Ecological Consequences of Land Use Change in the Southern Appalachian Mountains

Renewal Proposal Submitted to

Long-Term Ecological Research Program

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I. RESULTS FROM PRIOR NSF SUPPORT (DEB-9632854)

The southern Appalachian Mountains are characterized by steep environmental gradients and a complex pattern of current and historic disturbances that profoundly influence terrestrial and aquatic ecosystems. Understanding these complex interactions across a range of scales unified our 1996-2002 LTER research, while the >60 y record of ecosystem research in the Coweeta Basin provided a critical link to regional, national, and international research networks. The highlights of our research findings from prior support are grouped into the three initiatives of our prior proposal (DEB-9632854): (A) to characterize disturbance and environmental heterogeneity; and to determine the effects of disturbance and environmental heterogeneity on (B) populations and communities and on (C) biogeochemical cycling and ecosystem processes.

I.A. Characterizing Disturbance and Environmental Heterogeneity

Elevation and landform are key drivers of environmental heterogeneity in the southern Appalachian Mountains. A vegetation map of the Coweeta Basin derived from over 400 permanent plots was combined with basin-wide climate modeling to determine how well forest composition and productivity were predicted by topography (Bolstad et al. 1998). Vegetation diversity decreased with increasing elevation, but was not influenced by landform; productivity responded to both landform (increasing from ridge to cove) and elevation (increasing from high to low).

Paleoecological analysis of fossil pollen shows that elm, hornbeam, hemlock, birch and pine were less important in pre-European forests than in 20th century secondary forests (Lynch and Clark, in prep.). Fossil pollen and other evidence suggest that human use of fire before AD 800 probably altered forest composition in favor of oaks. Charcoal accumulation increases dramatically in the early 19th century in tandem with the sharp increase in human population. This and other work in preparation (e.g., Gragson and Jurgelski in prep) provide some of the first systematic retrospective insights on land use in the southern Appalachian Mountains.

Contemporary land-use changes were studied in four representative areas and the changes in land-use/land cover (LULC) mapped for 1950, 1970 and 1990 using aerial photos and satellite imagery to create a common data set. A spatially explicit model of land-use change over the 40-year period (Wear and Bolstad 1998) identified physical and human factors determining land-use patterns, e.g., topography and the primary road network strongly influenced building density and land-cover change. Land-cover changes are more frequent at lower elevations and near roads suggesting that development concentrates in sensitive riparian areas (Wear et al. 1998).

I.B. Effects on Populations and Communities

We studied how plant and animal populations respond to biotic and abiotic variation at plot-to-landscape scales, as well as how biota responds to past and present land use patterns.

I.B.1. Causes of Community Structure. Debate continues over the relative importance of natural disturbance versus biotic interactions in maintaining the structure and diversity of ecological communities. Our 10-year research shows (Grossman et al. 1998) that hydrologic variability (i.e., floods and droughts) impacts fish assemblage structure and diversity more significantly than biotic interactions (i.e., predation or interspecific competition). The presence and relative abundance of fish species in assemblages cluster by hydrologic period (i.e., pre-drought, drought, and post-drought) rather than calendar year.

Fish and crayfish were excluded from streams draining an intact forest (Ball Creek) and a pasture (Jones Creek). Chlorophyll *a* and ash free dry mass were higher, and aquatic insect larvae were larger (>4 mm) in exclusion than control areas of both streams. We concluded that macrobiota influence the structure of southern Appalachian benthic communities by (a) decreasing the amount of organic matter (algae and detritus) available for other consumers, and (b) preferentially preying on certain sizes and taxa of invertebrates (Schofield 2001).

Five research plots established along an altitudinal gradient varying in species distribution, light attenuation, and herbivory yielded vegetative biomass figures ranging from 150 Mg $ha^{-1}yr^{-1}$ in the moisture- and nutrient-limited xeric oak-pine site to 236 Mg $ha^{-1}yr^{-1}$ in the cove site. We used seed dispersal and seedling demography models to identify short dispersal distances as limiting the availability of *Quercus, Cornus, Carya, Fraxinus, Pinus rigida*, and *Nyssa*, although not *Acer, Liriodendron, Tsuga*, or *Betula*. Nevertheless, seed production and dispersal are much less limiting than germination success (Clark et al. in review).

<u>I.B.2. Impacts of Land-use Change on Terrestrial and Aquatic Biodiversity</u>. We used the LULC database noted in Sec. I.A to establish study sites of biotic responses to past and present land use. Vascular plants, birds, ants, terrestrial salamanders, fish, and aquatic invertebrates were sampled at 22-24 sites each in the Little Tennessee (LT) and the French Broad (FB) River watersheds differing in current landscape configuration and land-use history. Bird diversity declined with forest patch size (Pearson and Smith in prep), which in turn influenced plant community composition (Pearson et al. 1998). Some plant groups (e.g., *Liliaceae* and myrmecochores) with diaspores dispersed by ants were scarce or absent in patches subjected to intensive past land use (Pearson et al. 1998). Land-use history was more important than patch size in explaining variation in abundance and composition of seed-dispersing ants (Mitchell et al. 2002).

Terrestrial salamander diversity did not differ, however, with land-use history although abundance was higher at sites with little history of human use (Hicks and Pearson in review). Forb abundance and distribution were highly correlated with measured light (PAR) and soil moisture levels, but not with soil nutrient levels (Pearson and Smith in prep). Our analysis indicates that cove hardwood and oak-pine communities have been most affected by land-cover changes since 1950, and species-rich cove hardwood communities are most vulnerable to future land-use change (Turner et al. in review).

The current invertebrate and fish diversity of aquatic communities is best predicted by land use in the 1950s, indicating that past land use and in particular agriculture produces long-term modifications in aquatic systems regardless of reforestation. Land use in the 1970s explains the current ratios of endemic to cosmopolitan species (Scott and Helfman 2001) while fish density and diversity are affected by upstream than streamside deforestation (Jones et al. 1999). The "legacy effect" and upstream effects point to the importance of large-scale and long-term restoration, and suggest that localized efforts may contribute little (Harding et al. 1998).

