Indicators of Ecological Change

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Oak Ridge National Laboratory
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A SERDP Ecosystem Management Project (SEMP)
being implemented at Fort Benning, GA

SEMP Technical Advisory Committee Meeting
September 2004

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
- Sharon Hermann and Dan Wyrick, Department of Biological Sciences, Auburn University — Terrestrial indicators
- Virginia Dale and Dan Druckenbrod, Environmental Sciences Division, Oak Ridge National Laboratory — Terrestrial and landscape indicators, integration

Objectives

1) To identify indicators that signal ecological change in intensely versus lightly used ecological systems.
2) To ensure that these indicators are feasible for the installation staff to measure and interpret and thus can become a part of the ongoing monitoring system at the installation.

Technical Approach

(a) Determine criteria for indicator selection *

(b) Analyze historical trends in environmental changes to identify potential indicators;

(c) Collect supplemental data relating to proposed indicators (building upon existing data);

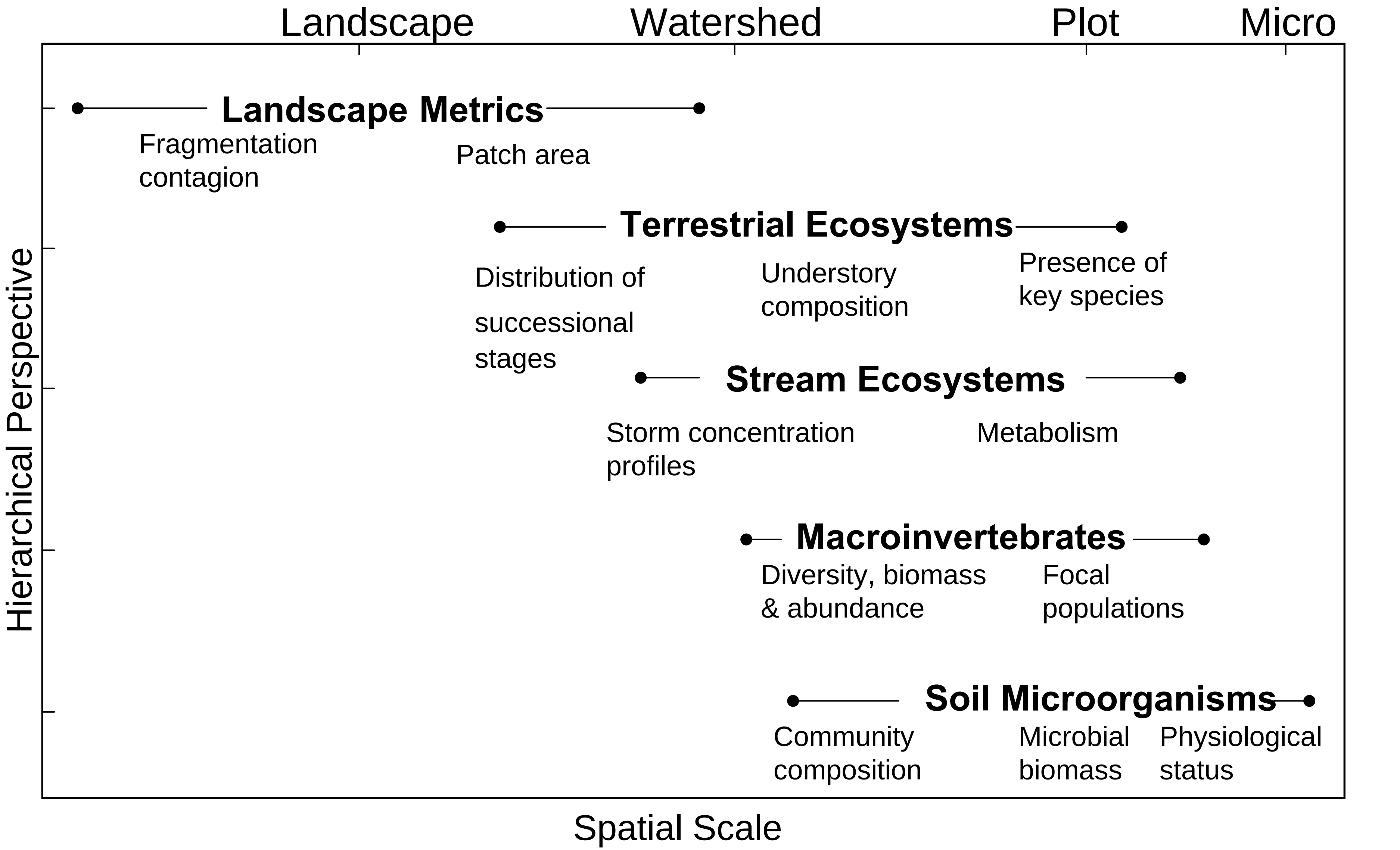
(d) Perform experiments to examine how training affects indicators;

(e) Analyze resulting set of indicators for appropriateness, usefulness, and ease of taking the measure;

(f) Develop and implement a technology transfer plan.

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

Hypothesis: There is a suite of ecological indicators



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

Landscape Approach

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

Landscape Analyses: Major Results

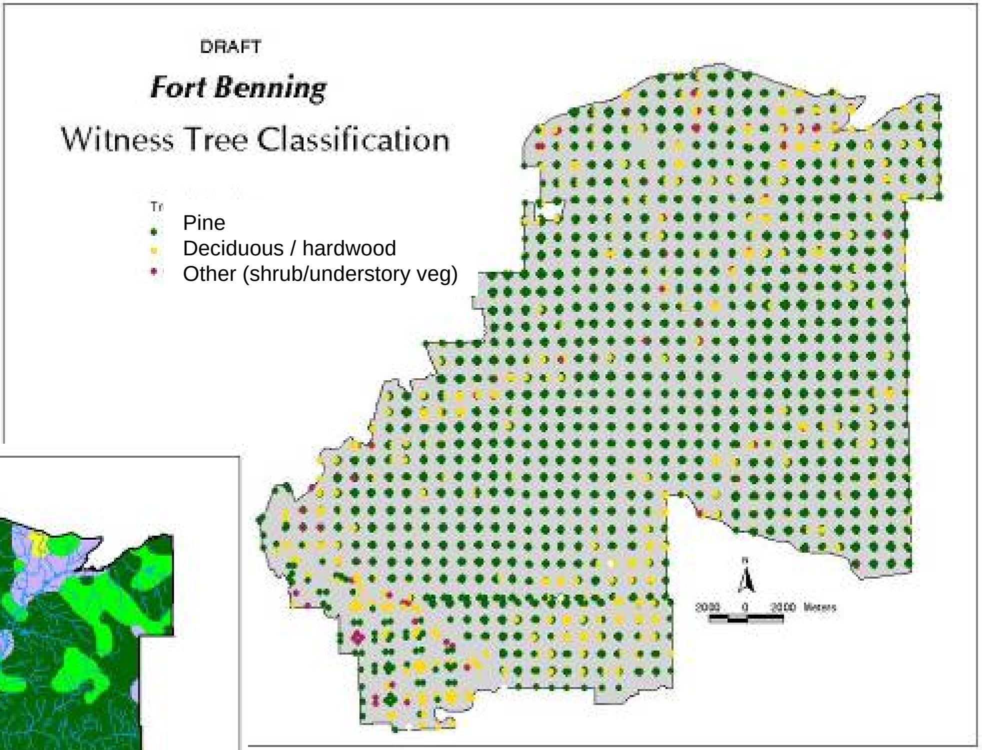
- **Vegetation maps developed from different data sources can be compared**
- **Changes over time occurred in the vegetation at Forest Benning**
  - 1827 to 1974
    - Percent cover of forest declined
    - Pine coverage decreased
    - Increase in deciduous, mixed and nonforest cover
  - 1974 to 1999
    - Gradual increase in the nonforest vegetation (esp. on slopes)
    - Decline in cover of forest vegetation
      - Increase in pine cover
      - Decrease in deciduous cover

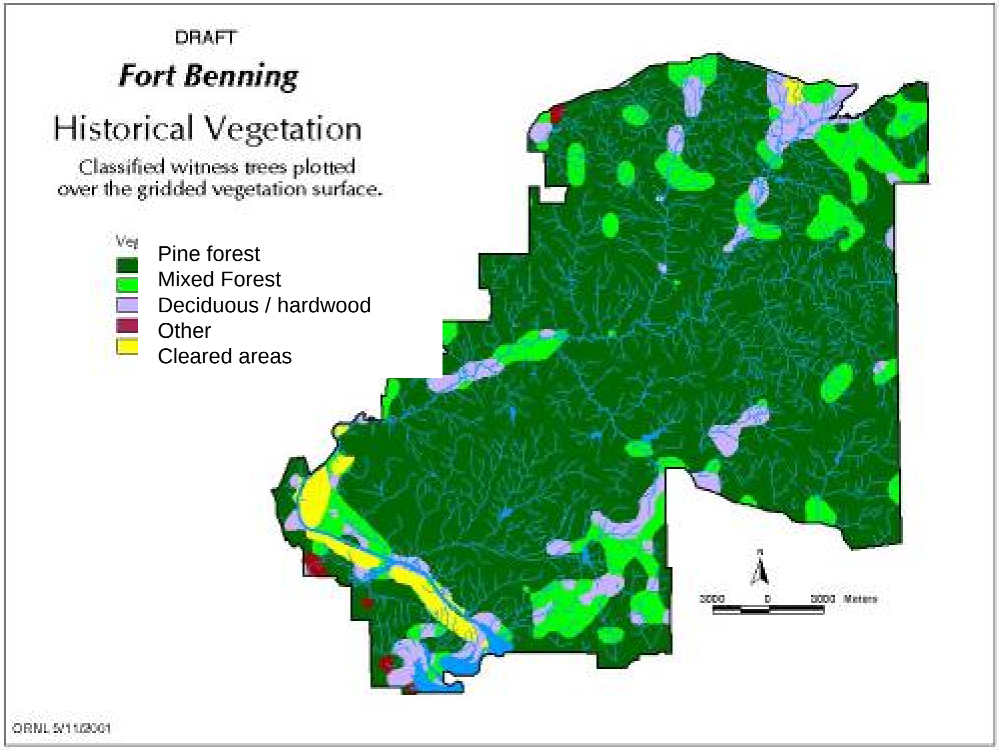
ESRI proceedings: http//www.esri.com/library/userconf/proc01/professional/papers/pap765/p765.htm

Olsen, L.M., Washington-Allen, R.A, and V.H. Dale. In prep. Using Landscape Metrics to Detect Changes over 173 Years at Fort Benning,GA, USA. GIScience and Remote Sensing

Fort Benning Historical Vegetation – 1827

1. Witness tree data
2. Tree classification
3. Interpolation of surface
4. Estimation of cleared areas- large settlements/towns





Foster, T., B. Black, M. Abrams. 2004. A witness tree analysis of the effects of Native American Indians on the pre-European settlement forests in east central Alabama. Human Ecology 32 (1)

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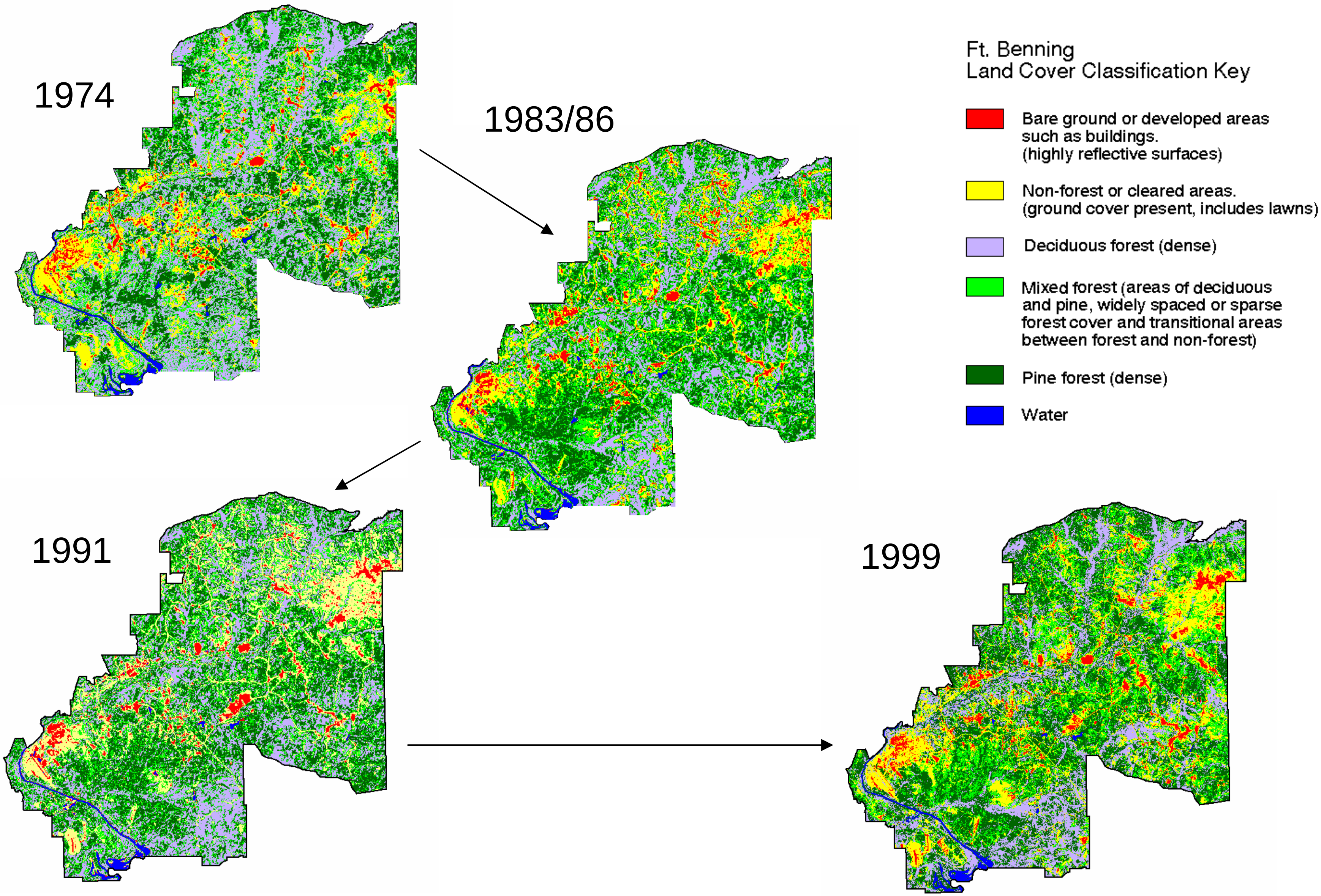
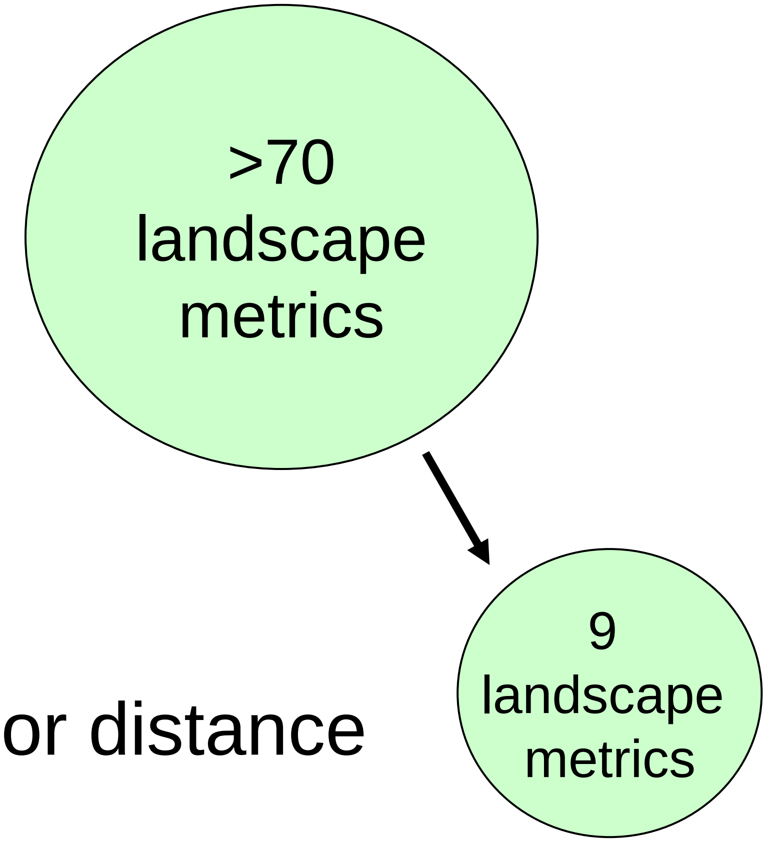
OAK RIDGE NATIONAL LABORATORY



