In 2001 two sets of sampling stations were established in K11E, the compartment receiving (in 2002) an experimental military intervention: one set of stations was established upstream of the planned intervention and second set was established downstream of the intervention.

Classification of in-stream disturbance regimes

A key element of our analysis is to relate in-stream manifestations of sedimentation with potential sources of sediment occurring in catchments from military land use. If such a terrestrial-aquatic linkage exists and can be quantified, then it is possible to build an empirical model that describes the functional relationship between landscape-level sediment movement, measurable at the catchment spatial scale, and stream biotic community response to sediment inputs. Using this general approach, LANDSAT and digital orthophotograph imagery have been downloaded from the ECMI database, and are being used to characterize and refine our initial disturbance classification levels for each study catchment. We plan to use LANDSAT imagery to classify the amount (as % of each catchment) as unvegetated ground, grassland, pine and deciduous vegetative cover, roaded area, and other continuous landscape variables. The amount of each land cover type will be and combined with slope data (from Digital Elevation Models) to derive our final disturbance classification. Digital orthophotos along with GPS corroboration are being used to ground-truth output of the LANDSAT-based disturbance classification.

Stream habitat characteristics

Streambed Sediment Analysis.—Sediment cores were collected August and September from all streams sampled in 2001. Cores were taken from the streambed at 3 sites per stream, and are being analyzed for organic matter (OM) content and inorganic particle size distribution. Organic matter is being used as a measure of food availability for macroinvertebrates, which may account for much of the variation in invertebrates observed among sites. Inorganic particle size distributions are being used as indicator of disturbance (sedimentation) severity, which in turn may explain additional variation in macroinvertebrate communities. Preliminary data indicated that streams in K13, K11W, and D12/13 showed an average of ~0.3–0.8% OM/dry mass, whereas sites in K11E, K20, D6, and F2/3 showed only 0.1–0.2% OM/dry mass (Fig.15). Although there was some high within-site variation in OM (especially in the F2/3 catchment), there was a general trend of decreased streambed organic matter with increasing catchment disturbance (Fig. 15). Particle size analyses are in progress.

Bedload Sediment Movement.-- Stream sediment movement (accretion, erosion), as measured by changes in bed height recorded on scour pins (4-5 per stream), was higher in catchments receiving moderate to high disturbance from military training than low-disturbance or reference sites (Fig. 16). The streambed in highly disturbed F2/3 ranged from a -92 mm (eroded) to +31 mm (accreted) change from the initial bed position (i.e., absolute change of 123 mm), compared to an absolute bed height change of only ~8mm in the reference site (K13, Fig. 15). Using this measure, beds of reference or low-disturbance catchments appeared more stable than those of moderately or highly disturbed catchments.

Macroinvertebrate indices

Species Richess Metrics.– Total numbers of macroinvertebrate taxa and EPT taxa (i.e., number of taxa within the aquatic insect orders Ephemeroptera, Plecoptera, and Trichoptera) were not altogether useful in differentiating disturbance regimes among catchments (Figs. 17 and 18). Total taxa in the reference catchment (K13) was only slightly higher than richness in the high-disturbance catchment (F2/3). The EPT metric did somewhat better at discriminating the reference (K13) from the highly disturbed site (F2/3), but not in the spring sampling period (Fig. 18). Within a given stream richness usually was slightly higher in winter than in the other 2 seasons (Fig. 17); EPT richness showed this same trend (Fig. 18).

Community Similarity.– The Bray-Curtis similarity index (B_c) was calculated for streams sampled during 2000. This metric computes the average faunal similarity between each pair of streams based on numbers of shared taxa and their relative abundance. Values range from zero, where sites share no species, to 1.0, where all species and their abundances are the same between sites. Preliminary analysis indicates that sites within a disturbance class were generally more similar to each other than to sites in other disturbance classes (Table 1). Similarity values between the 2 reference sites (K13 and A17: B_c =0.52) and the 2 highly disturbed sites (F2/3, K20: B_c=0.57) were the highest observed. In contrast, the lowest similarity (B_c=0.31) occurred between the reference site A17 and the moderately disturbed site D12/13 (Table 1).

Community Tolerance.– All species (taxa) currently are being assigned tolerance values for the North Carolina Biotic Index (NCBI) and the Family Biotic Index (FBI), two widely used water quality indices involving macroinvertebrates. For many taxa unique to the SE Coastal Plains NCBI and FBI tolerance values are unavailable; for these unknown taxa we are developing our own tolerance values based on 1) their taxonomic similarity with other invertebrates having known tolerance values, and 2) consultation with macroinvertebrate water quality specialists (e.g., Dr. David Lenat, North Carolina Division of Water Quality). Once all taxa have been assigned tolerance values we will compute site-specific values and compare them among sites with contrasting sediment disturbance regimes.

Focal Populations.– Total abundance of the sediment-tolerant chironomid midges in the genera *Rheosmittia* and *Lopescladius* quantified over the first 4 seasons (Winter 1999 through winter 2000-01) were consistently higher in 2 of the 3 highly disturbed sites (K20 and F2/3, Fig. 19), and uniformly lower in the reference and moderately disturbed sites (K13, A17, K11W, D12/13). These species were absent in the third highly disturbed site (D6, Fig. 15), however, to date we have analyzed data for only 1 season (winter 2000-01) for this stream. These preliminary data suggest that abundance of these 2 insect taxa may be a useful indicator of high sediment disturbance in streams at Ft. Benning.

References

Bourdo, E.A., Jr. 1956. A review of the General Land Office Survey and its use in quantitative studies of former forest. Ecology 37: 754-768.

Brown, D.G. (1998a) Mapping historical forest types in Baraga County Michigan, USA as fuzzy sets. Plant Ecology, 134, 97-111.

Brown, D.G. (1998b) Classification and boundary vagueness in mapping presettlement forest types. International Journal of Geographical Information Systems, 105-129.

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

Ebert, Donald, Timothy Wade, James Harrison and Dennis Yankee. 2001. Analytical Tools Interface for Landscape Assessments (ATtILA) User Guide- Version 2.9. DRAFT

Foster, H. Thomas. 2001. Behavioral Ecology of Creek Indian Residential Mobility. Ph. D. Dissertation, Department of Anthropology, Pennsylvania State University.

Foster, HT, II, and Abrams, MD. In review. Physiographic analysis of the pre-European settlement forest in east-central Alabama. Canadian Journal of Forest Research.

Godfrey, Robert K. 1988. Trees, shrubs, and woody vines of northern Florida and adjacent Georgia and Alabama. University of Georgia Press, Athens.

Hong, S. He, David J. Mladenoff, Theodore A. Sickley and Glenn G. Guntenspergen. 2000. GIS interpolations of witness tree records (1839 – 1866) for northern Wisconsin at multiple scales. Journal of Biogeography 27: 1031-1042.

He, H.S. & Ventura, S.J. 1995. Apostle Islands vegetation coverage-a GIS framework. Symposium of International Society for Photogrammetry and Remote Sensing, pp. 59-68. Commission IV, Mapping and Geographical Information Systems, Madison, WI.

Kane, S. and Keeton, R. 1998. Fort Benning: the land and the people. Southeast Archeological Center, National Park Service. Tallahassee, Florida.

Leslie, M., G.K. Meffe, J.L. Hardesty, and D.L. Adams. 1996. Conserving Biodiversity on Military Lands: A Handbook for Natural Resources Managers. The Nature Conservancy, Arlington, Virginia.

McGarigal, Kevin,, & Barbara J. Marks. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Rep. PNW-GTR-351. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 122 p.