A surprising finding was that upland areas of high fish endemism are being invaded, displaced, and homogenized by native species, not by exotics. Native invaders capitalize on habitat degradation from changes in land use. Since traditional metrics of stream integrity overlook native invasion, the early signs of stream ecosystem deterioration may be similarly overlooked (Scott 2001, Scott and Helfman 2001, Scott et al. in review).

I.C. Effects on Biogeochemical Cycling and Ecosystem Processes

Understanding biogeochemical cycles and ecosystem processes in terrestrial and aquatic systems is the longest continuous data-collection effort of the Coweeta LTER Project. In 1996-2002 we investigated the role of environmental heterogeneity, disturbance/stress, and their interaction in regulating ecosystem pools and processes in streams, riparian zones, and forests.

I.C.1. Effects of Natural Disturbances in the Coweeta Basin. Hurricane Opal struck the Coweeta basin on 05 October 1995. Wind gusts exceeded 130 km/h and 23 cm of rain fell. In rapidly assessing the hurricane damage we discovered that microbursts had generated replicated gaps across the site. We leveraged LTER infrastructure and long-term data to obtain additional funding (NSF DEB-9615661) and explored the effects of gap creation on insect herbivores and the foliage quality of surviving trees. Our results revealed that increased insolation, not nutrient availability, was the major factor influencing post-hurricane foliar quality (Hunter and Forkner 1999).

We also compared a hurricane-disturbed hillslope to one where rhododendron (a species that has increased in cover since 1976) was experimentally removed. Between 1995-2000, soil water nutrient concentrations from soil lysimeters did not vary significantly on the experimental removal hillslope, but on the hurricane-disturbed hillslope NO_3-N concentrations increased at least two orders of magnitude (Wright and Coleman 2002). There were also marked and persistent changes in SO_4 (decrease), Ca (increase), and Mg (increase), with the greatest variance occurring in summer and early autumn (Yeakley et al. in revision).

In May 1998 we had a study linking canopy herbivores to soil processes in progress when a sawfly (Hymenoptera: *Symphyta*) outbreak took place in a high-elevation hardwood forest in the Coweeta Basin (Hunter 2001). Using the instrumentation in place at defoliated and undefoliated sites we were able to measure the effects of the outbreak on soil nutrient dynamics, soil respiration, and litter decomposition. Within one month of the sawfly outbreak, elevated levels of nitrate were measured in throughfall, soil resin bag samples, and stream water draining the affected watershed. Furthermore, insect frass generated "blooms" of collembola and nematodes in forest litter (Reynolds et al. 2000, Reynolds and Hunter 2001, Hunter et al. in review).

I.C.2. Long-Term Measurements in the Coweeta Basin. The length of our long-term data record is critical to our understanding of fundamental processes in the southern Appalachian Mountains. We analyzed 23 years of data for trends and dynamics in inorganic N deposition and loss for 6 reference and 8 disturbed watersheds at Coweeta (Swank and Vose 1997). Reference watersheds are in a transition phase between stage 0 and stage 1 of N saturation that is partially attributed to significant increases in NO_3 and NH_4 in bulk precipitation and/or reduced biological demand due to forest maturation. Disturbed watersheds were in stages 1, 2, and 3 of N saturation.

Hydrologic and solute responses were analyzed for Watershed 7 (WS 7) at regular intervals since it was clearcut and cable-logged in 1977 (Swank et al. 2001). Explanations for rapid water yield recovery and nutrient retention were linked to long-term process level studies (Knoepp and Swank 1997, Elliott et al. 1999). We used time series analysis of WS 7 and its reference (WS 2) to examine long-term stream water NO_3 concentrations (Worrall et al. 2001, Worrall et al. 2002). We determined that the hydrological pathways and N reserves of WS 7 are in metastable equilibrium, but in dynamic equilibrium with respect to long-term temperature change. These results are guiding ecosystem management in the southern Appalachian Mountains (Meyer and Swank 1996).

We have monitored the long-term recovery of a WS 7 stream by periodically measuring litter content, leaf decay rates, benthic organic matter, stream geomorphology, nutrient and dissolved organic carbon concentrations, and invertebrate community structure and production (Webster et al. 1992). Stream geomorphology and biology changed in response to experimental additions of woody debris: depth increased, current velocity decreased, cobble substrate was covered by sand and silt, and benthic FPOM and CPOM standing stock increased (Wallace et al.

1995). Invertebrate community structure changed dramatically, although solute uptake lengths did not.

We synthesized breakdown and transport of allochthonous detritus from many Coweeta stream studies, and demonstrated that leaves generally break down near where they enter streams at a rate predicable from litterbag measurements (Webster et al. 2000). Fine particles of organic matter, however, travel long distances before being metabolized (Webster et al. 1999). We also found that small streams are very efficient in retaining dissolved inorganic nitrogen (Tank et al. 2000, Peterson et al. 2001). Flood entrainment of floodplain detritus is a measurable source of organic matter in the middle reaches of the Little Tennessee River, but is nevertheless small compared to leaf fall and in-stream primary production (Neatrour 1999).

We used the extensive data for above- and belowground resources from the Coweeta LTER terrestrial gradient plots (i.e., five plots, 788 m to 1389 m in elevation) to examine soil biological quality (Knoepp et al. 2000). In ranking soil biological indices such as soil carbon and nitrogen availability, microarthropod populations, and forest floor processes we were able to compare aboveground plot overstory productivity and diversity.

I.C.3. Scaling to the Region. We combined small-scale measurements taken in 2000 at three locations in the Little Tennessee and French Broad watersheds, and from southwestern Virginia with landscape-level modeling to determine the impacts of land-use change on C budgets. The sites selected differ in land use (i.e., pasture, early successional forest <30 y, mature secondary forest 80-150 y, and old-growth forest >150 y) and topographic position (i.e., cove, slope, and ridge). We are quantifying C pools (soil, forest floor, and plant) and measuring flux rates to develop net ecosystem C budgets, and our initial results indicate large differences in woody biomass pools among land-use types (Bolstad and Vose in prep).