The most useful metrics for distinguishing changes in land cover classes at Fort Benning:

- 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
- Clumpiness



[Choice of metric depends on question]

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

Terrestrial Indicators: Sampled vegetation and soil microbes in five discrete land-use types

(based on observations and experience of Fort Benning staff)

- Reference

- Ground infantry

- Marginal to tracked vehicles use

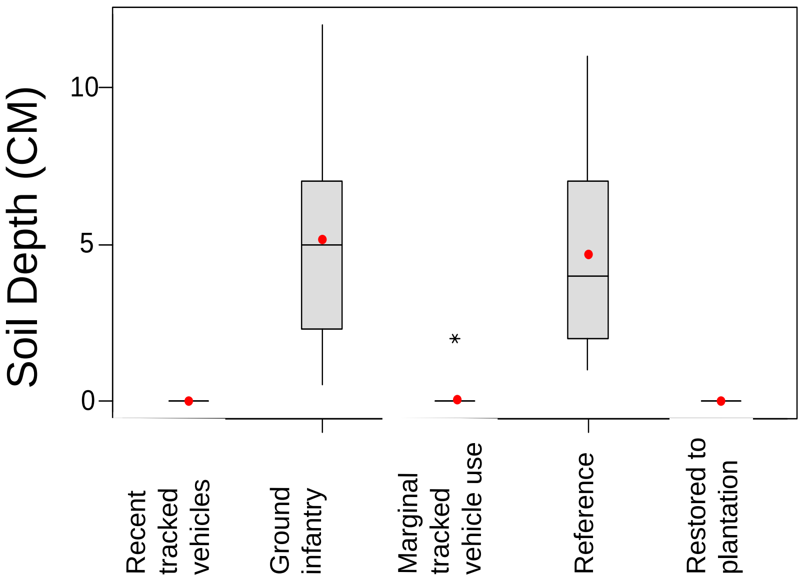
- Recent tracked vehicle use

- Restored to plantation

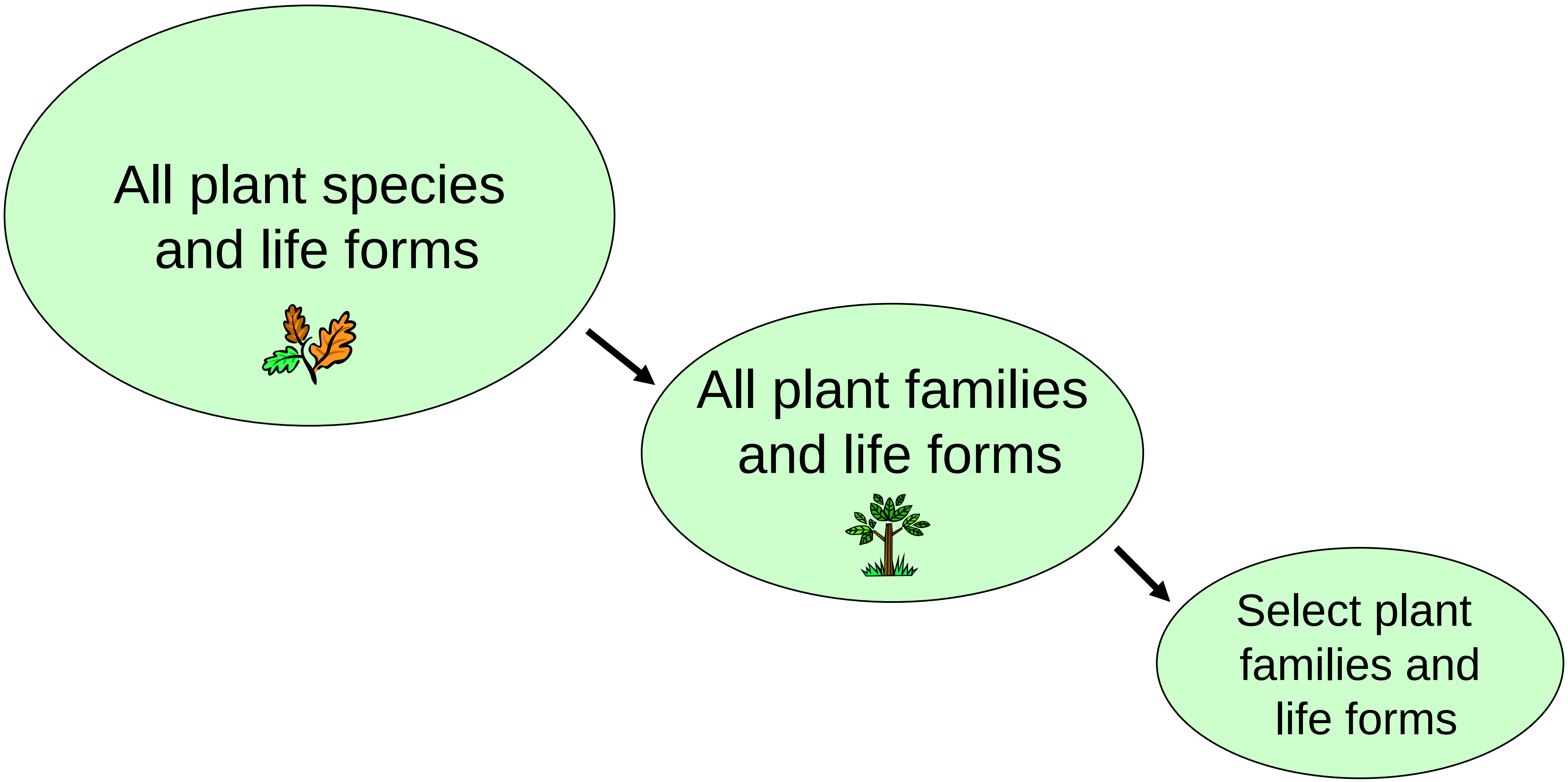
Terrestrial Indicators

- Overstory
  - Maximum tree age
  - Canopy cover
- Understory
  - – Percent cover by life form
  - – Percent cover by plant family
- Soils
  - – Depth of A horizon
  - – Soil microbial attributes (as determined by lipid biomarker analyses)
    - – Biomass
    - – composition

Boxplots of Depth of A Horizon by Disturbance Type



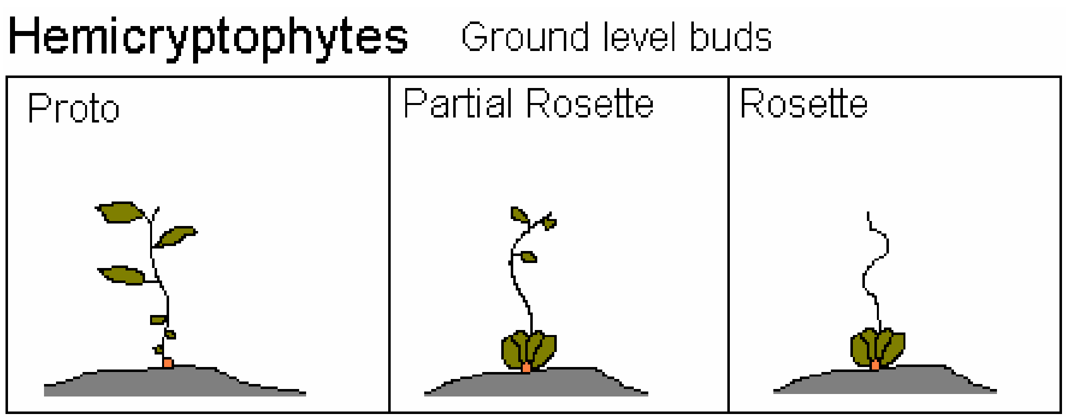
Narrowed List of Plant Indicators



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.

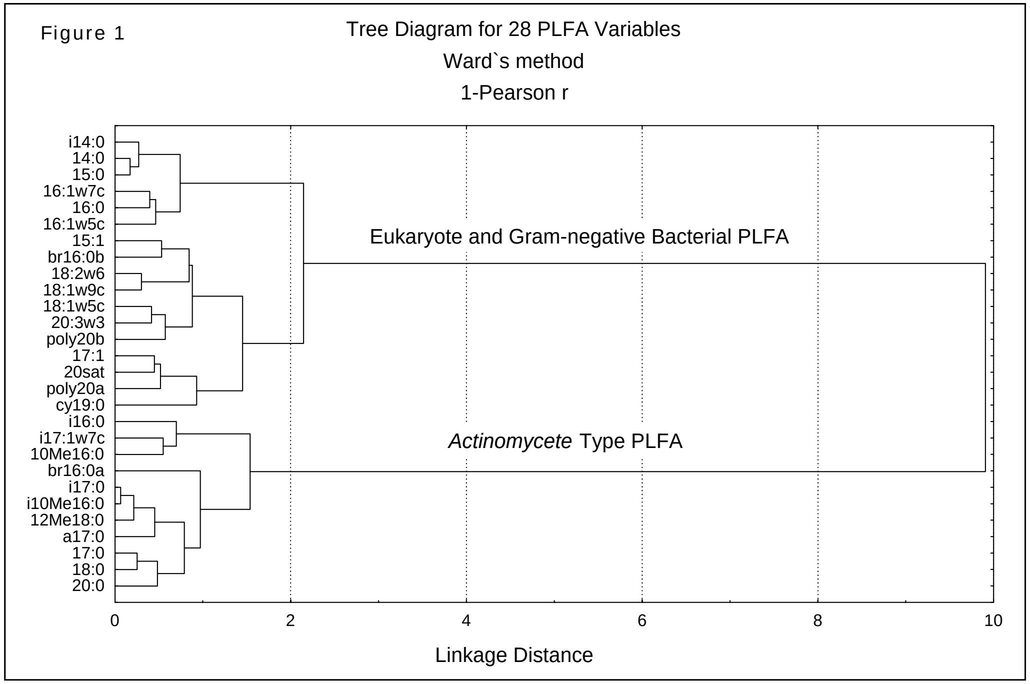
Transfer of Information

Plant Families and Life Forms Seen in the Fort Benning Area: A Field Guide



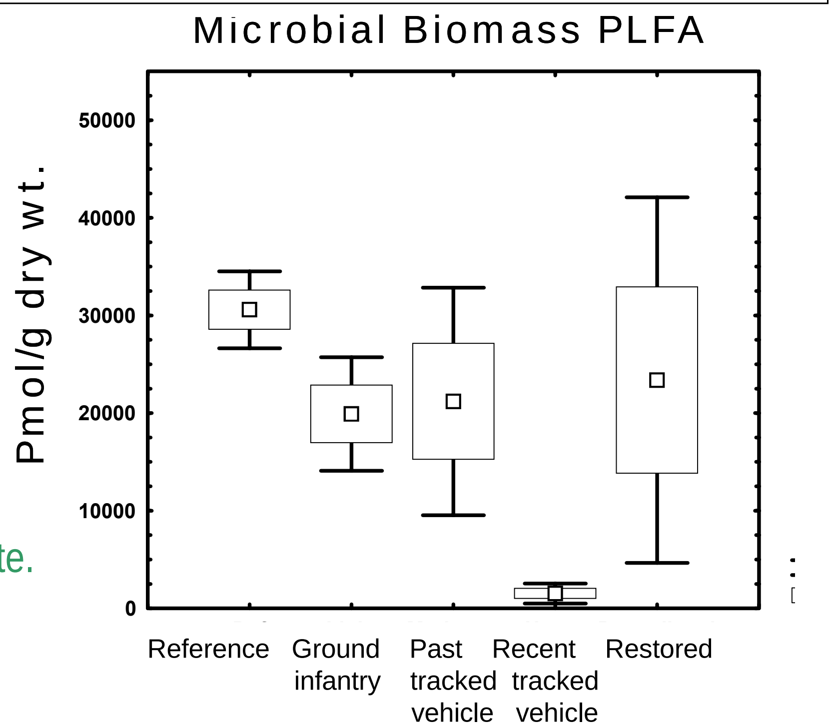
Field guide delivered to Fort Benning Resource Managers. 2002.