O'Neill, RV, Krummel, JR, Gardner, RH, Sugihara, G., Jackson, B., Dangelis, DL., Milne, BT, Turner, MG, Zygmunt, B., Christensen, SW, Dale, VH. And Graham, RL. 1988. Indices of landscape pattern. Landscape Ecology 1: 153-162.

White, M.A. & Mladenoff, D.J. 1994. Old-growth forest landscape transitions from pre-European settlement to present. Landscape Ecology 9, 191-205.

Whitney, Gordon G. 1994. From coastal wilderness to fruited plain: a history of environmental change in temperate North America 1500 to the present. Cambridge University Press, Cambridge.

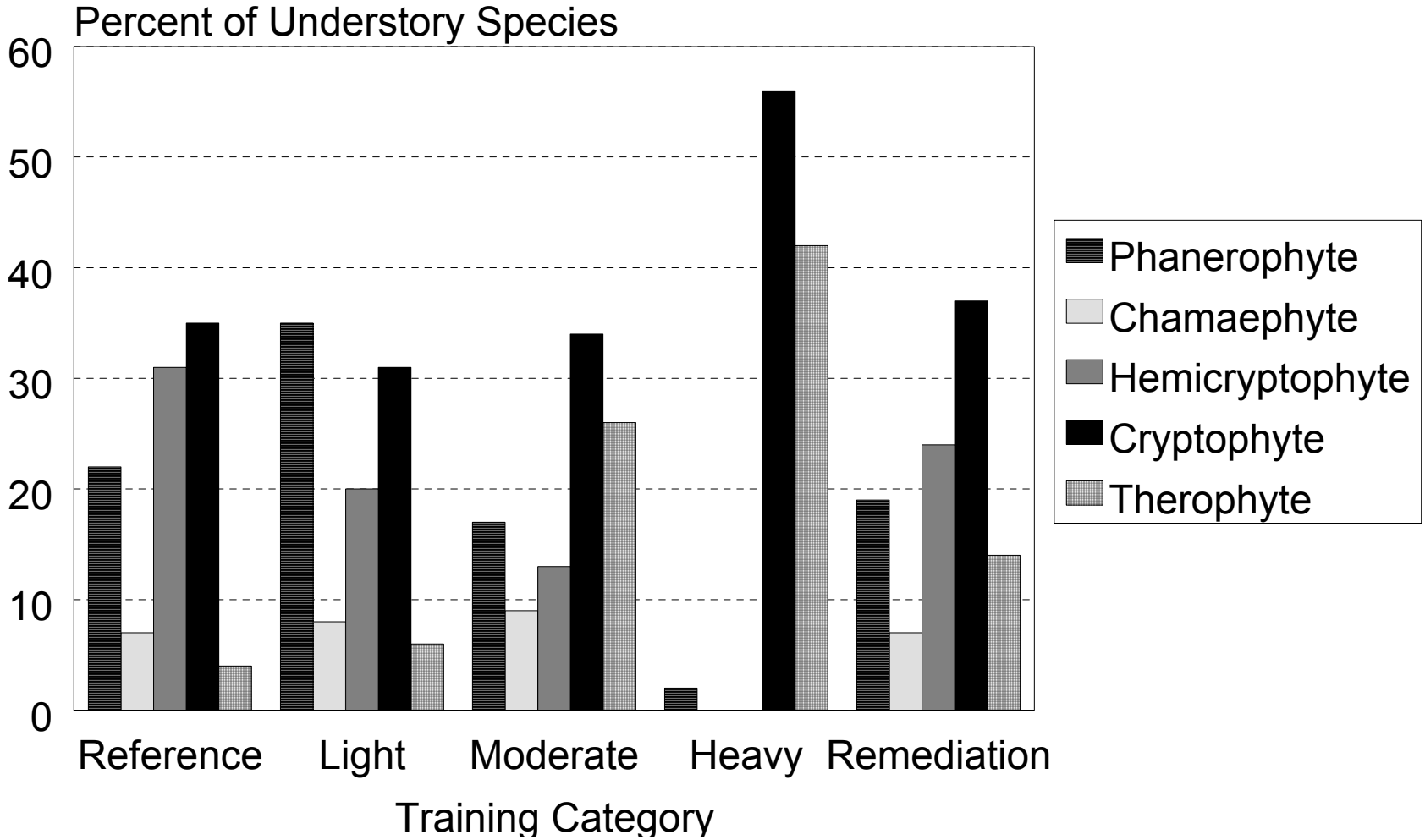


Figure 4. Life form distribution of understory plants under five training conditions.

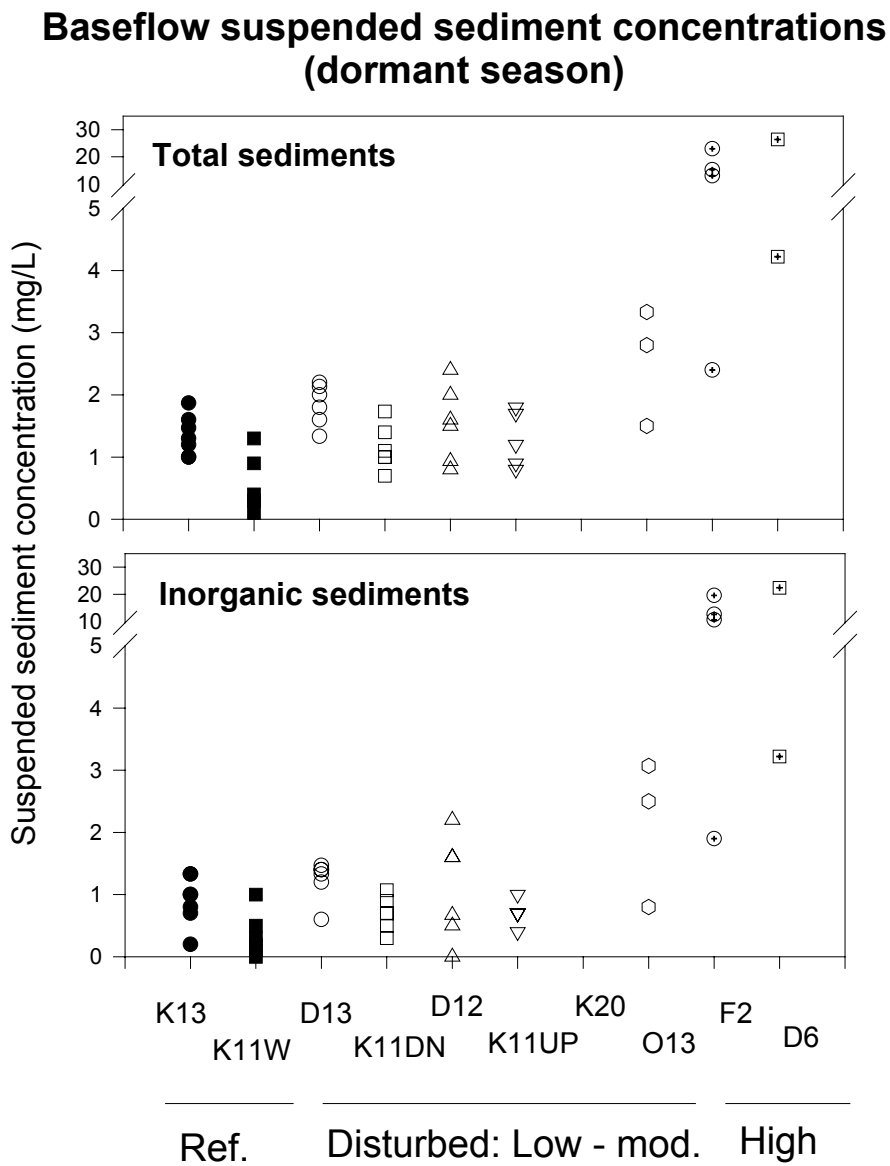


Figure 5. Suspended sediment concentrations during baseflow periods, December through March