Woody biomass in old growth forest is 2- to 8-fold greater than in early and mid-successional forest, and the variation due to topographic position is of lesser magnitude than the variation between land-use types. If respiration rate differs widely among species, then species composition could directly influence C balance within and between land-use types. We are therefore measuring tree-stem CO_2 flux attributable to both growth and maintenance respiration, and analyzing the roles of litter and soil temperature, soil moisture, fine and coarse root mass, root and soil N and C, and litter mass N and C in regulating these differences.

The dramatic effects of land-use patterns and environmental heterogeneity on populations and communities led us to begin a new 30-year study of stream regions forecast to differ over time in type and risk of development (Gardiner et al. in prep). Stream indicators (e.g., water quality, fish populations, benthic invertebrates, stream morphology, riparian size, and condition) were sampled at 8 sites in 2000 and will be sampled every five years until 2030. This research integrates social and economic modeling with aquatic and riparian ecology in novel ways that can unravel the complexities of southern Appalachian disturbance and heterogeneity.

I.D. Intersite and Collaborative Activities

In the past 6 years we led or participated in more than 30 LTER intersite or international research projects, and are currently involved in 11 that include virtually all LTER sites and a joint USA/Russia bilateral project. The collaborations include comparison of organic matter budgets in streams within and outside the LTER network and a chironomid bioassay technique to assess quality of fine particulate organic matter in streams from five LTER sites. It also involves examining the linkage between biodiversity of litter-inhabiting microarthropods and the decomposition of leaf litter in aquatic and terrestrial ecosystems at Coweeta, Luquillo, and La Selva (Heneghan et al. 1999).

Coweeta scientists participated in a cross-site comparative mycorrhizae ecosystem function experiment at Bonanza Creek, Sevilleta, and sites in California. They also participated in the 10-year LIDET (Longterm Intersite Decomposition Experiment Team) study designed to test the effects of substrate quality and macroclimate on long-term decomposition and nutrient release dynamics of fine litter at 28 participating sites. In the LINX project (Long-term Intersite Nitrogen Experiment), investigators at several LTER sites (including Coweeta) from across North America and Iceland followed nitrogen flows in riparian and stream ecosystems. In mid-2001 they received additional NSF funding from the Integrated Research Challenges program.

I.E. Summary

Our 1996-2002 research revealed surprisingly strong effects of land-use history on the current state of terrestrial and aquatic ecosystems in the southern Appalachian Mountains. Natural disturbances and human land use interact with steep environmental gradients to produce complex spatial patterns and temporal dynamics at the individual, population, community, ecosystem, and landscape levels. Coweeta LTER results and collaborative networks provide the foundation for understanding past, present, and future conditions of southern Appalachian ecosystems. Our 1996-2002 research results position us for significant advances in the scientific understanding of the spatial, temporal, and decision-making components of land use and land-use change in the southern Appalachian Mountains during 2002-2008.

Investigators associated with the Coweeta LTER Project produced 225 publications between 1996-2002 (**Table I.1**; complete list contained in Supplementary Document **Table S.1**). Our online searchable citations database contains full information and abstracts on 1146 publications http://coweeta.ecology.uga.edu/publications.html), and copies of all publications are available by request from the Coweeta Hydrologic Laboratory in Otto, NC.

Table I.1. Summary of Coweeta LTER Publications, 1996 to 2002.

Total Publications	Journal Articles	Books	Book Chapters	Dissertations and Theses	Other Publications
225	160	2	26	12	25

The Coweeta LTER website provides public access to site descriptions, publications, data sets, and other information that steadily attracts more visitors each year. Between 1997 and 2002 there was a 157% average increase each year in the number of unique machines accessing our website (n = 33,225 in 2001); there was a 170% increase each year in the number of “hits” (n = 417,761 in 2001) equivalent to an average of 11 accesses per unique machine. Accesses and downloads of Coweeta LTER Type I data are summarized in **Table I.2** (Supplementary Document **Table S.2** contains the complete list of all online Type I and II datasets).

Table I.2. Type I Data (publicly accessible) download statistics, March 1999 to January 2002.

Unique Datasets Downloaded	Users Accessing Datasets	Total Datasets Downloaded
89	198	819

Notes: a) Download statistics for Type II data (access limited to project personnel) are not currently logged, but we will start logging them in 2002; b) Countries accessing data include Australia, Canada, Finland, Germany, Ireland, Italy, Mexico, New Zealand, Portugal, Turkey, United Kingdom, and USA.

II. PROPOSED RESEARCH

II.A. Integrative Overview

The Coweeta LTER Research Program has evolved since 1980 from a site-based to a site- and region-based project examining the effects of disturbance and environmental gradients on biogeochemical cycling, and the underlying watershed ecosystem processes that regulate and respond to those cycles. The current interdisciplinary research integrates ecological and socioeconomic components across 54,000 km^2 (**Figure 1**) of the southern Appalachian Mountains, a biogeophysical and socioeconomic region in which evolutionary and historical processes converge (Whittaker 1956, Markusen 1987, Barnes 1991, Kretzschmar et al. 1993, Bailey 1996). Our research objective in 2002-2008 is to advance scientific understanding of the spatial, temporal, and decision-making components of land use and land-use change in the southern Appalachian Mountains over the last 200 years, and forecast patterns into the future 30 years. Our guiding hypothesis is that the frequency, intensity, and extent of land use represents human decision-making in response to socioeconomic and biogeophysical conditions with consequences that cascade through ecosystems.