Analysis of soil microbial community structure and biomass under different military uses



Benefits:

- Easy collection of soil cores
- Ship frozen
- Base or commercial laboratory for analysis
- Potential for monitoring changes
- Readily interpretable

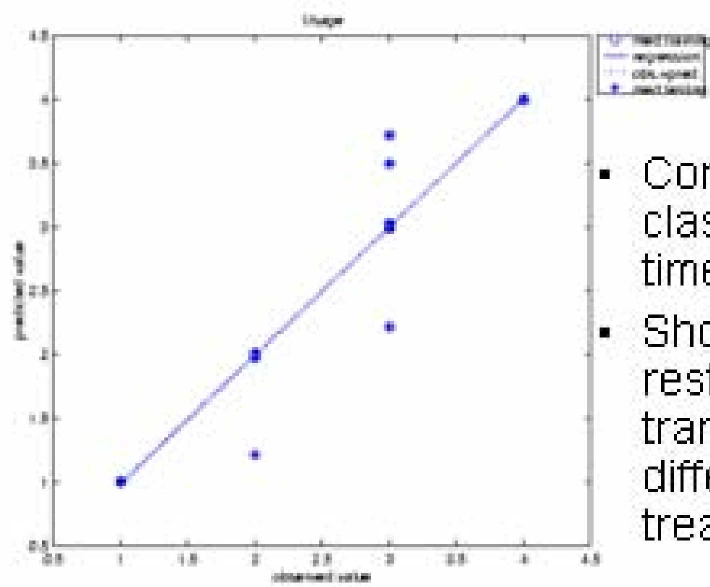


Peacock, A.D., S.J. MacNaughton, J.M. Cantu, V.H. Dale, D. C. White. 2001. Soil microbial biomass and community composition along an anthropogenic disturbance gradient within a longleaf pine habitat.

Ecological Indicators 1(2):113-121.

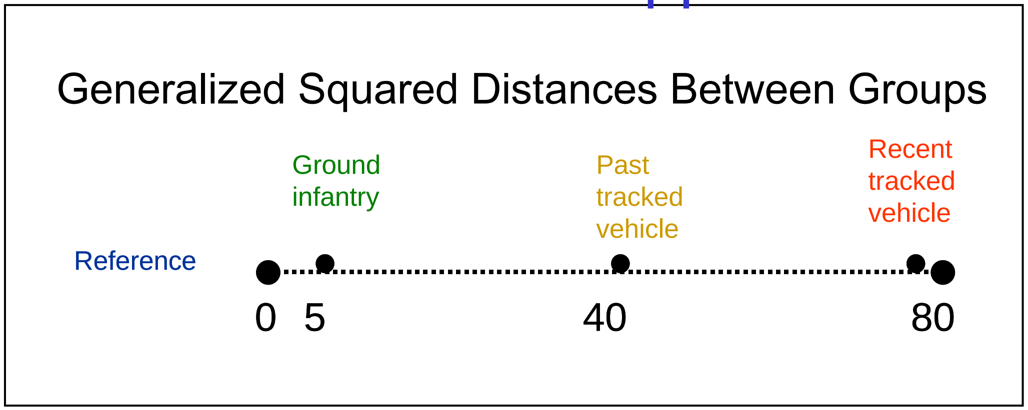
Non parametric approach and parametric approach can be used to classify new information.

Non-linear Artificial Neural Network Analysis



- Correctly predicts classification 66% of the time (25% chance)
- Shows that transects restored to plantations transects are very different from all other treatments

Parametric approach



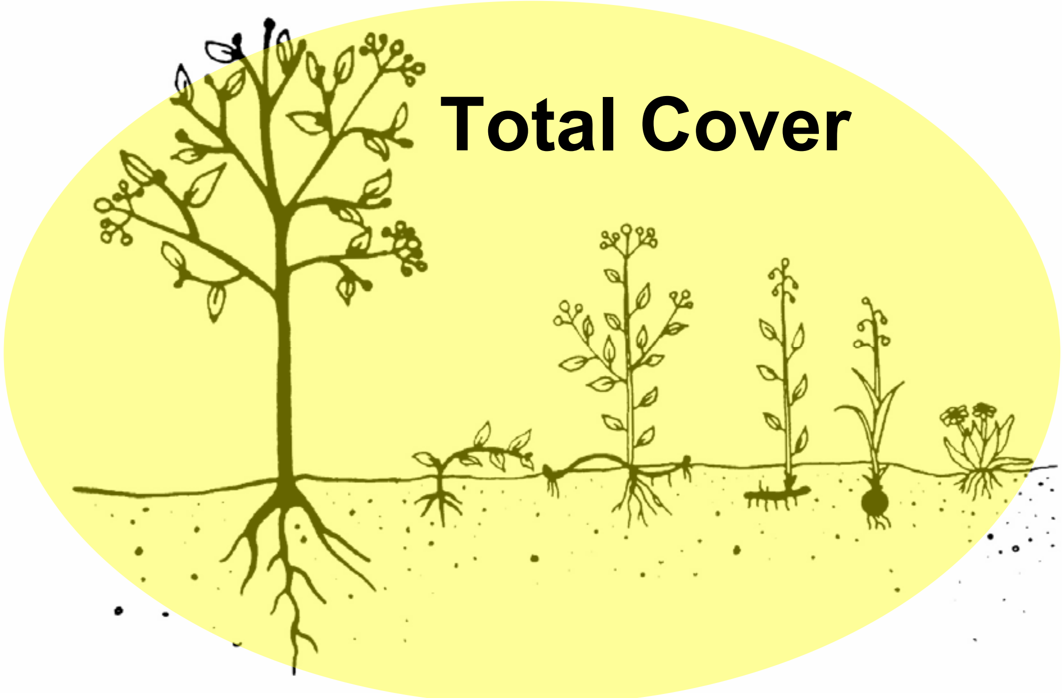
Interpretation guide and model will be provided to resource managers that will calculate distance relationships for new microbial data.

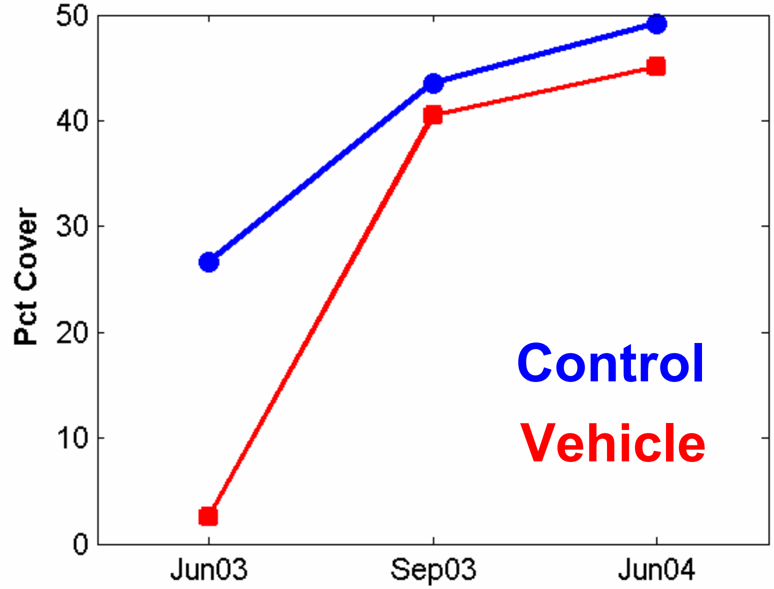
K11 Experimental Methods:

- Understory surveyed with Braun-Blanquet percent cover scale in June 2003, Sept 2003, and June 2004
- Raunkiaer (1934) Life-forms used as Functional Types
- % cover transformed using arcsine square-root
- Repeated-Measures ANOVA with SPSS 12.0 GLM

Photos by K. Maloney and D. Druckenbrod

Total Cover

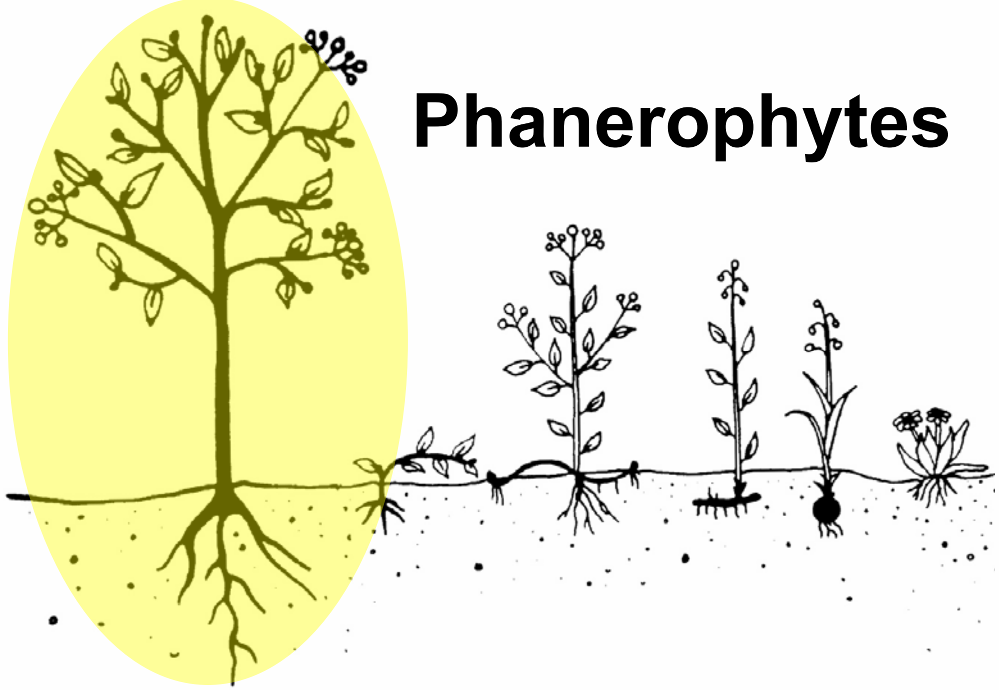


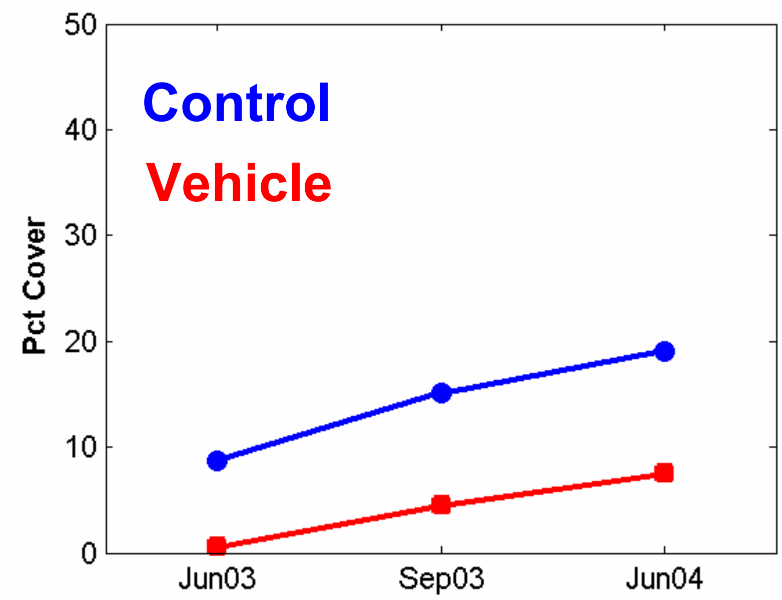


	F statistic	P-value*
Treatment	6.45	0.014
Time	131.97	<0.001
Linear	209.70	<0.001
Quadratic	44.09	<0.001
Treatment•Time	27.17	<0.001
Linear	37.30	<0.001
Quadratic	15.74	<0.001

*** G-G adjustment to df's**

Phanerophytes





	F statistic	P-value*
Treatment	8.12	0.006
Time	30.18	<0.001
Linear	41.25	<0.001
Quadratic	3.78	0.057
Treatment•Time	0.66	0.488
Linear	0.84	0.363
Quadratic	0.21	0.650

*** G-G adjustment to df's**

Research Conclusions

- **Total cover initially reduced; however, returns to control levels within growing season**
- **Phanerophytes and Cryptophytes account for majority of understory cover for both control and treatment**
- **Phanerophytes display reduced cover through time**
- **Chamaephytes increase cover through time but not impacted by tracked-vehicle disturbance**
- **Hemicryptophyte, Cryptophyte, and Therophyte cover may be promoted through time by tracked-vehicle disturbance**

Dale,V.H, Druckenbrod, D., Baskaran, L., Aldridge, M.., Berry, M., Garten, C., Olsen, L., Efroymson, R., and Washington-Allen, R. In review. Vehicle impacts on the environment at different spatial scales: Observations in west central Georgia. Journal of Terramechanics.