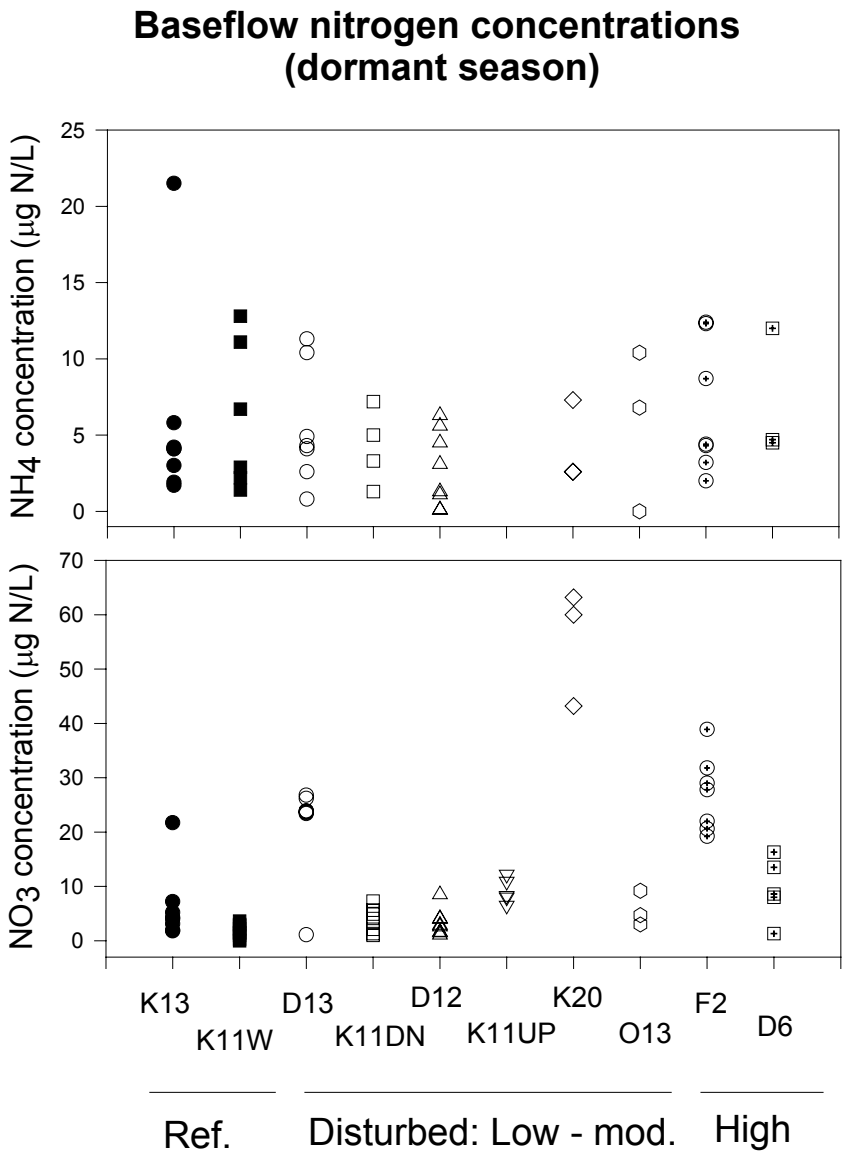


Figure 6. Dissolved nitrogen concentrations during baseflow periods, December throug
March.

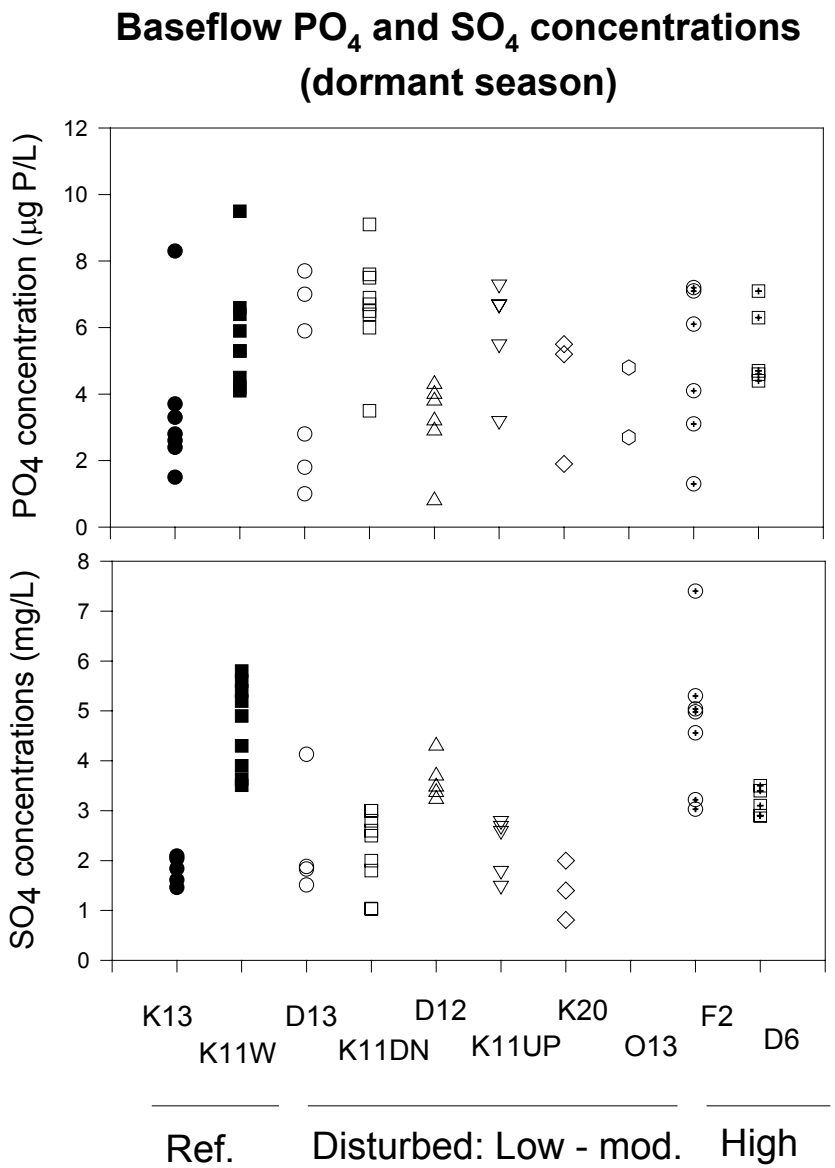


Figure 7. Dissolved phosphorus and sulfate concentrations during baseflow periods, December through March

Storm hydrographs of disturbed streams tend to be "flashier"