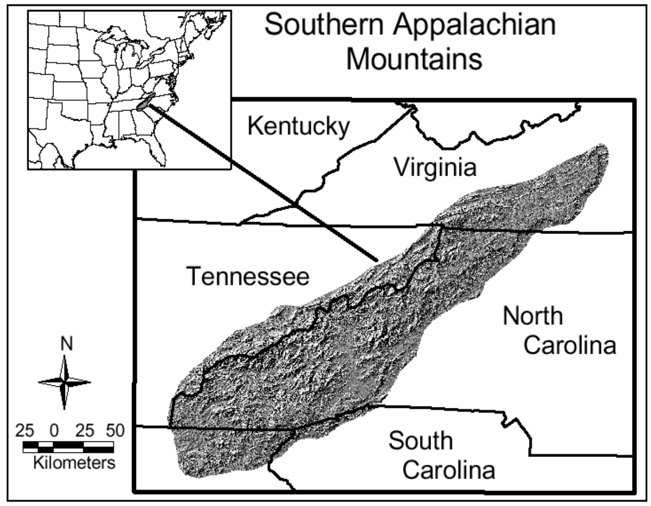

Figure 1. The southern Appalachian study region for the Coweeta LTER Project.

Our prior research demonstrates that current ecological conditions, including aquatic and terrestrial community structure, nutrient pools, and water quality are not explained without considering past and present land-use. Understanding the causes and consequences of land-use change is a critical research challenge at both national and global scales (Turner et al. 1996, Vitousek et al. 1997, Dale et al. 2000, NRC 2000). Our proposed research will address ecological and socioeconomic aspects of land-use change while continuing our studies of environmental gradients and natural disturbance regimes. This will produce a more complete understanding of ecological dynamics in the southern Appalachian Mountains and make possible the development of reasonable forecasts of its future ecological state.

Land use represents a series of decisions and actions carried out by humans to obtain products and/or benefits by using land resources (Veldkamp and Fresco 1996, Foster et al. 1997, Vitousek et al. 1997, Redman 1999b, McConnell and Moran 2001). Despite its pervasiveness, the causes of land use and the consequences of land-use change are poorly predicted by physical laws (Ulanowicz 1986, Pickett et al. 1994, Grove and Burch 1997, Vitousek et al. 1997). For example, recovery of invertebrate and fish assemblages in forested Appalachian streams lags behind the recovery of riparian forests by at least 50 years as a consequence of the complex interaction between human and natural forces (Harding et al. 1998). To achieve a comprehensive understanding of land use and land-use change requires focusing on spatial, temporal, and decision-making components of the process. It also requires resolving among contrasting process parameters: onset vs. duration, distinct land uses vs. site-specific changes, short-term vs. directional change, and past disturbances vs. continuing disturbances (Turner et al.

1990, Bahre 1991, Holling 1992, Russell 1997).

Our proposed research is organized into three initiatives: (1) Characterization of the Socio-Natural Template, (2) Ecosystem Responses to the Socio-Natural Template, and (3) Forecasting Ecosystem Responses to Changes in the Socio-Natural Template (**Figure 2**). By reconstructing *when* and *where* particular natural and human events occurred, we will quantify our understanding of spatial heterogeneity in disturbance legacies and the temporal heterogeneity

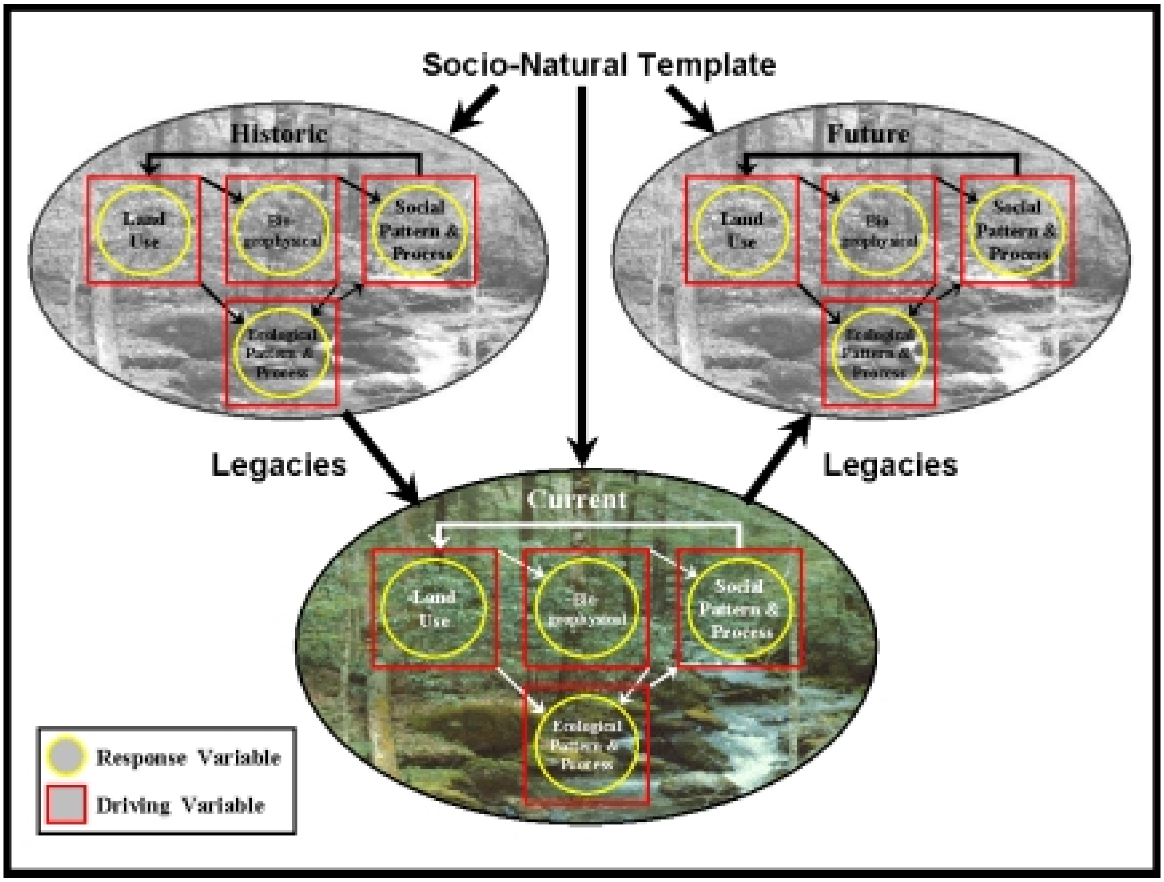

Figure 2. Land use is human decision-making in response to socioeconomic and biogeophysical conditions with consequences that cascade through ecosystems.