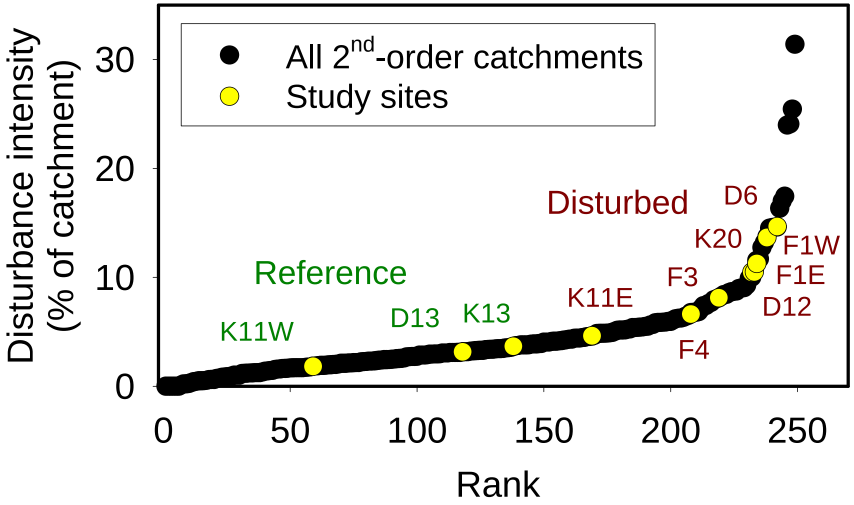
Management Implications

- Phanerophytes readily serve as an indicator of understory structure and cover that are reduced by tracked-vehicle activity
- Hemicryptophytes, Cryptophytes, and Therophytes may also serve as an indicator that are promoted by tracked-vehicle activity
- These functional types meet most of the criteria ideally associated with indicators (easily measured, sensitive, anticipatory, etc.)
- These indicators nest into the broader suite of indicators across spatial scales being developed at Fort Benning

Technical Approach: Stream Studies

Land-use gradient analysis (land-use intensity quantified at catchment scale as % land denuded)

Disturbance intensity defined as the sum of:
% bare ground on slopes > 3%
% road coverage

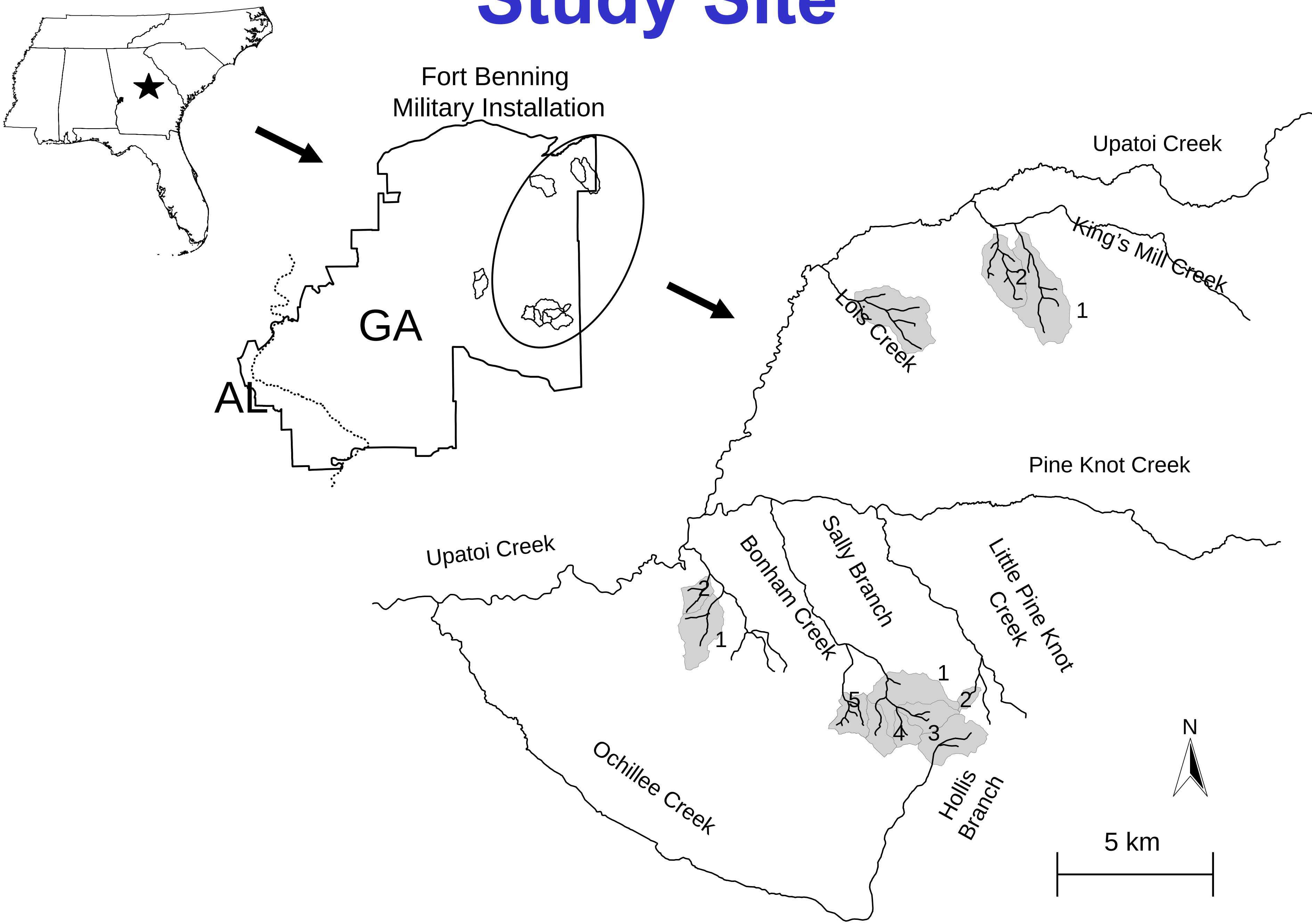


Disturbance classes:
Ref. – K11W, D13, K13 (1.8 – 3.7%)

Low – K11E, F4, F3 (4.6 – 8.1%)

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

Study Site


Fort Benning
Military Installation
GA
AL
Upatoi Creek
King's Mill Creek
Lois Creek
1
2
Pine Knot Creek
Upatoi Creek
Bonham Creek
Sally Branch
Little Pine Knot
Creek
Ochillee Creek
Hollis
Branch
1
2
3
4
5
N
5 km

Part I:

Potential stream indicators of land use at Fort Benning?

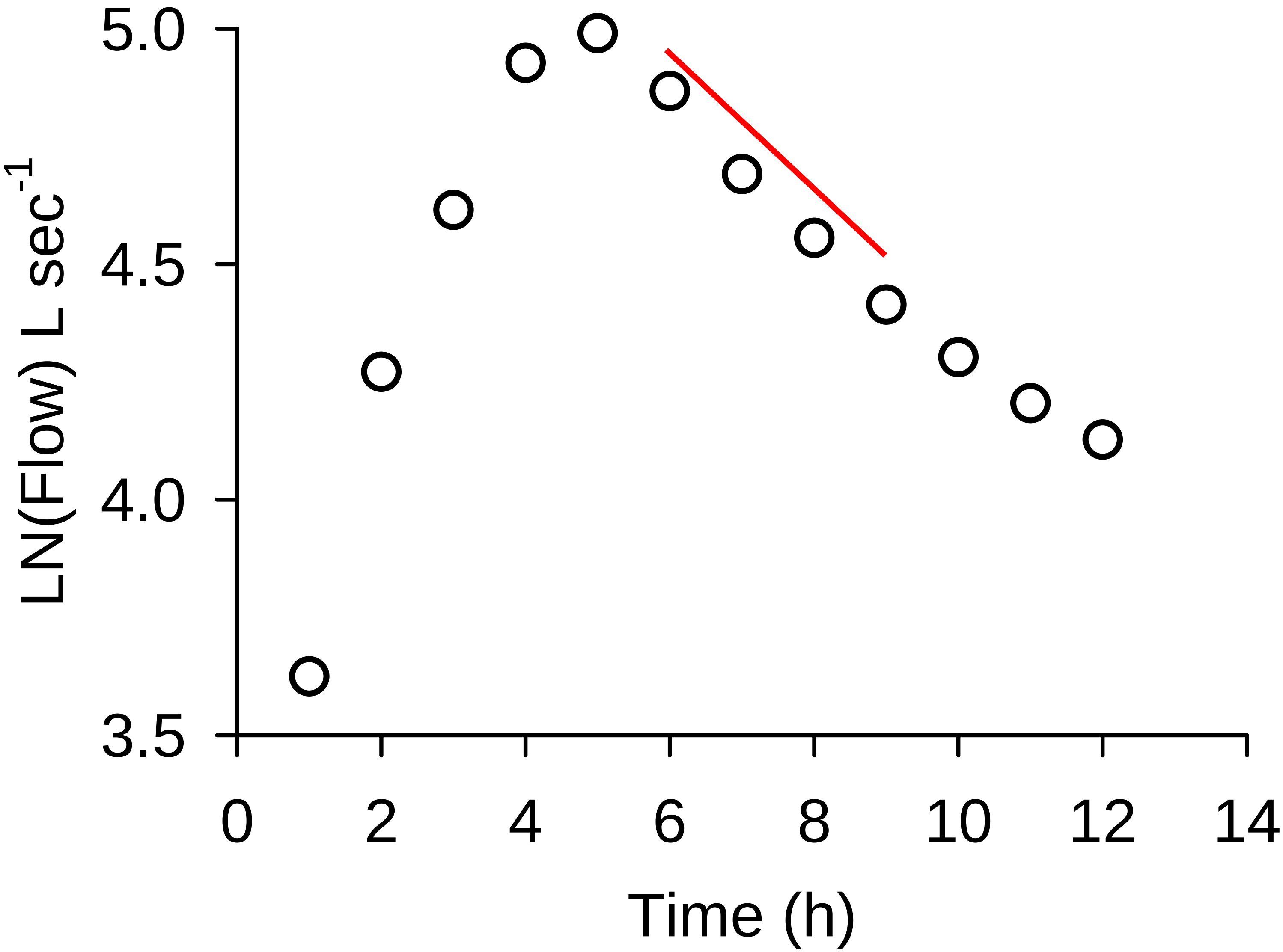
Methods

Water Chemistry –
12 streams 2000 – 2002
grab samples
~ 6 times per year
DOC and pH

coarse woody debris & streambed organic matter – 12 streams measured in 2002 and 2003

CWD

Flashiness (9 streams)



Bed stability

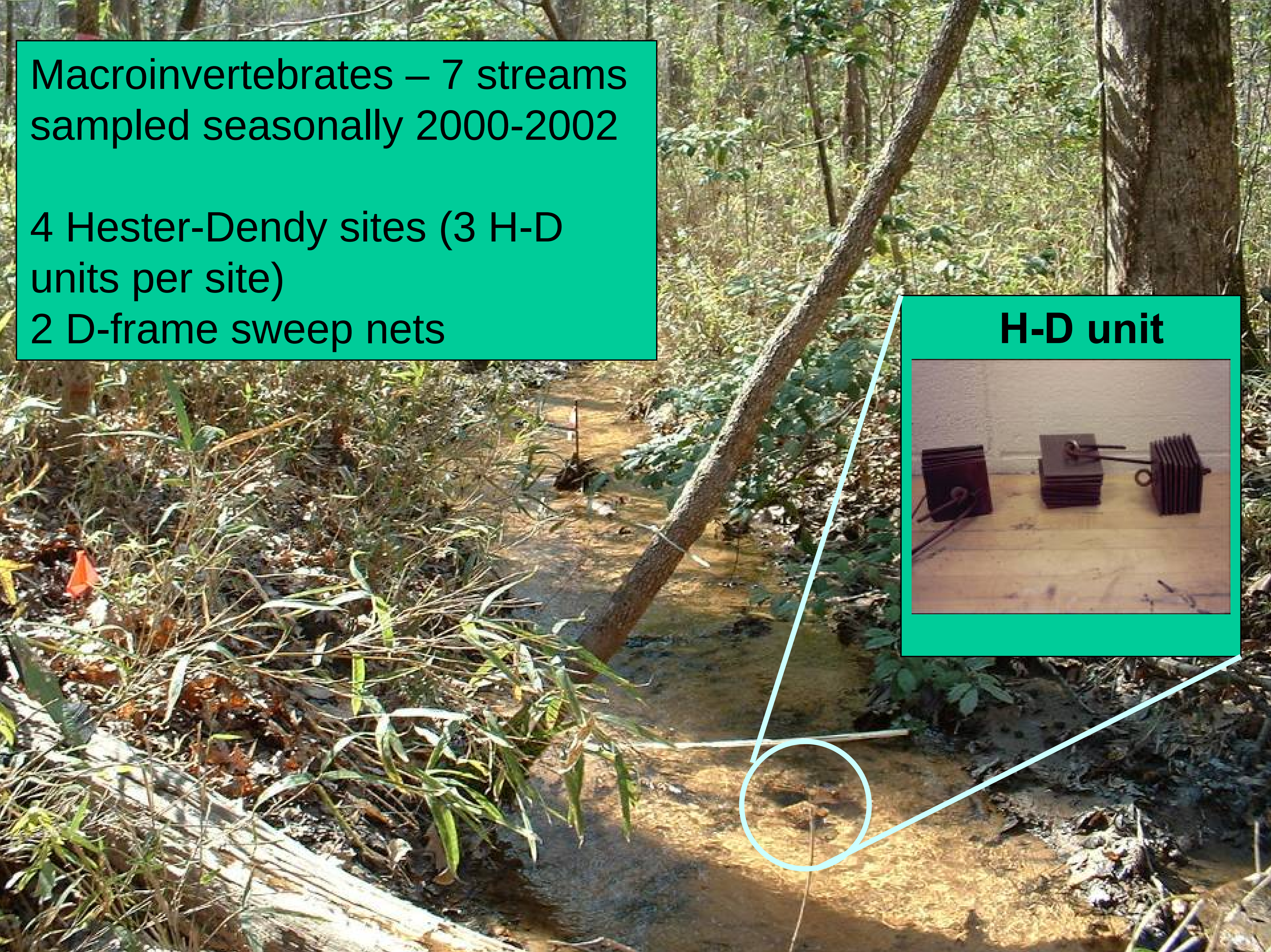
9 streams measured in Jan. and July 2003

Stability estimated as absolute difference in height between 2 periods

Maloney, K.O., J.W. Feminella, P.L. Chaney, A. Abebe. In review. Comparison of three methods to quantify the effects of catchment land use on streambed stability. Journal of the American Water Resources Association.