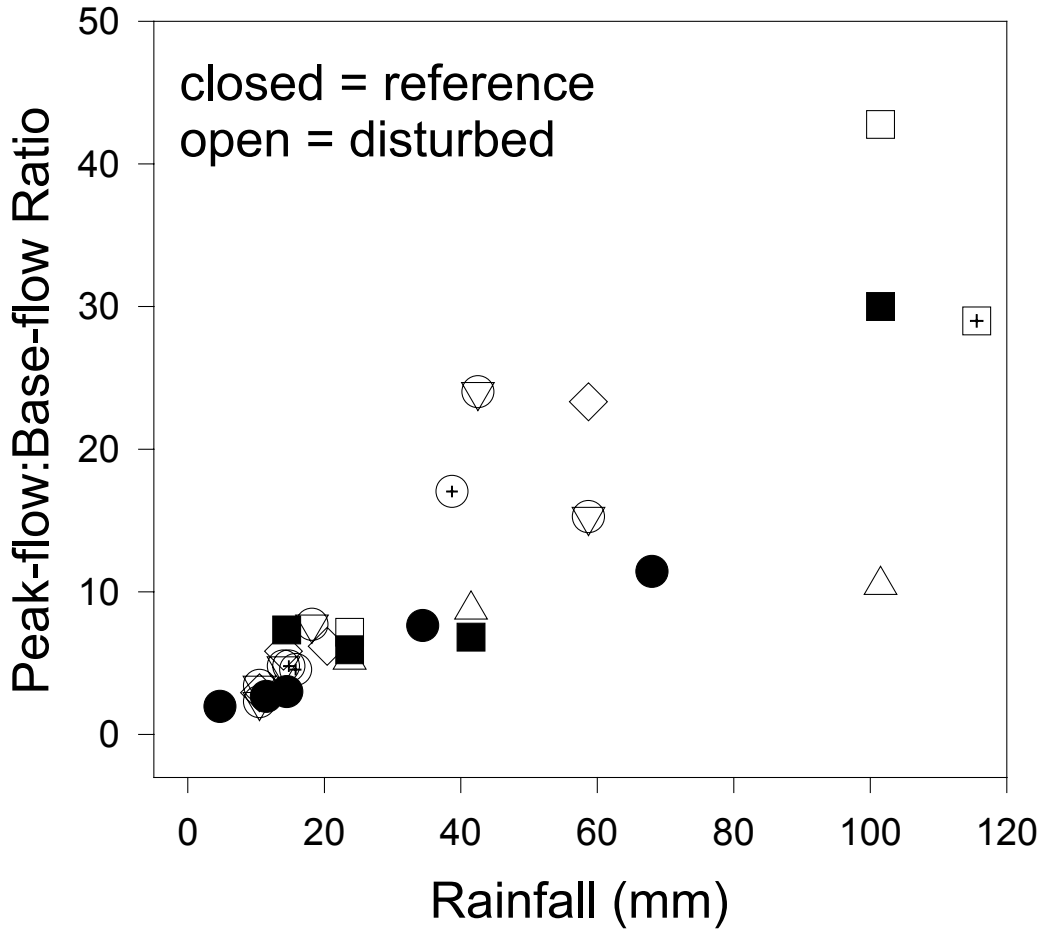


Figure 8. Relationship between peak-flow:base-flow ratios and rainfall amounts during storms, December through March

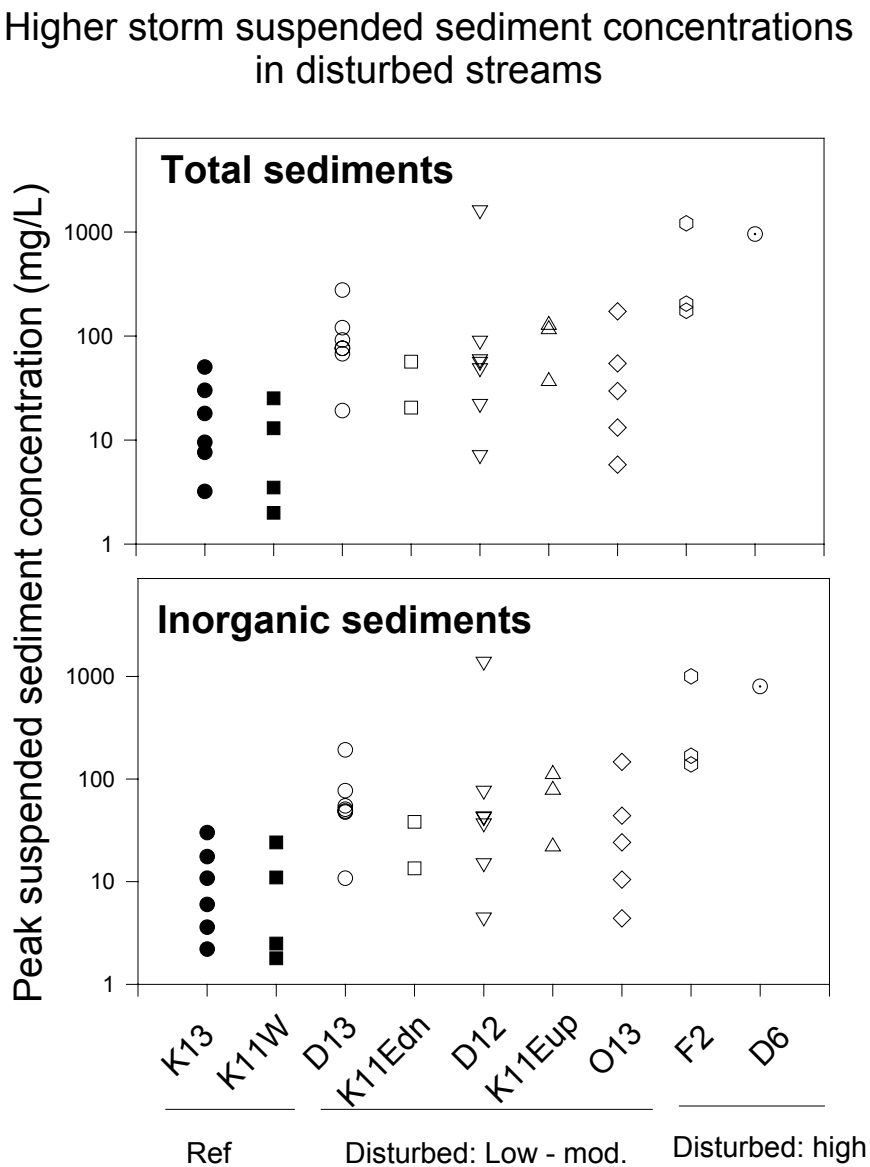


Figure 9. Peak suspended sediment concentrations during storms, December through March, versus disturbance level