of disturbance trajectories. From these we will calculate the duration and magnitude of consequences at different organizational levels to develop forecast scenarios of future ecological responses. Our integrated scientific research will provide both a description as well as an explanation of the underlying causes of land use and the consequences of land-use change for southern Appalachian ecosystems and society. It thus recognizes the complexity of land use as a process and the research needs as defined in the LTER Program and the broader scientific community (Redman 1999a, Kinzig et al. 2000, Calwell 2001). **Table II.1** lists all project Co-PIs along with the expertise they bring to the project and the principal research activities they will be collaborating on.

II.B. Initiative 1 - Characterization of the Socio-Natural Template

Research activities in **Initiative 1** will focus on collecting coarse grained information on the spatial and temporal variation in factors relevant to land use and land cover change, environmental gradients, and disturbance regimes (Geoghegan et al. 1997, Koning et al. 1999, Clark et al. , Endre and Green 2000, Grimm et al. 2000). The purpose is to develop a common, web-accessible dataset for use by all project investigators (see **Section 4**) and identify driving variables for research activities in **Initiative 2** and **Initiative 3**. While our research does not depend on them, we do anticipate collaborations in this initiative with the UVT Gund Institute for Ecological Economics (pending NSF 0215885) and the ASU Center for Environmental Studies (pending NSF 0216560).

Table II.1. Project Co-PIs by institution of affiliation, specialty and research project(s).

Investigator	Institution	Specialty	Research Project(s)
F. Benfield	Virginia Tech	Stream processes	1.3.c; 2.2.b; 2.3.a; 3.2.a; 3.2.b
P. Bolstad	U Minnesota	Forest processes	1.1; 1.3.b; 1.3.c; 2.2.a; 3.1
J. Clark	Duke U	Forest succession	2.4.a; 2.4.b; 2.4.c; 3.1
B. Clinton	USDA-USFS	Response to disturbance	1.2; 1.3.a
D. Coleman	U Georgia	Soil ecology/nutrient cycling	2.3.b
K. Elliott	USDA-USFS	Plant community ecology	1.2; 1.3.a
T. Gragson	U Georgia	Human disturbance processes	1.1; 1.3.a; 1.3.b; 1.3.c; 3.1; 3.2.c
G. Grossman	U Georgia	Community/population ecology	2.1; 2.2.c; 3.1
B. Haines	U Georgia	Nutrient cycling in plants	2.4.a; 2.4.b; 2.4.c
G. Helfman	U Georgia	Fish ecology	2.2.b; 3.2.a; 3.2.b
R. Hendrick	U Georgia	Forest ecology	2.4.a; 2.4.b; 2.4.c
M. Hunter	U Georgia	Canopy herbivory	2.3.b; 2.4.b; 2.4.d
B. Kloeppel	U Georgia	Physiological gradients	1.2; 2.4.a; 2.4.b
J. Knoepp	USDA-USFS	Soil processes	1.2; 1.3.a; 2.4.b; 2.4.c
D. Leigh	U Georgia	Geomorphic processes	1.3.c; 2.2.a; 3.2.a; 3.2.b
J. Meyer	U Georgia	Stream processes	3.2.a
D. Newman	U Georgia	Forest economics/policy	1.3.b; 3.1; 3.2.c
S. Pearson	Mars Hill	Landscape ecology/modeling	2.4.a; 2.4.b; 2.4.c; 3.1
C. Pringle	U Georgia	Stream processes	2.3.b; 3.2.a
R. Pulliam	U Georgia	Theoretical ecology/modeling	2.2.b; 2.4.a; 2.4.b; 2.4.c; 3.1
B. Reynolds	UNC Asheville	Insect herbivory/litter organisms	2.4.b; 2.4.d
M. Riedel	USDA-USFS	Hydrology	1.3.c; 2.2.a; 2.2.c; 3.2.b
W. Swank	USDA-USFS	Hydrological dynamics/cycling	1.2; 2.2.a
M. Turner	U Wisconsin	Landscape ecology/modeling	2.4.a; 2.4.b; 2.4.c; 3.1
J. Vose	USDA-USFS	Forest processes	1.2; 1.3.a; 2.2.a
B. Wallace	U Georgia	Stream processes	1.3.c; 2.3.a; 3.2.a
D. Wear	USDA-USFS	Forest economic modeling	1.1; 1.3.b; 3.1; 3.2.c
J. Webster	Virginia Tech	Stream processes	1.3.c; 2.3.a; 3.1

II.B.1. Mapping Long-Term Land-Use Trajectories. We will develop decadal site- and time-specific characterizations of land use and land cover on a detailed categorical level from 1800 to the present. The questions guiding our mapping of land-use trajectories are:

1. How does land use/land cover vary across spatial, temporal and measurement scales?
2. What are the spatial and temporal linkages between biogeophysical and socioeconomic processes?
3. How is previous transformation of a site linked to subsequent transformation of the same and surrounding sites?

Our 1800 onset date marks the beginning of significant Euroamerican settlement in the southern Appalachian Mountains. From this date forward we can bring together multiple and independently derived social, economic, and biophysical evidence to map historic patterns across the region (e.g., U.S. Census and State records of various kinds, historical cartography, aerial photography, eyewitness and personal accounts). To map contemporary land use/land cover we will use medium and high-resolution satellite data (one and three m IKONOS, 15 and 30 m ETM+, and 250 and 500 m MODIS) and ground truth.