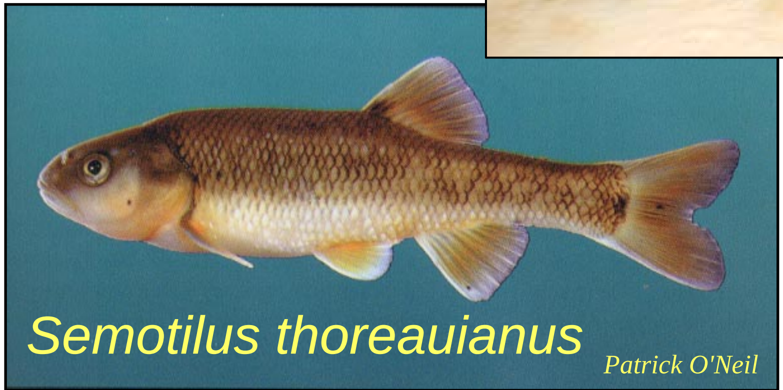
Macroinvertebrates – 7 streams sampled seasonally 2000-2002

4 Hester-Dendy sites (3 H-D units per site)
2 D-frame sweep nets

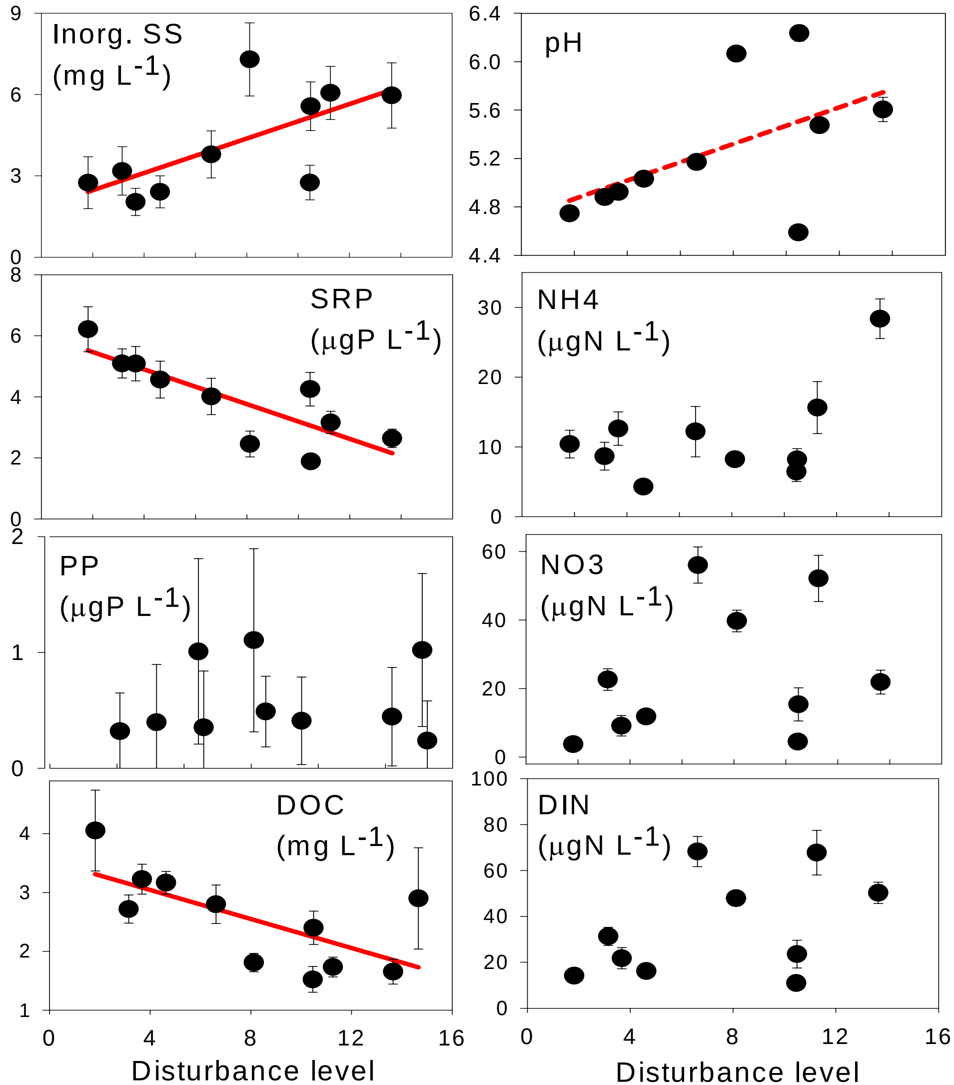


H-D unit

Fish – 8 streams sampled seasonally in 2003



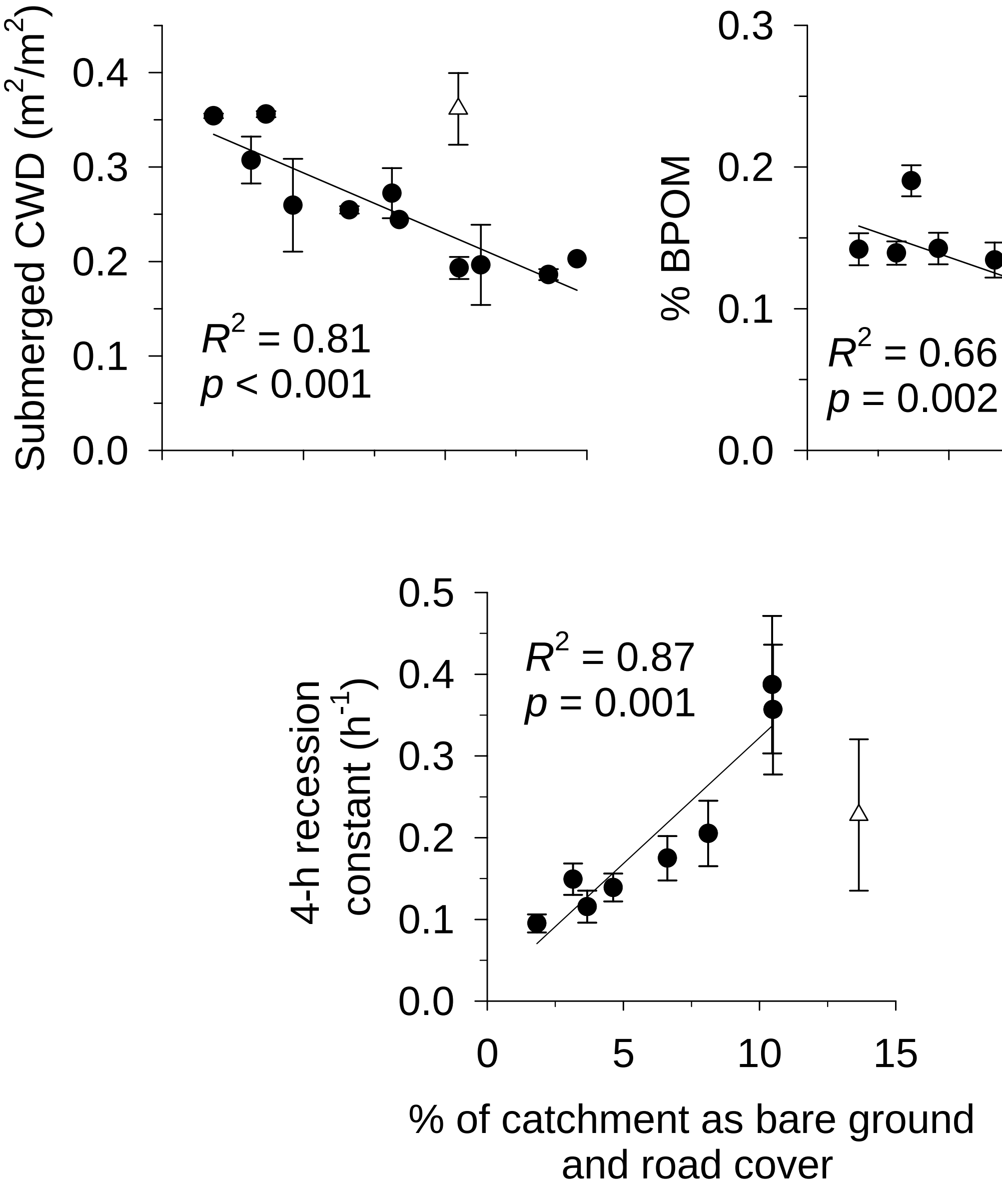
Stream Chemistry (baseflow)



With increasing disturbance level:

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

CWD, BPOM, and Flashiness



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

Macroinvertebrates

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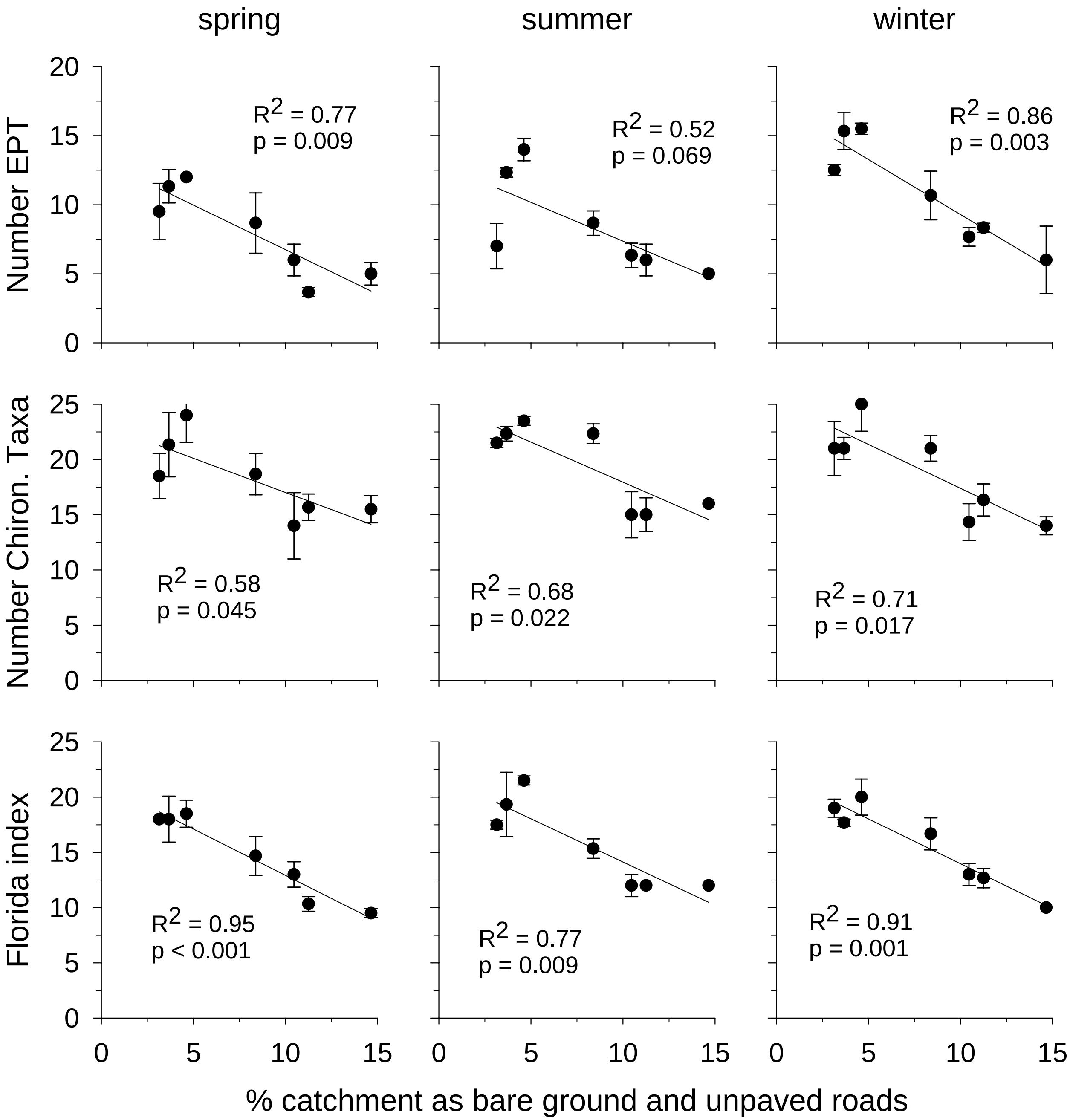
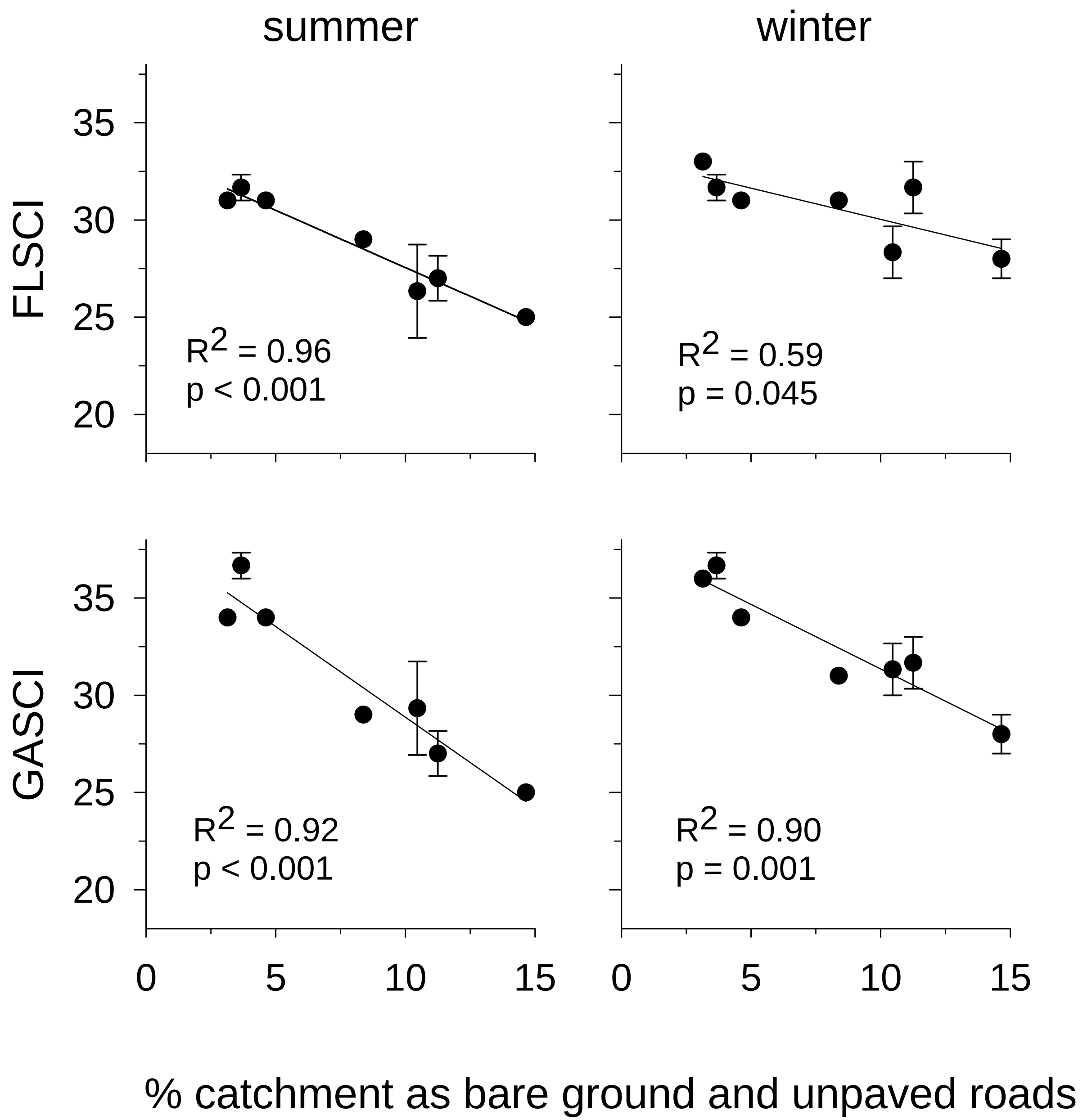
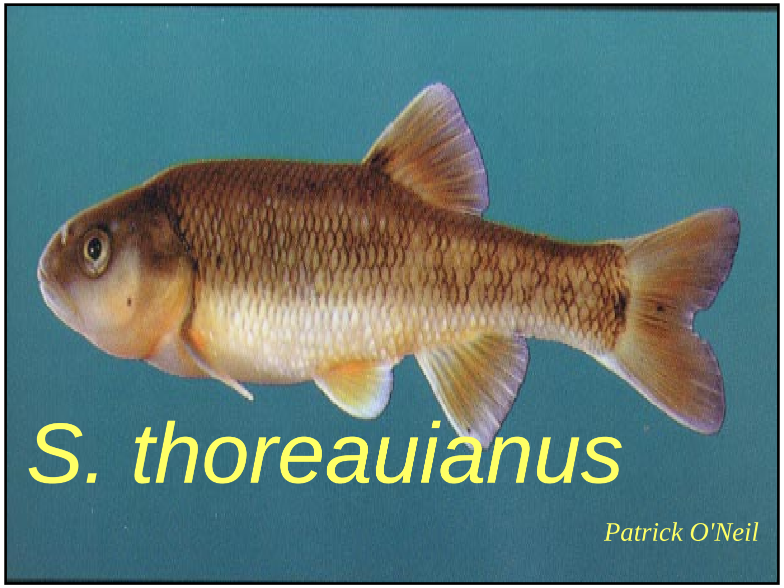
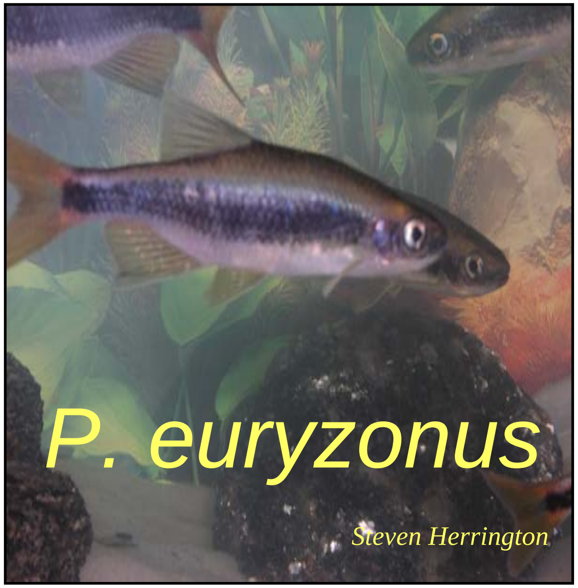