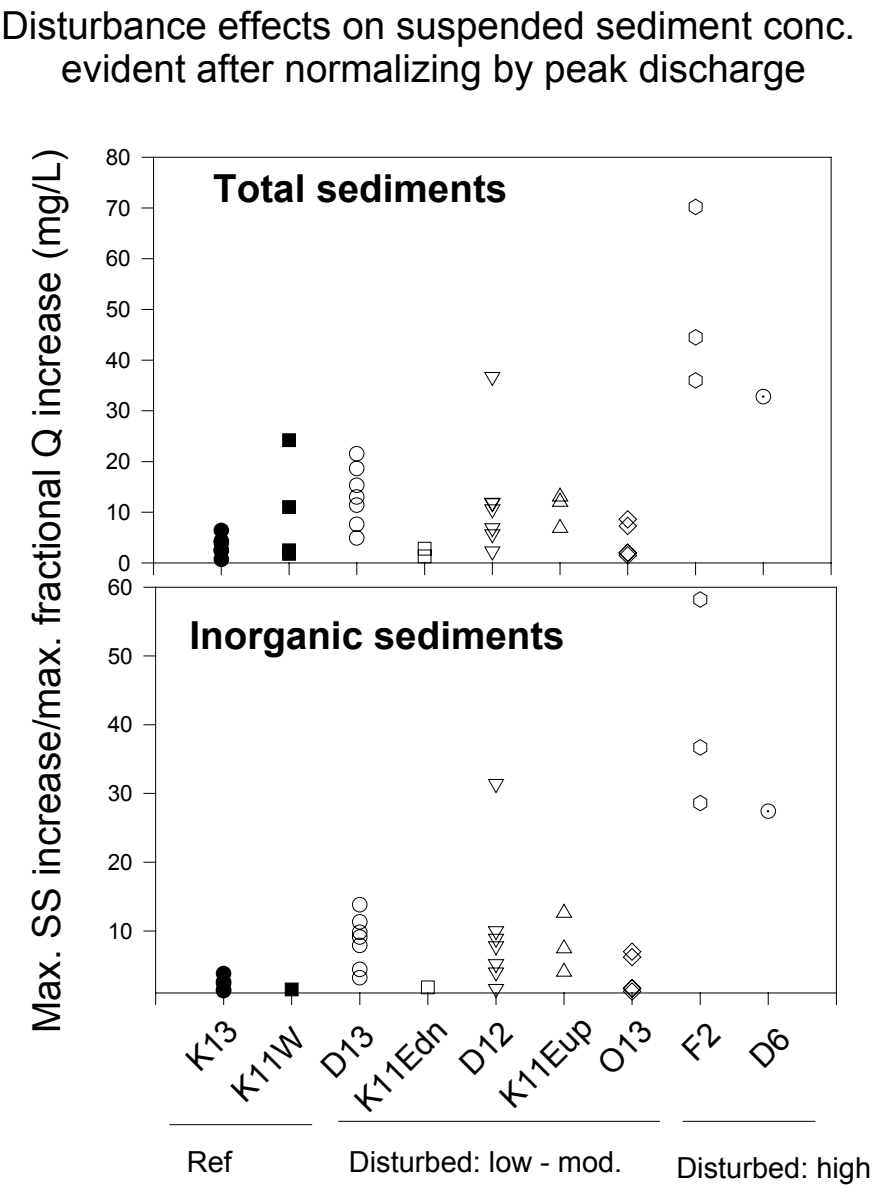


Figure 10. Peak suspended sediment concentrations normalized by the maximum fractional increase in discharge during storms (December – March) versus disturbance level.

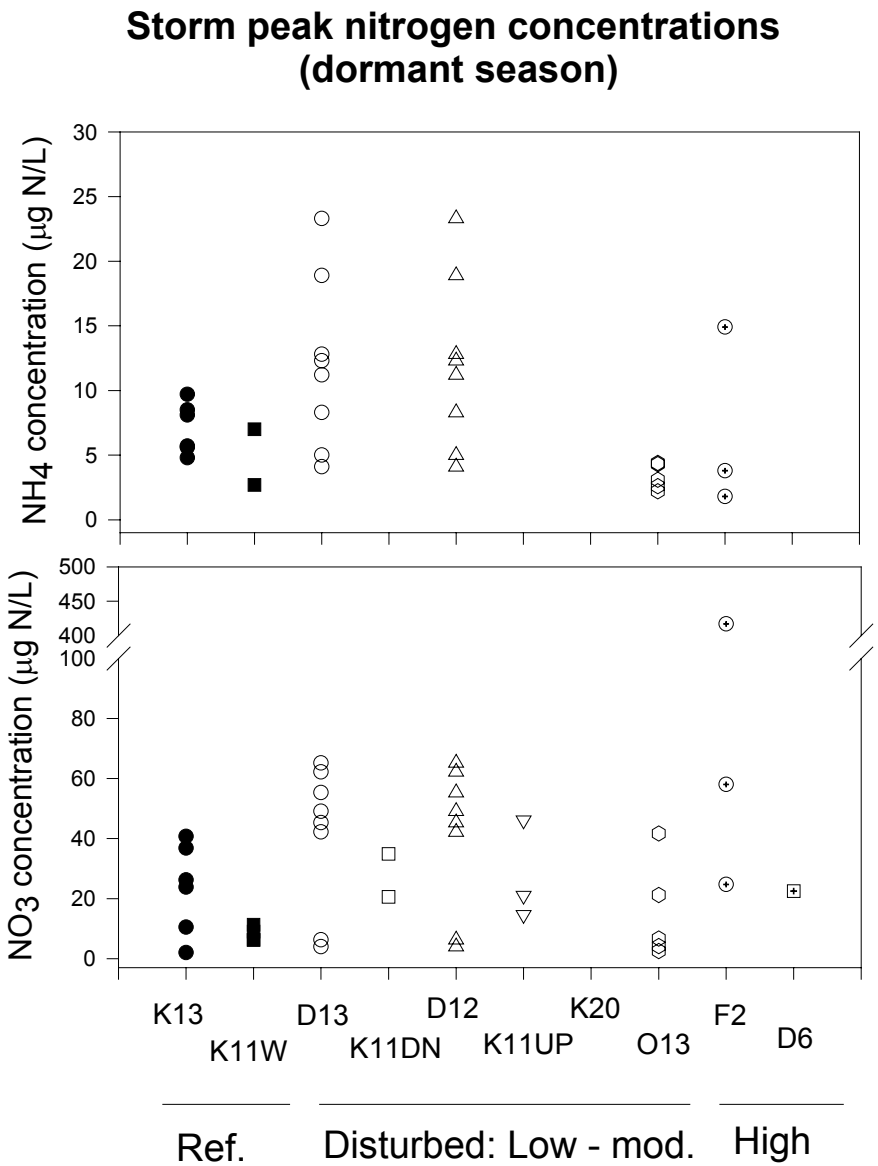


Figure 11. Peak dissolved nitrogen concentrations during storms, December through March, versus disturbance level

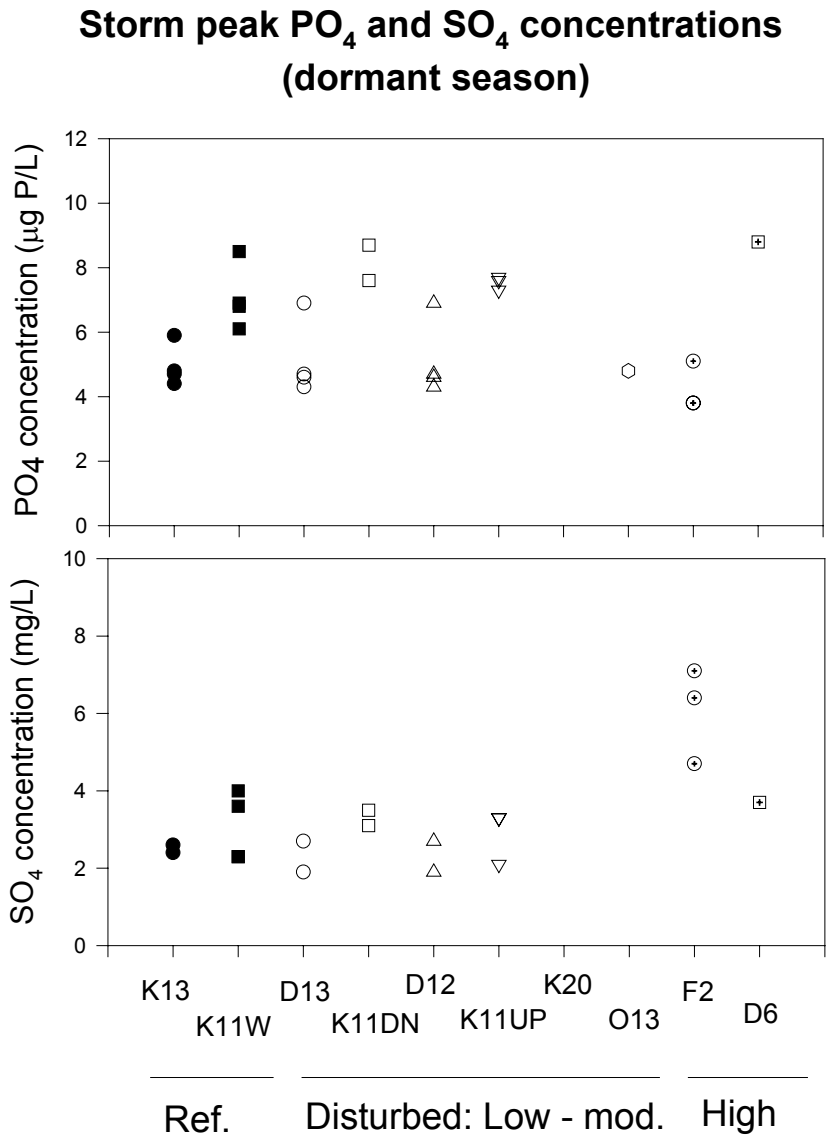


Figure 12. Peak dissolved phosphorus and sulfate concentrations during storms, December through March, versus disturbance level.