We have successfully used many of the historic sources in our analysis of the 1820 Robert Love Land Survey and our cross-sectional analysis of 19th century industrialism (Gragson and Basnet in prep, Gragson and Jurgelski in prep). We have similarly been successful in using contemporary image sources to predict overstory vegetation from terrain factors and assess changes in cover type due to land use (**Figure 3** Bolstad and Swank 1997, Bolstad et al. 1998).

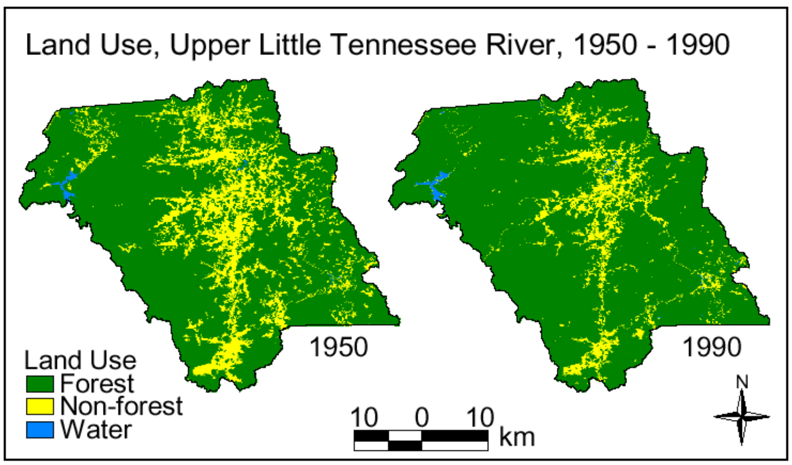

Figure 3. Non-forested land declines from over 10% to less than 5% of the Little Tennessee watershed between 1950 and 1990.

The 1800 onset date will also make it possible to evaluate the effects of critical turning points in the transformation of Appalachia (Salstrom 1994, Dunaway 1996, Yarnell 1998) including the start of market segmentation in 1820, the apogee in forest clearing after 1900, and the recreation and real estate boom beginning in 1970. We will use information-theoretic techniques (Wear and Bolstad 1998) to evaluate the land-use trajectories that will then serve as the cartographic template for other research projects as described.

II.B.2. Environmental Gradients. One of the defining characteristics of the southern Appalachian Mountains is significant and predictable environmental heterogeneity over small spatial scales; understanding how gradients influence the structure and function of watershed ecosystems has been a persistent focus of the Coweeta LTER (e.g., Knoepp et al. 2000). Along the environmental gradient, the physical template appears more important in regulating ecosystem structure (i.e., community assemblages) than function (i.e., biogeochemical cycling Knoepp et al. 2000). However, considerable gaps remain in our understanding of how environmental gradients control ecosystem structure and function, and this knowledge is critical to forecasting future ecosystem responses.

Long-term measurements have been made on a wide array of environmental variables at Coweeta (**Table II.2**), and the measurements represent one of the most comprehensive, long-term and best-studied environmental data sets in the world. We propose continuing long-term macro- and microclimatic measurements in the Coweeta basin and to characterize the larger region from climate, atmospheric deposition, stream chemistry and streamflow measurements obtained from the environmental monitoring network managed and operated by state and federal agencies (e.g., USGS, National Park Service, NCDC network). Continued measurement is critical to the proposed research since it will provide baseline data to analyze temporal trends (e.g., Swank and Waide 1988, Swank and Vose 1997), identify driving variables (e.g., Swank and Vose 1990/91, Vose and Swank 1993), and develop and validate spatially-explicit models (e.g., Bolstad et al. 1998).

II.B.3. Disturbance Regimes. Disturbance is an important driver of southern Appalachian ecosystem structure and function that interacts with human decision-making and environmental gradients. Much of our previous research on ecosystem responses to disturbance focused on a subset of important forces acting on large scales and/or short-time intervals (e.g., the pattern and magnitude of wind damage in the Coweeta Basin from Hurricane Opal,Hunter and Forkner 1999, Wright and Coleman 2002). We propose developing a comprehensive understanding of disturbance regimes for the region through a linked set of research projects focused on deriving disturbance signatures, probabilistic decadal land-use choice functions, and quantifying fluvial sedimentation patterns.

Table II.2. Characterizing environmental variation in the Coweeta LTER Program.

Data Description	Record Length	Locations	Elevational Range (m)
Air Temperature	1934 to present	12	695 to 1389
Air Relative Humidity	1936 to present	12	610 to 1417
Solar Radiation	1965 to present	2	610 to 695
Vapor Pressure	1983 to present	6	610 to 1417
Barometric Pressure	1934 to present	6	610 to 1417
Wind Speed and Direction	1936 to present	6	610 to 1417
Precipitation	1934 to present	10	695 to 1417
Atmospheric Chemistry	1972 to present	9	695 to 1417
Stream Flow	1934 to present	16	702 to 1021
Stream Chemistry	1972 to present	16	702 to 1021
Soil Moisture	1992 to present	6	788 to 1389
Soil Temperature	1978 to present	11	695 to 1417
Soil Solution Chemistry	1991 to present	5	695 to 1389

II.B.3.a. Dendroecological Analyses of Historic Disturbance Regimes. The distribution, diversity, and net primary productivity of southern Appalachia species represents the combined effects of environmental driving variables, natural disturbances (i.e., drought, insect damage, etc.), and human disturbances (i.e., logging, grazing, etc.). Previous studies of forest composition in the Coweeta Basin (Elliott et al. 1999) indicate that only 50% of the variation in the distribution of vegetation is explained by site factors such as slope, aspect, and soils.

Similarly, only 30 to 60% of ANPP variation (above-ground net primary productivity) across the landscape is explained by environmental driving variables (Bolstad et al. 2001).