ORNL
Oak Ridge National Laboratory

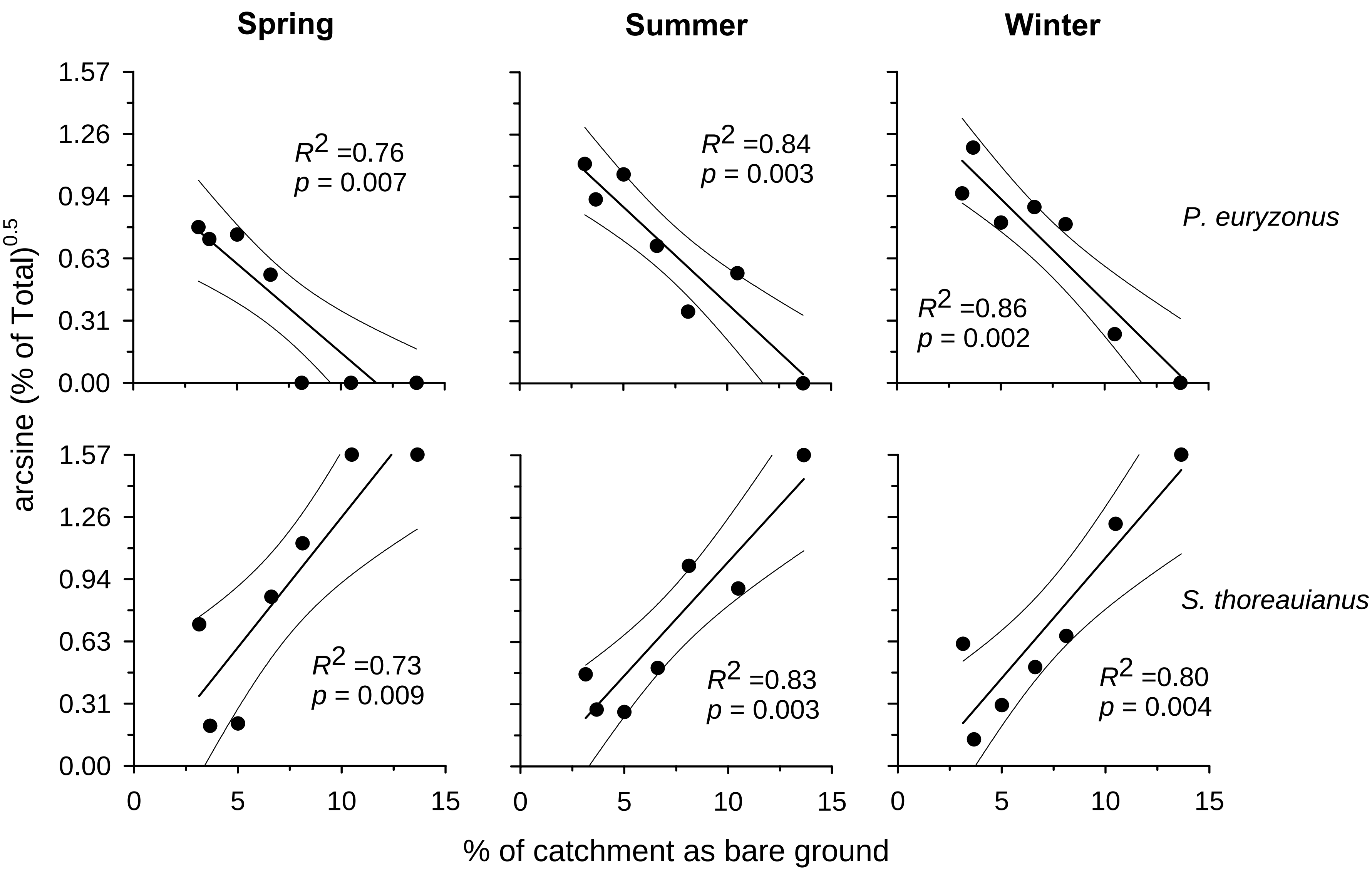

summer
winter
FLSCI
GASCI
35
30
25
20
R2 = 0.96
p < 0.001
R2 = 0.59
p = 0.045
R2 = 0.92
p < 0.001
R2 = 0.90
p = 0.001
0
5
10
15
% catchment as bare ground and unpaved roads

Fish





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



Spring
Summer
Winter
arcsine (% of Total)^0.5
1.57
1.26
0.94
0.63
0.31
0.00
R^2 =0.76
p = 0.007
R^2 =0.84
p = 0.003
R^2 =0.86
p = 0.002
P. euryzonus
R^2 =0.73
p = 0.009
R^2 =0.83
p = 0.003
R^2 =0.80
p = 0.004
S. thoreauianus
0
5
10
15
% of catchment as bare ground

Part II:

Are small streams influenced more by historic than contemporary land use?

Historic land use (pre-1942)

DEKALB COUNTY
Harvesting wheat on the Flowers farm, ca. 1910. The men are, left to right, E. W., Emmitt, and Marion Flowers. (DEK-2)

FLOYD COUNTY
Workers at a sawmill in the timber near Rome, ca. 1900. The owner of the mill, Ben Camp, is the man standing near the saw at far left. (FLO-167)

Military land use

CRACK RIFLEMEN firing as advance is made. Recalls "Charge of Light Brigade."

A RIVER IS CROSSED. The two biggest demonstrations seen by OC's are the battalion in attack and the river crossing, shown here in part.

A GENERAL GRANT MEDIUM TANK plows through a puddle brought on by a Georgia rain storm.—[illegible]

FIRING 37 MILLIMETER service ammunition in anti-tank instruction on Bickford Range.

Contemporary land use

Selective Harvest

Roads

M1 Abrams

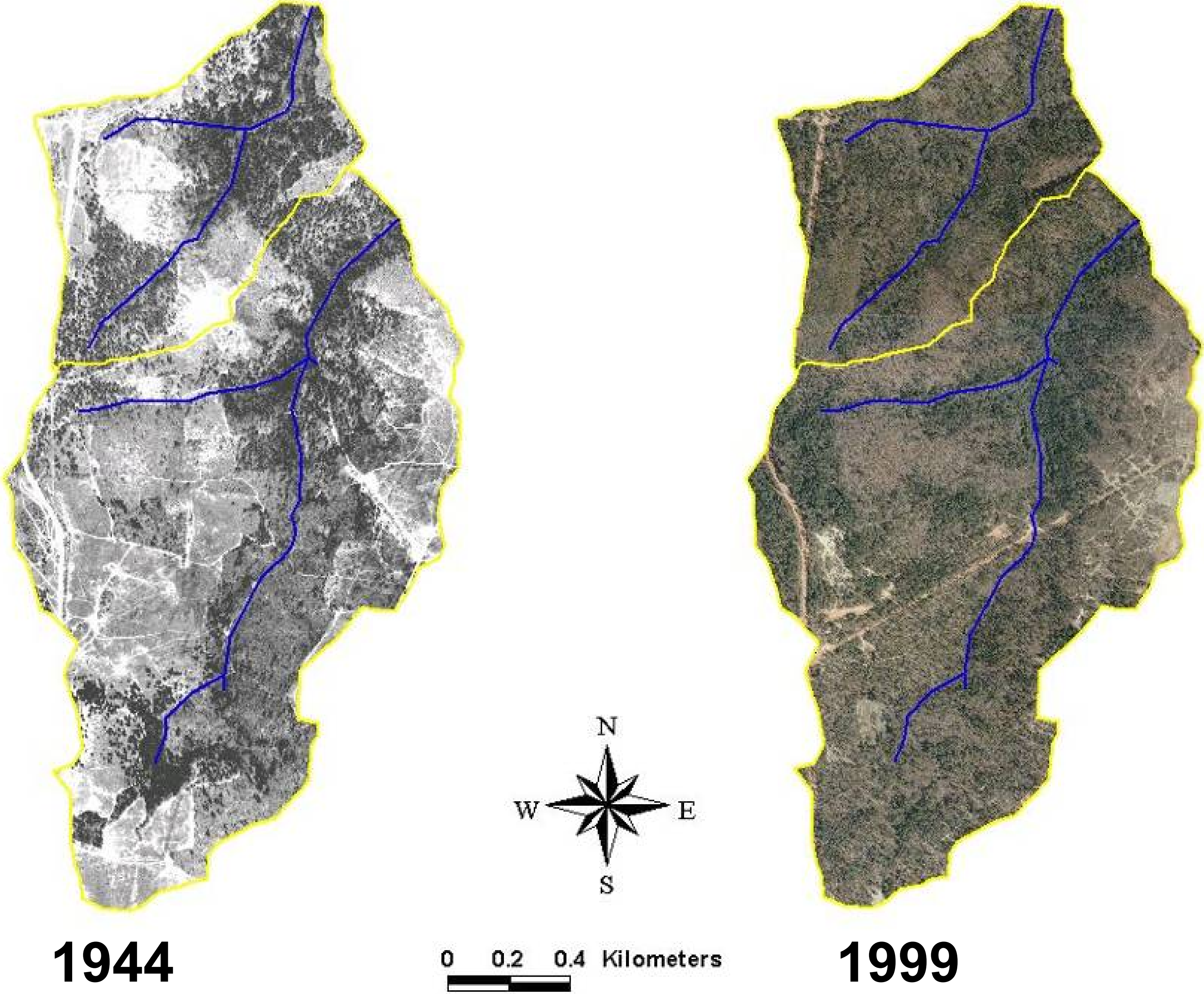
Controlled Burn

Methods

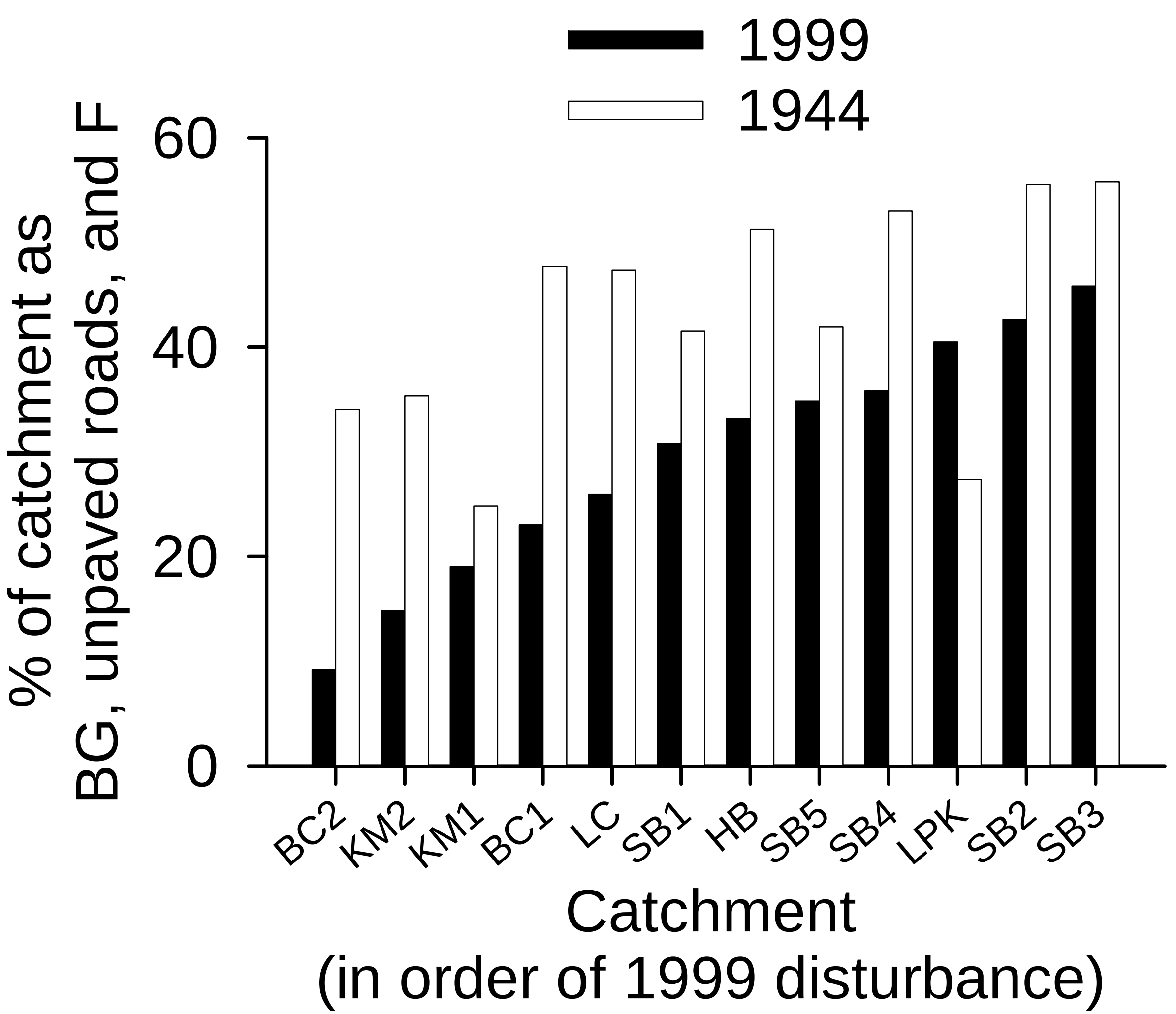
Land use: Aerial Photography (1944)
Landsat Thematic Imagery (1999).