Dissolved Oxygen Profiles (8 Mar 2000)

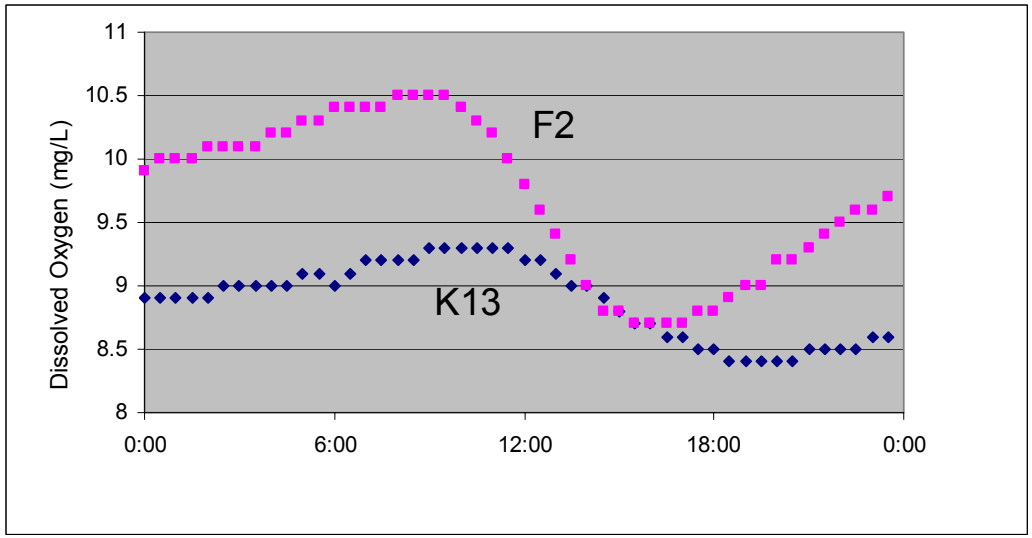
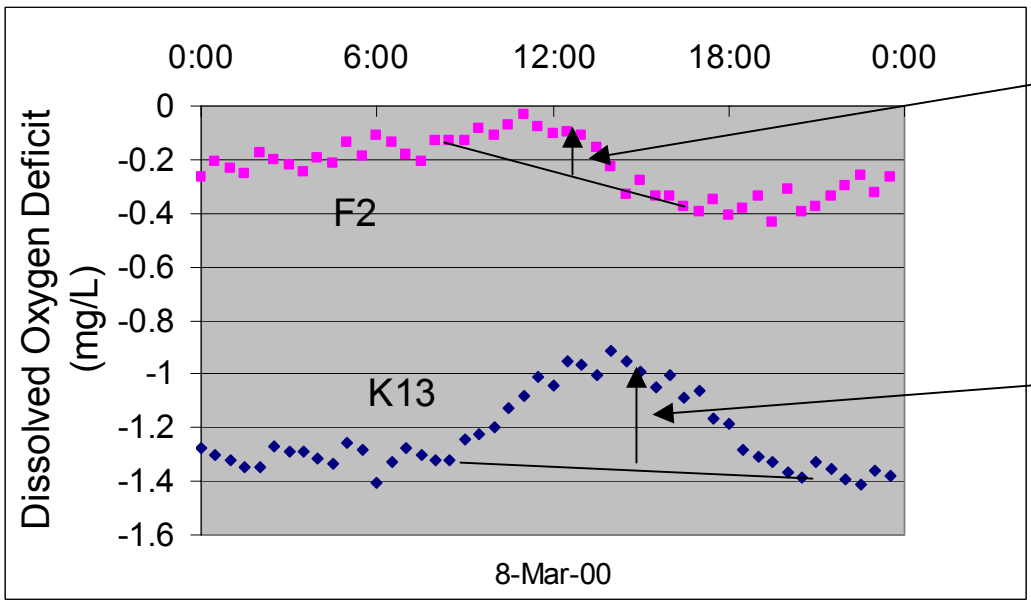


Figure 13. Diurnal dissolved oxygen profiles in a reference stream (K13) and a highly disturbed stream (F2) showing differences resulting from differences in gross primary productivity (GPP).



Low gross primary productivity in highly disturbed stream

Higher gross primary Productivity in reference stream

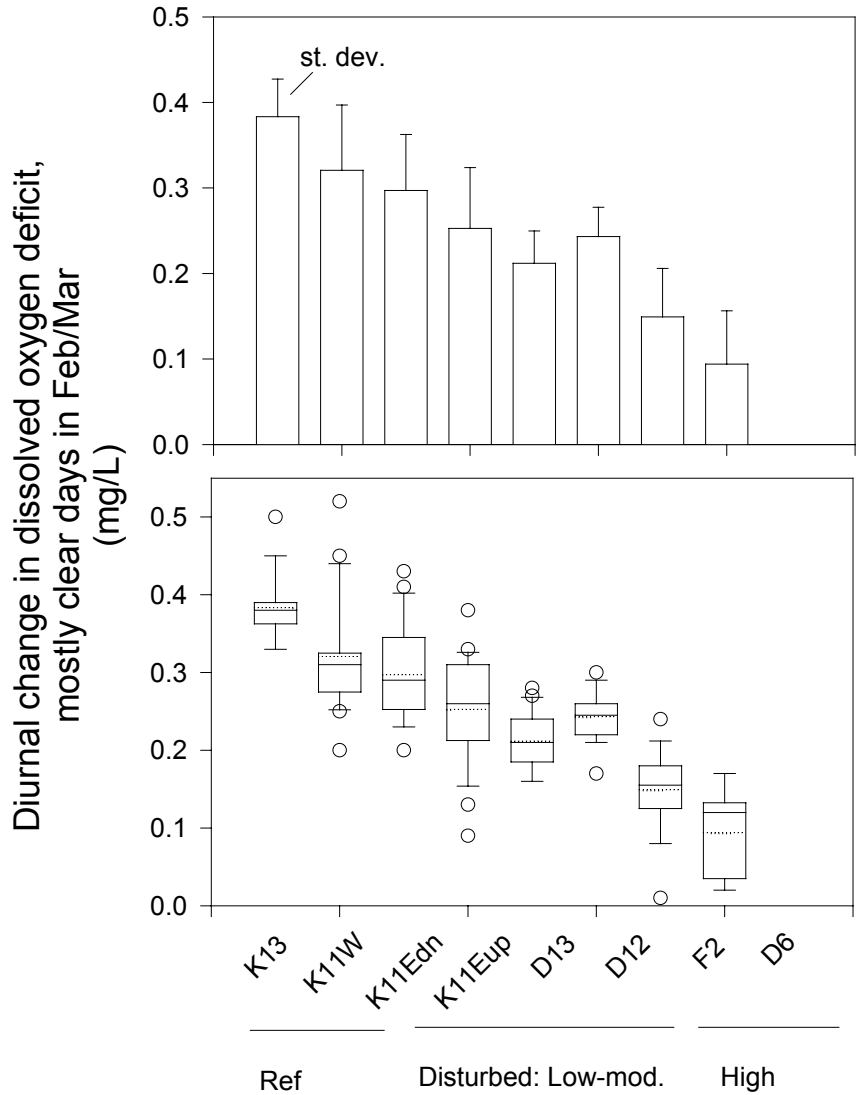


Figure 14. Relationship between amplitude of diurnal dissolved oxygen deficits curves and stream disturbance