We hypothesize that human disturbance will account for a large portion of the remaining variation and once its proportional contribution is determined we can improve our ability to predict vegetation composition and ANPP. We seek answers to the following questions:

1. What are the signatures for local disturbance regimes in southern Appalachian hardwoods over the last 100-200 years?
2. How much has local (small plot) disturbance regimes over the last 100-200 years affected current vegetation distribution and ANPP?

We will use dendroecological (tree ring) techniques to reconstruct disturbance histories from stands with a minimum of 10-20 stems per ha^{-1} in the 100-300 y age classes. Several stands will be located in the Coweeta basin since the disturbance history is well documented and it can serve as a cross-dating reference. We will also establish study sites in Joyce Kilmer Memorial Forest (one of the few remaining old-growth forests in southern Appalachia) and in the Little Tennessee and French Broad drainages in conjunction with other proposed research.

Each stand will be sampled with replicated fixed-area plots to determine overstory composition and size structure. Stems of all major species and size classes will be cored, air-dried, sanded, and each decade marked to visually cross-date the cores using marker rings or signatures. We will measure radial increments with a Velmex moving stage system. Disturbances will be inferred from several lines of evidence from the tree rings using standard procedures and including recruitment of new cohorts of similar ages, rapid early growth rates, sudden and sustained increases in radial growth rates, and years of very slow growth followed by a return to previous growth rates (Fritts and Swetnam 1989, Lorimer and Frelich 1989, Orwig and Abrams 1995, Grissino-Mayer et al. 1997, Orwig and Abrams 1999).

II.B.3.b. Human-disturbance: Analyses of Land-use Choices. Human land-use choices are the primary disturbance on private lands, which cover approximately 55% of the study region. Typical studies evaluate land use choice probabilities as a function of physical measures of land quality (e.g., the Von Thünen model, Samuelson 1983, the Central Business District model, Capozza and Helsley 1989), but must assume that social variables remain constant across the landscape. Historical accounts of land use in the southern Appalachian Mountains (e.g., Silver 1990, Salstrom 1994, Davis 2000) are similarly incomplete because they seldom quantify impacts across time or evaluate their heterogeneity across space.

We will derive a probabilistic model of land-use choice across the region for each decade from 1800 to the present by using land use and property records, oral histories, geneology, population and agricultural census records, and remote imagery. We will address the following questions:

1. What is the relation between land use choices and changing markets, institutions and environmental conditions?
2. How do economic transitions over time relate to the nature and the distribution of land conversion?
3. How do the costs and benefits of environmental policies affect the spatial dimensions of land use decisions across time, and therefore the storage of carbon or delivery of sediment to streams?

In this research we will combine empiricism with modeling to achieve a fine-grained assessment of owner response (Waldrop 1992, Casti 1994, Axelrod and Cohen 2000). We will begin with factors such as price and technology on the assumption that land is allocated to the use with the highest value: the probability of observing land use j is related to the rent accruing to land use j. The estimated production functions may not capture all relevant attributes so we will also include site variables affecting access and operational expenses (i.e., slope, distance-to-roads) and therefore the relative returns to different land uses (Wear and Flamm 1993, Turner et al. 1996). Land-use choices will be modeled using a procedure we have already developed (Wear and Bolstad 1998), and which has the added advantage of allowing us to estimate land use probabilities for sites and periods for which neither imagery nor records are available.

Macro-level forces such as how institutional circumstance affect owner decisions about land use will be assessed from information we will collect on taxation, zoning, and policy at county and state levels (Scott 1995, Knoke 2001). We will use organizational network analysis to assess the effectiveness of owner decisions in transforming inputs into outputs (Hannan and Freeman 1977, 1989, Carroll and Hannan 2000).

II.B.3.c. Impacts of Historic Land-use on River Channels and Floodplains. Our focus will be on changes in river channel morphology and bottomland sedimentation patterns in the upper Little Tennessee and French Broad River systems. These rivers and their wide alluvial valleys underwent pronounced changes beginning in the late 1700s. The changes steadily increased through the mid to late 1800s as widespread agricultural and timber-harvesting activities accelerated erosion and sedimentation across the region (Ayres and Ashe 1905, Glenn 1911). Subsequent changes in land use played an equally important role in the ongoing and complex sequence of fluvial landscape response and recovery.

Preliminary observations and a radiocarbon date from an exposed stream bank (**Figure 4**) indicate prehistoric sedimentation rates of 0.5 mm/y, and 5.0 mm/y since 1800. Preliminary calculations suggest major morphological changes in floodplains following European settlement. We anticipate these changes can be linked to flood frequency, and ecological interaction between the channel and its floodplain. We therefore seek answers to the following questions:

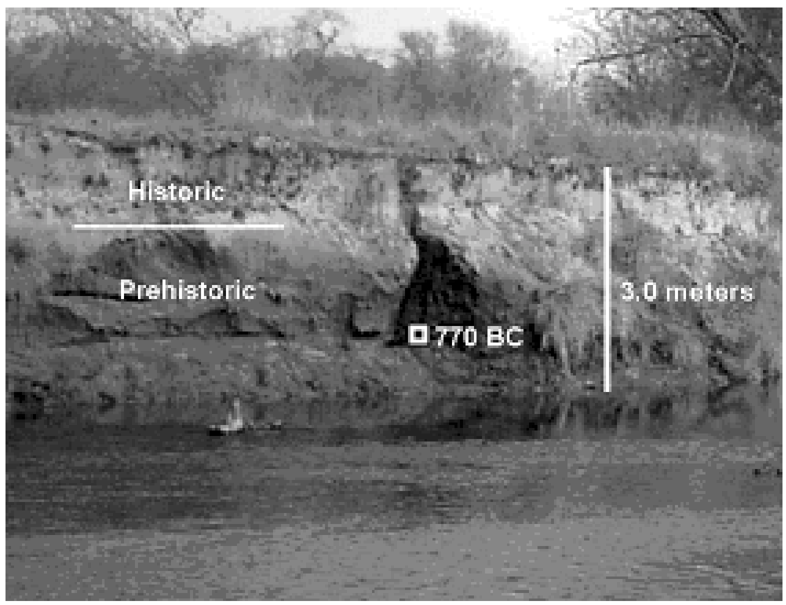

Figure 4. Little Tennessee River cutbank showing historic and prehistoric strata, and the position of a radiocarbon date of 770 BC (UGA-9054). Long-term average sedimentation rates in the prehistoric strata are about 0.5 mm/y versus 5.0 mm/y in the historic strata.