Proportion of land on slopes > 3% for each time period as:

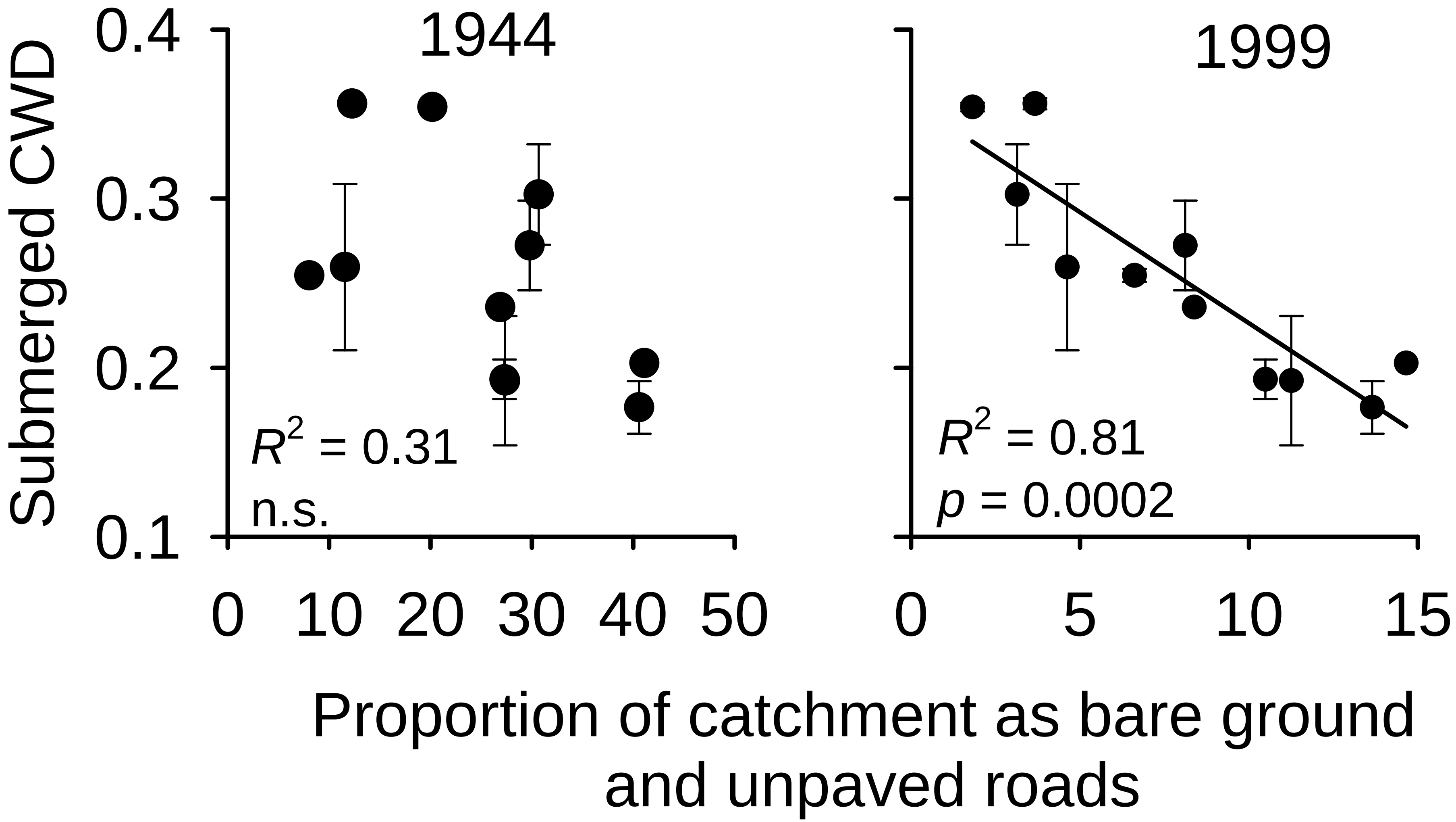
- bare ground and unpaved road cover (BG)
- non-forested (fields)