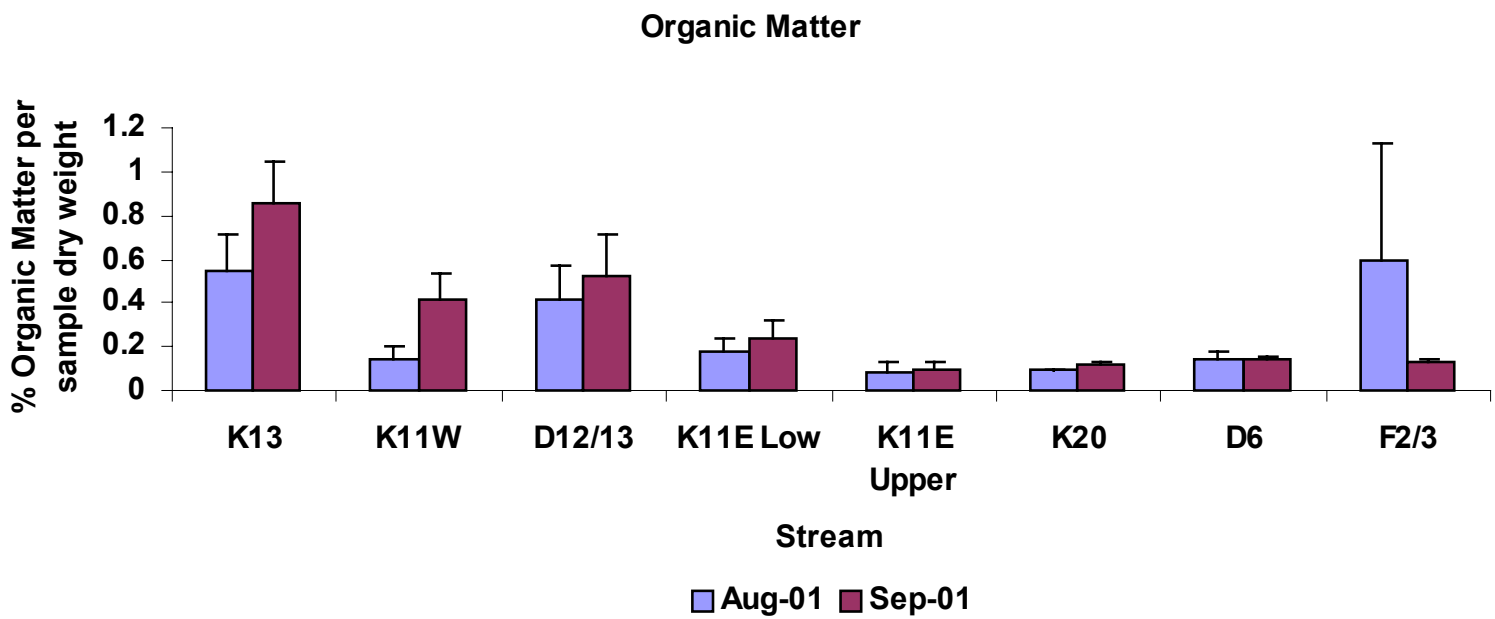


Figure 15. Percent organic matter contained in the streambed of SEMP sites. Sites are arranged from left to right in order of increasing catchment disturbance, with K13 and F2/3 representing the least and most disturbed sites, respectively. Values are means +1 SE.

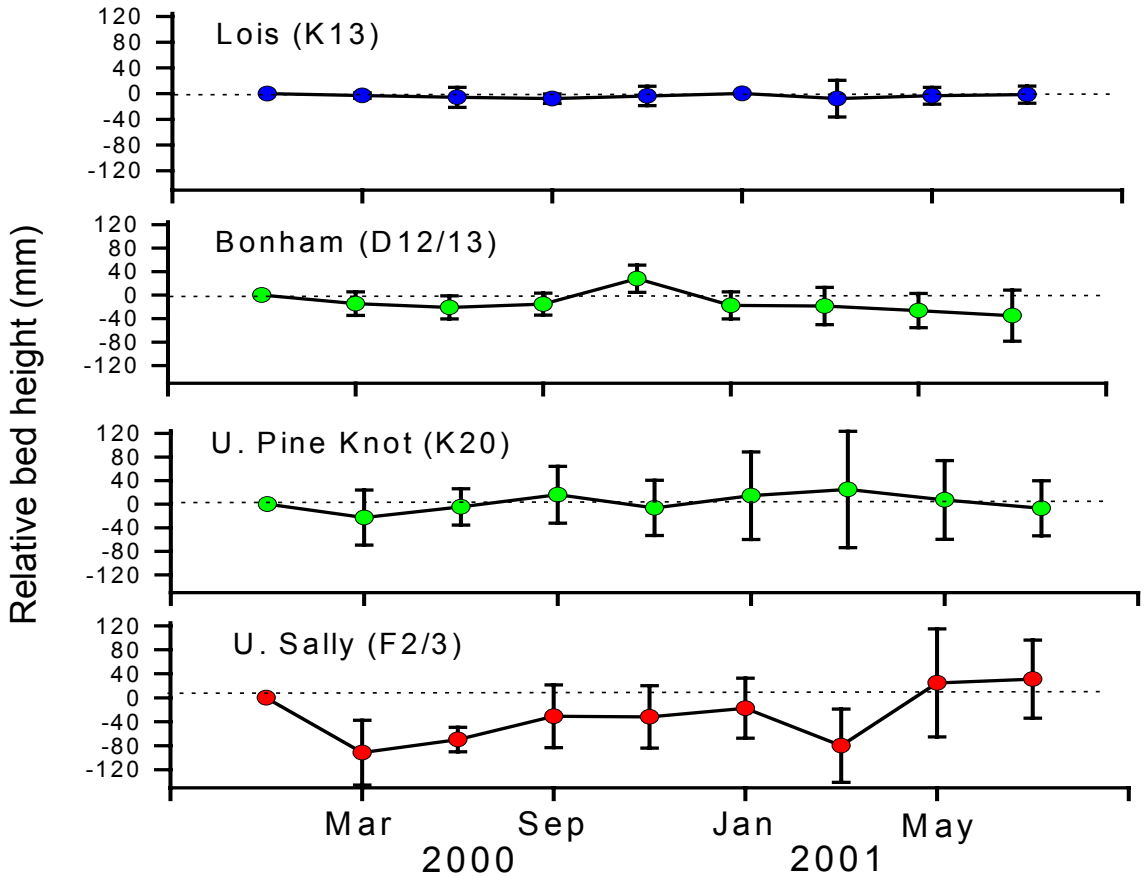


Figure 16. Streambed sediment profiles for four of the SEMP sites sampled from January 2000 through September 2001, as relative height of the streambed on scour pins (n=4-5 per site). Dashed lines indicate original position of the streambed at the beginning of the sampling period for each stream. Sites are arranged from top to bottom in order of increasing catchment disturbances, with K13 and F2/3 representing the least and most disturbed sites, respectively.