N
W
E
S
0 0.2 0.4 Kilometers
1944
1999

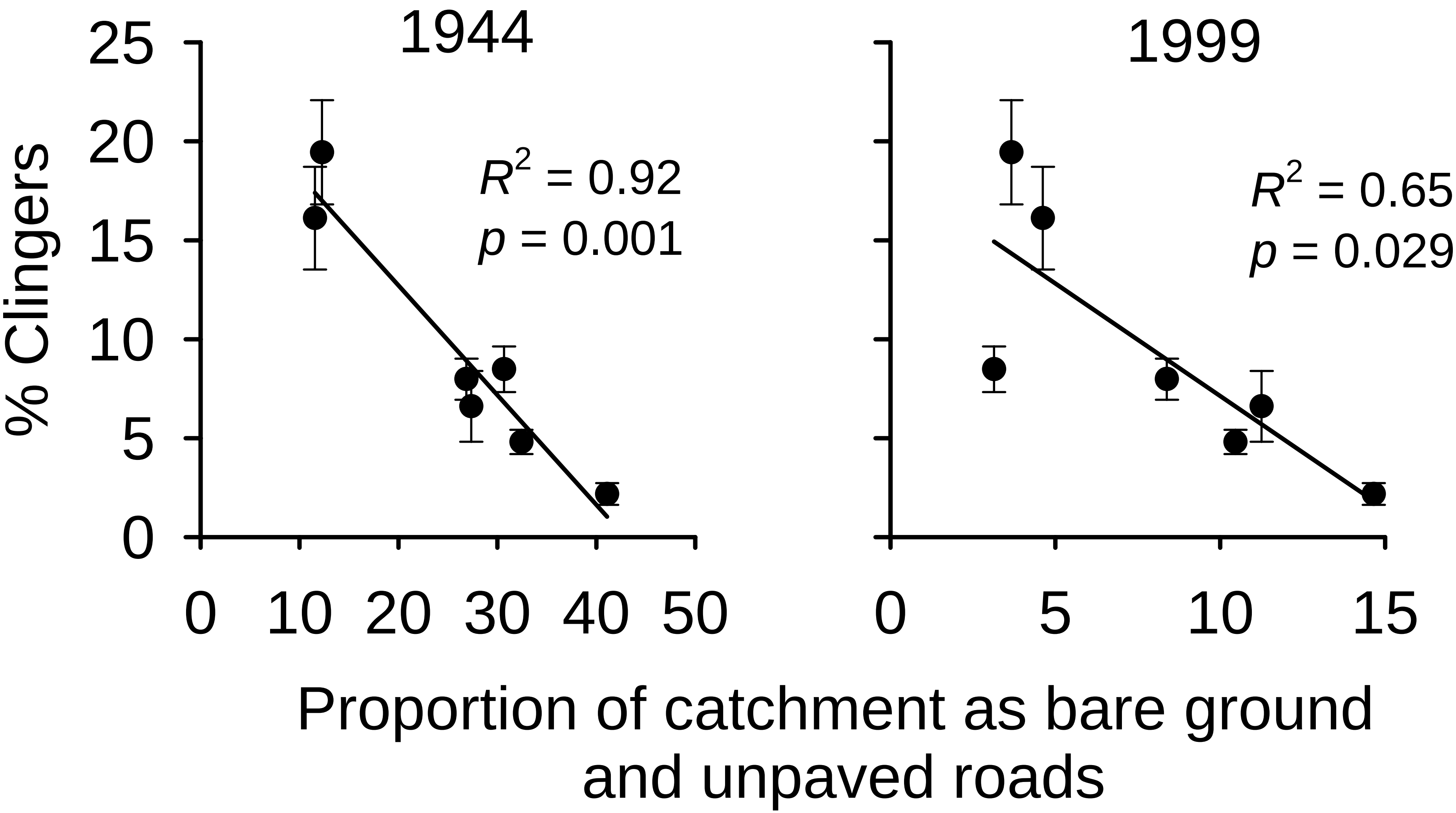
Proportion of Catchment Disturbed



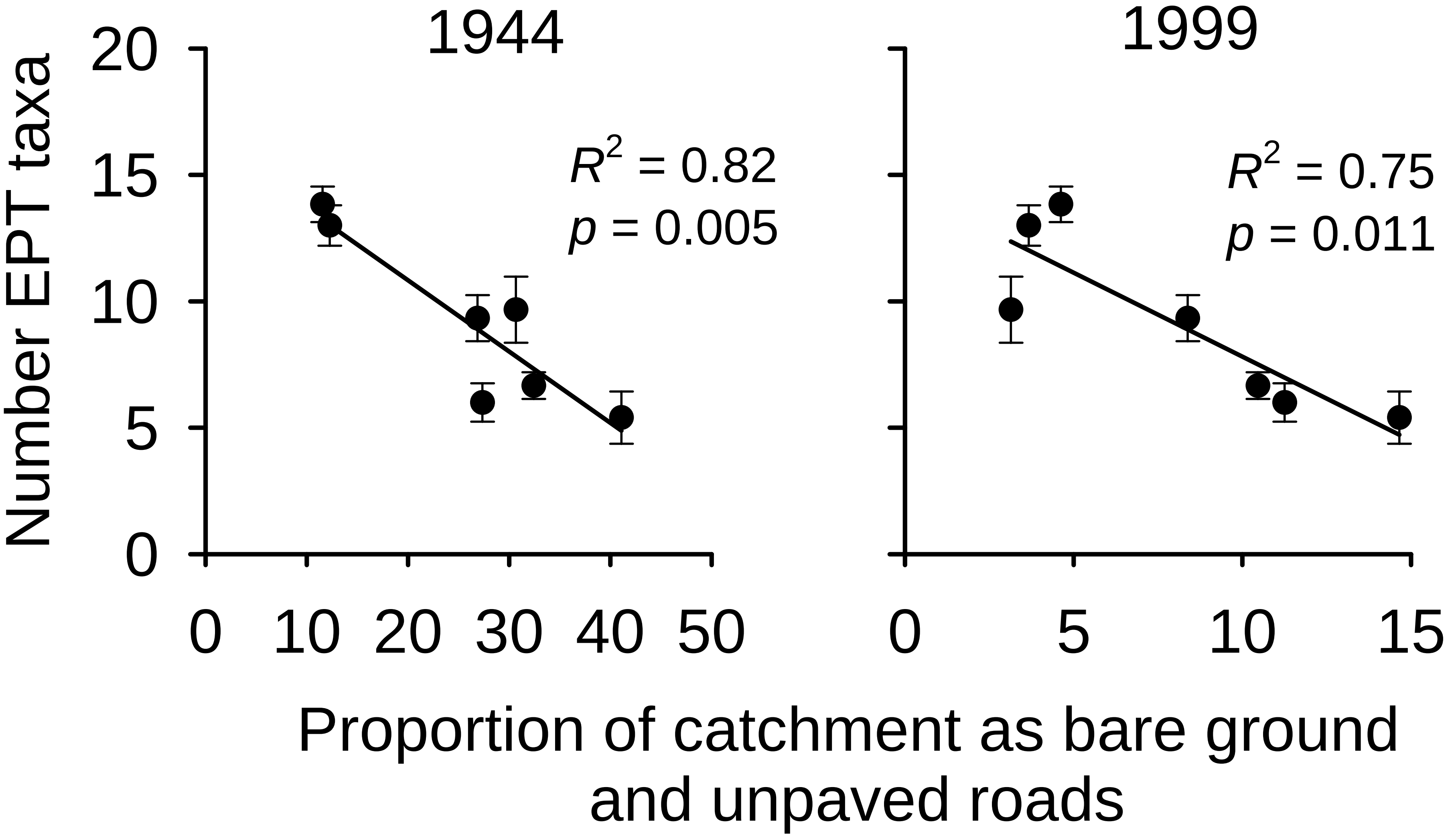
Submerged Coarse Woody Debris



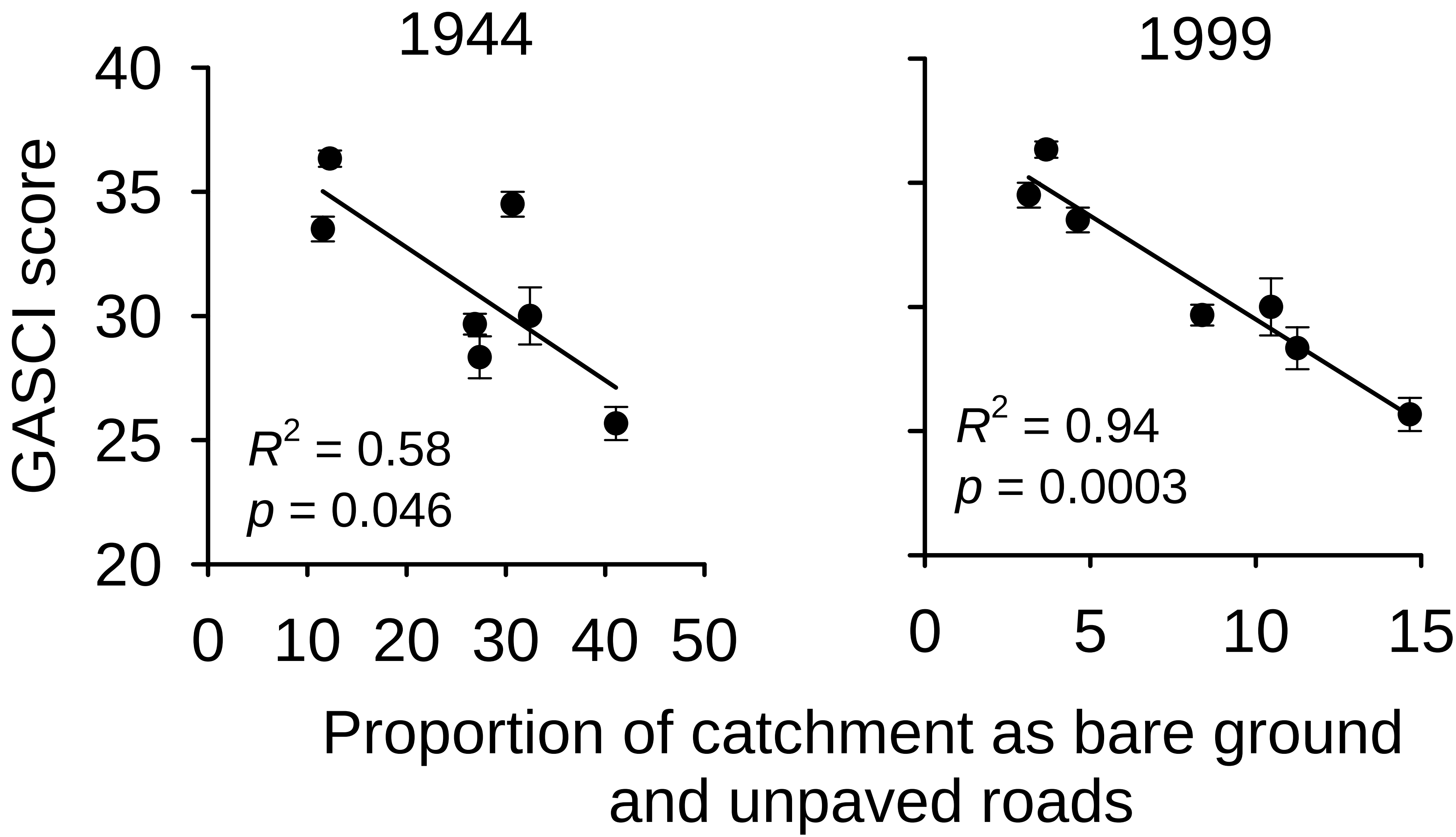
Percent Macroinvertebrates as Clingers



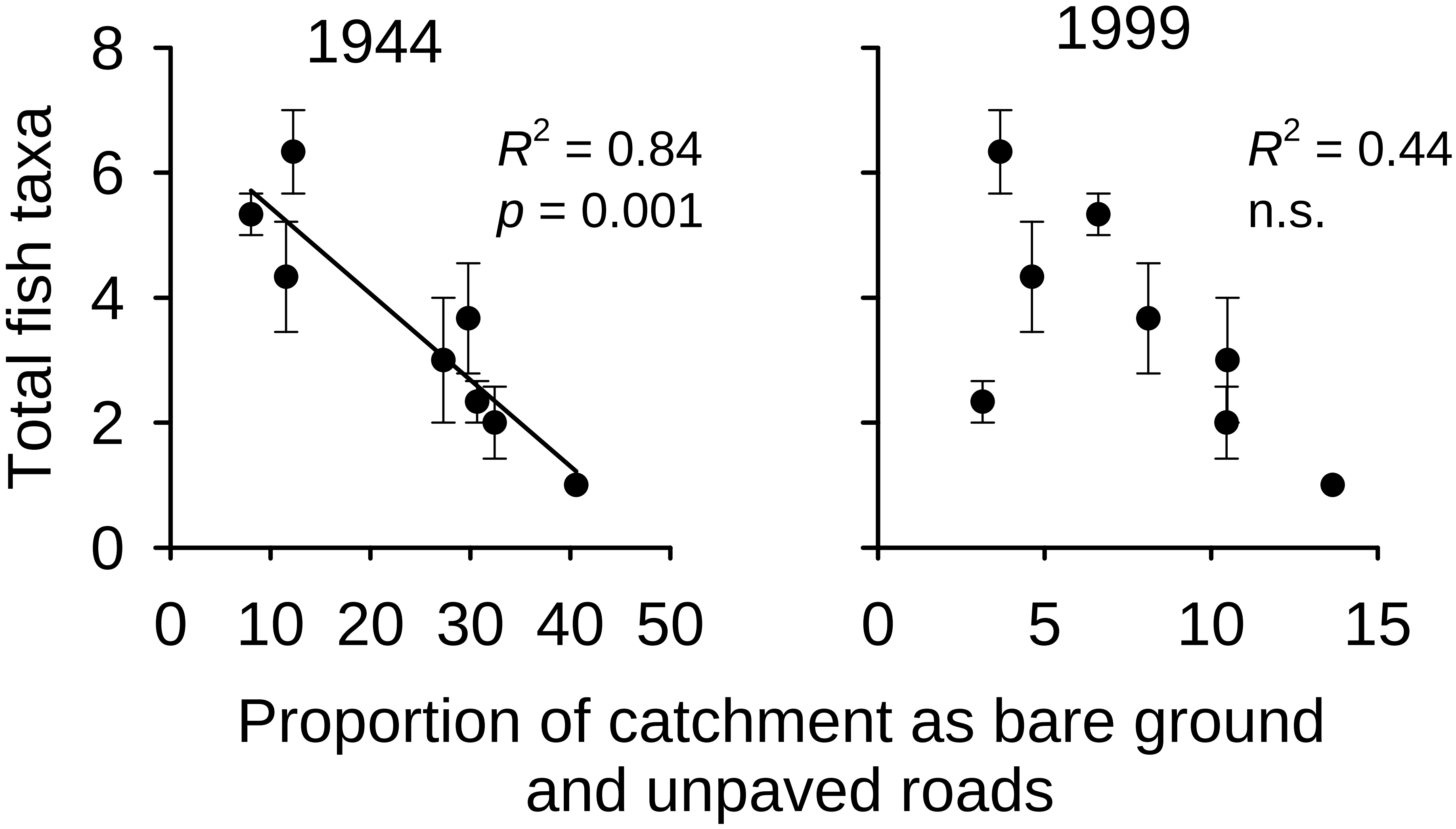
Number of EPT Taxa



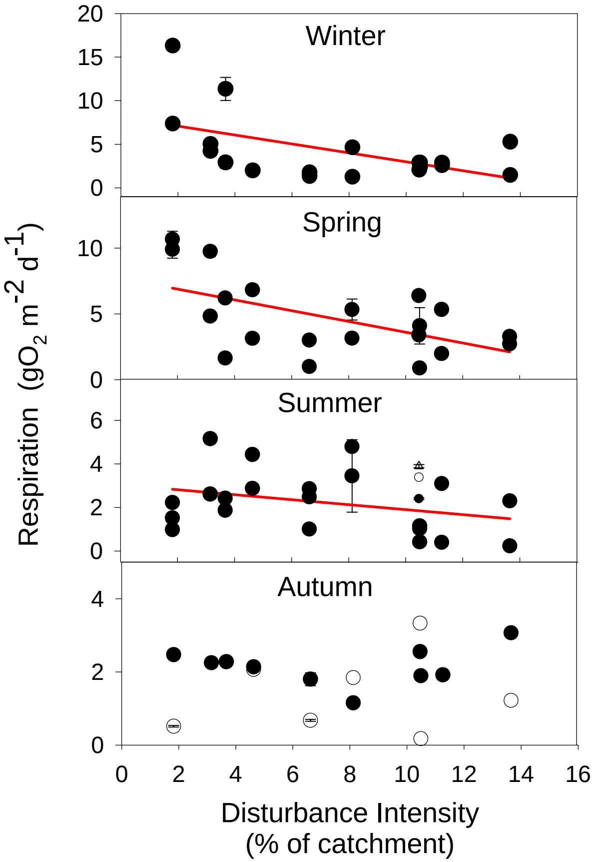
Georgia Stream Condition Index

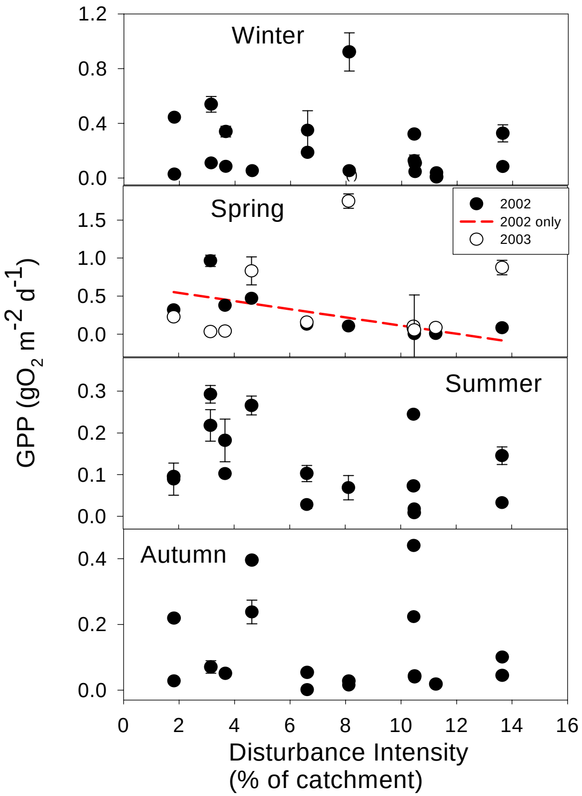


Number Fish Taxa



Ecosystem Process:
Stream Metabolism





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

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

Summary

- **DOC** and **pH**
  - weak indicators
  - best explained by contemporary land use
- **Stream physical habitat:**
  - **CWD, BPOM, Flashiness**: good indicators and best explained by contemporary land use
  - **Stability**: weak indicator, explained by historic land use
- **Macroinvertebrates:**
  - **EPT**: good indicator, explained by historic land use
  - **Chironomidae richness** and **GASCI**: strong indicators and no legacy effect
- **Fish:**
  - **Assemblage metrics**: poor indicators, related to historic land use.
  - **Population metrics**: good indicators, both sensitive and tolerant populations related to contemporary land use

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Submitted Data to the SEMP Data Repository

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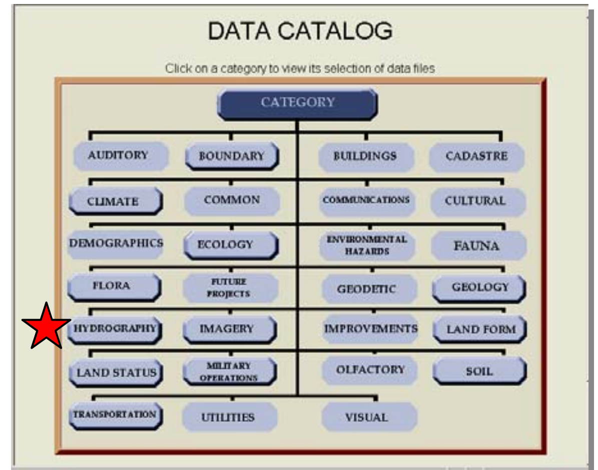
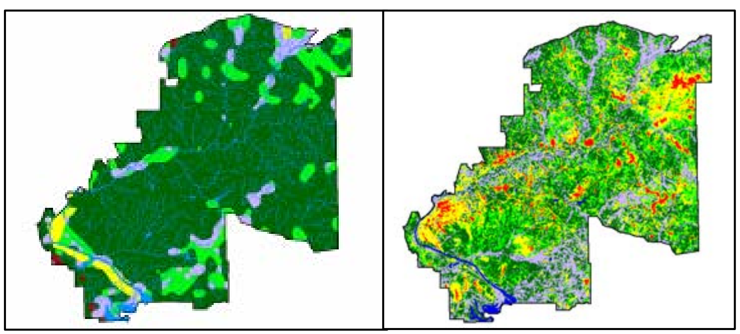
Oak Ridge National Laboratory

- Landscape Data
- Understory Vegetation
- Microbial Community
- Benthic Invertebrates
- Storm Chemistry Data





Historical and Current Land Cover

Integration

Contributions to Other SEMP Projects

- Criteria for selecting a suite of indicators
- Protocol for selecting indicators
- Data from our studies on indicators: terrestrial, stream, and soil microbes
- Historical vegetation map
- Disturbance experiment

Coordination with Other SEMP Projects

- Baseline information provided by ECMI and LCTA
- Co-location of sampling sites and sharing of data with other SEMP projects
    - Storm hydrological chemistry
    - Stream macroinvertebrates
    - Soil samples
- A comprehensive picture of changes in microbial community structure

Products

Publications:

Journal: 8 published or in press and 7 in review

Book chapter: 1

Other: 3

Presentations:

32 Professional meetings – for example:

Alabama Water Resources Conference
American Society of Testing and Materials (plenary)
Ecological Society of America (symposia)
Ecological Society of Germany, Switzerland and Austria (plenary)
American Society of Agronomy (symposium)
DoD Conservation Conference
Geological Society of America (symposium)
International Association of Landscape Ecology
Integrating the Science (Plenary)
North American Benthological Society
Southern Forestry and Natural Resource Management GIS Conference
Society of American Archaeology
Ecology Interactions in the Microbial World (symposium)
The World Conservation Union (IUCN) workshop

8 Other meetings

Outreach to other efforts

- Co-Chair NEON workshop on land use and habitat alteration, August 2004
- Co-Chair NEON workshop on climate change, August 2004
- Member, Science Advisory Committee of the US Department of Interior Grand Canyon Monitoring and Research Center, 2000-2004
- Member: National Academy Committee on Ecological Impacts of Road Density, 2001-2004
- Environmental Protection Agency Scientific Advisory Board
  - Ecological Processes and Effects Committee-Chair 2002-2004
  - Chair of review panel of EPA's report on the Environment, 2004
- Advisory Committee and participant in workshop and symposium on "Land Use in Rural America" 2001-2003 *
- Scientific Review Committee for The Nature Conservancy, 2000-2001
- Sustainable Biosphere Initiative, Chair of Advisory Committee for the Land Use Initiative, 1999-2000

* Theobald, D.M., T. Spies, J. Kline, B. Maxwell , N. T. Hobbs, V. H. Dale. In review. Ecological support for rural land-use planning and policy. Ecological Applications.

Dale, V. H., S. Archer, M. Chang, and D. Ojima. In press. Ecological impacts and mitigation strategies for rural land management. Ecological Applications.

Next Steps

- Complete data analysis
- Submit scientific papers
- Debriefing for Fort Benning resource managers
- Poster at SERDP Symposium
- Lessons learned from the application of experimental disturbances
- Final report
  - clear definition and descriptions of each indicator
  - sampling protocols
  - laboratory protocols
  - data analysis and interpretation guidelines
- Testing of indicators
  - DMPRC proposal (submitted February 2004)
  - Fort Bragg Fall Line proposal (revised version submitted Sept 2004)