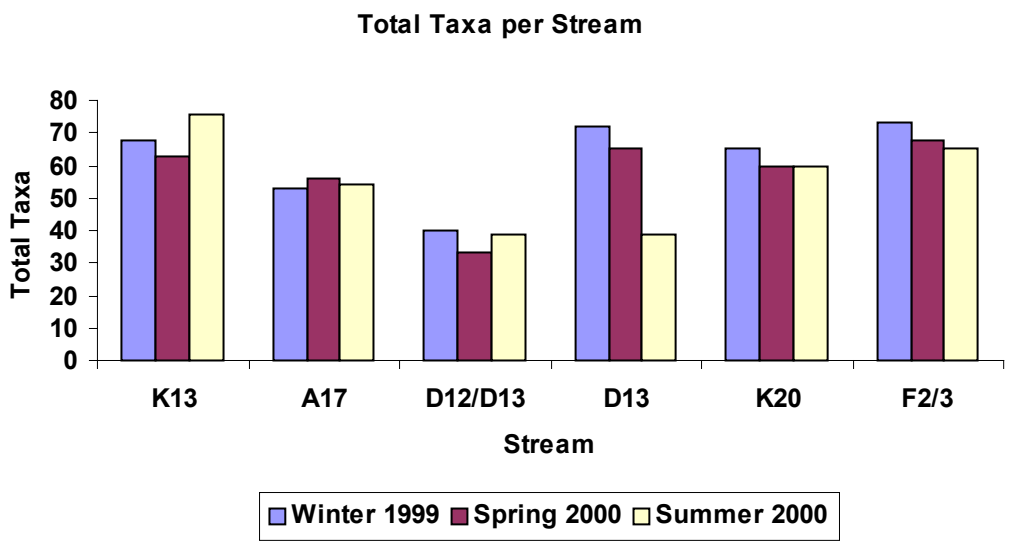


Figure 17. Total number of macroinvertebrate taxa for each stream over the first year of sampling (2000). Streams are arranged from left to right in order of increasing catchment disturbance.

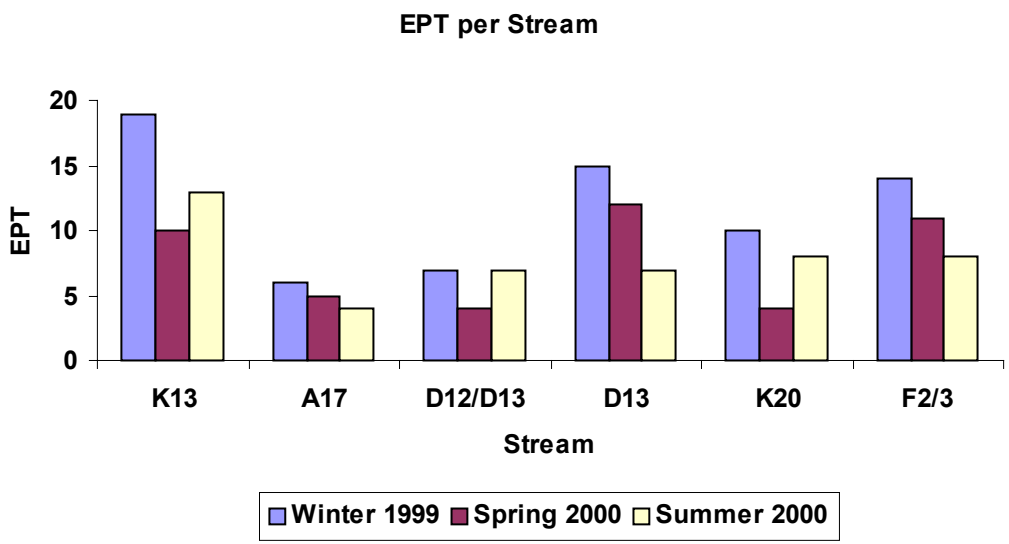


Figure 18. Total number of EPT taxa (species in the orders Ephemeroptera, Plecoptera and Trichoptera) for each stream over the first year of sampling (2000). Streams are arranged from left to right in order of increasing catchment disturbance

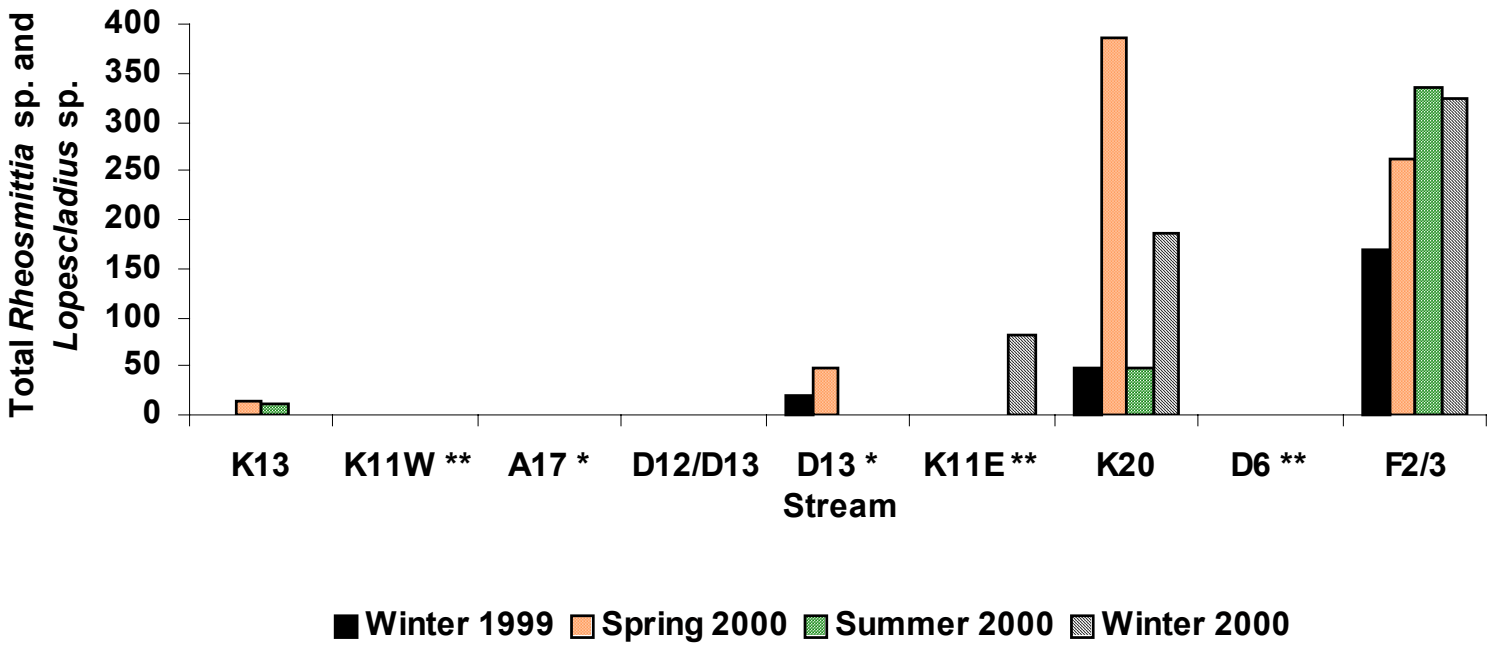


Figure 19. Abundance of sediment-tolerant chironomid midges (in the genera *Rheosmittia* and *Lopescladius*) for SEMP streams sampled during 1999-2001. Streams are arranged from left to right in order of increasing catchment disturbance. *--streams sampled only in 2000; **-- streams sampled only in 2001. All other streams were sampled both years.

Table 1. Bray-Curtis similarity matrix for stream sites sampled during Year 1 (2000). Values range from zero (sites share no species) to 1.0 (all species shared between sites). Stream sites in green are reference sites, sites in orange are highly disturbed sites, and sites in blue are streams in moderately disturbed catchments.

Stream	K13	A17	D12/13	D13	K20	F2/3
K13						
A17	0.52					
D12/13	0.48	0.31				
D13	0.51	0.45	0.38			
K20	0.48	0.38	0.51	0.51		
F2/3	0.48	0.35	0.39	0.42	0.57	