1. What is the chronology, frequency, and magnitude of floods and their interactions with vegetation and land use?
2. What is the rate of sediment accumulation and related changes in channel morphology?
3. What are the impact signatures of distinct disturbance regimes?

In year one (2002-2003) we will select three 0.5 km reaches on the mainstem of the Little Tennessee River that include sites studied with 1996-2002 funding (Grubaugh et al. 1996, Rosi-Marshall and Wallace 2002, McTammany et al. in prep, Neatrour et al. in preparation). We will survey on each reach approximately 10 valley and three stratigraphic cross-sections, sampling 10 to 20 profiles on each (depending on valley width) using a drill rig or a backhoe. In year two, we survey and sample two tributaries of the Little Tennessee River representing end-points on the continuum of early 1990 land disturbance. Based on our results, we will extend our sampling in subsequent years to 4-6 tributary streams selected to represent the range of known land uses and their trajectories.

Using paleoflood hydrology techniques (Baker et al. 1988) we will analyze sediment cores and bank exposures, and the stream channel cross-sections to determine regional flood frequency curves and how the historical flood regime has changed since 1800 due to human land use. We will reconstruct flood chronology and rates of sediment accumulation by dating recovered sediments (e.g., radiocarbon, ^{137}CS, ^{210}Pb, and dendrogeomorphic methods). Land-use narratives will be developed for valley cross-sections to highlight the modes of temporal legacies, critical scales, or shifting stability regimes (e.g., Gragson and Jurgelski in prep). Finally, we will model flood regimes for the past 200 years with flow simulations (i.e. HEC-RAS program) to evaluate historical changes in stream channel morphology and streambed sedimentology.

II.C. Initiative 2 - Ecosystem Responses to Variation in the Socio-Natural Template

Ecosystem responses are often subtle and can take decades or centuries to be observed (Webster et al. 1992, Swank et al. 2001). Coweeta researchers have used short- and long-term studies since the 1930s to document the interactions between aquatic and terrestrial systems, within-watershed processes, and the regulation of ecosystem structure and function across southern Appalachia (Webster and Meyer 1997). Understanding is nevertheless limited about how distribution and productivity of forest species is linked to underlying causes, or how different land uses and land-use changes cumulatively affect water quality, quantity, and aquatic biota. This constrains efforts to forecast future ecosystem responses or execute management strategies that anticipate the most likely outcomes from established trajectories of change. In **Initiative 2**, we propose developing specific understanding about tradeoffs underlying ecosystem responses to variation in the socio-natural template. We will do this by combining long-term baseline studies with new studies testing key hypotheses about the effects of anthropogenic drivers on ecosystem processes, and mechanistic controls on forest form and function.

<u>II.C.1. Baseline Conditions of Stream Fish</u>. To assess and predict the effects of land-use change on biota first requires quantifying natural levels of variation in organisms, and determining the factors that affect population size in the absence of land-use change. We propose determining the relative importance of density-dependent and density-independent processes to long-term population regulation and demography of fishes by continuing our long-term quantitative fish population sampling in the three permanent Coweeta gradient sites (3^{rd} - 5^{th} order streams). We will match the results to removal experiments and, resources permitting, construct a model of fish population responses to environmental change. This study parallels research in II.C.4 addressing similar questions about forest tree assemblages.

Fish populations and habitat availability will be sampled through 2005 using the methodologies of Freeman et al. (1988) and Grossman and Freeman (1987). This round of sampling will yield up to 4 generations of data for the dominant species at the three sites, and will thus represent one of the longest quantitative data sets on fish population assemblages. We will use Akaike's Information Criterion (Anderson et al. 2000, Burnham and Anderson 2001) to quantify the individual and combined effects of density-dependent (e.g. resource limitation) and density-independent (e.g. natural disturbance) processes on data patterns. This technique avoids many of the statistical pitfalls present in descriptive studies of population regulation (Anderson et al. 2000, Burnham and Anderson 2001), but if possible we will also examine our data using hierarchical Bayesian models as proposed in II.C.4 below.

Manipulative experiments (e.g., removals) will be designed to test for the relative importance of density-dependent vs. density-independent forces after the long-term descriptive data patterns are analyzed. With descriptive and manipulative experiment results we will be able to construct environmentally-based population models (Individual-Based Models similar to Jaeger et al. 1997) to forecast the response behavior of fish populations to changes in environmental regimes and disturbance frequency.

II.C.2. Understanding The Role of Sediment. A unifying theme of both present and historic research in the Coweeta LTER Program is the quantification of ecological responses to natural and anthropogenic disturbance on levels ranging from the organism to the ecosystem. The stream flora and fauna of southern Appalachia evolved in predominantly forested systems with shaded streams that were clear, cool, and unproductive. Sediments were well sorted and primarily derived from instream sources and hillslope failures (i.e., debris flows and landslides). This changed as humans altered their land-use patterns on both local and regional levels, so that increased sedimentation from surface runoff is now one of the most deleterious impacts on aquatic ecosystems (Waters 1995). Current species composition furthermore depends on sedimentation legacies, not only on present sedimentation patterns (Harding et al. 1998, Scott and Helfman 2001).

In a series of integrated studies we propose quantifying land-use influences on historic and present patterns of erosion and sedimentation, as well as the spatial extent and mechanisms driving responses of organisms and ecosystems to this anthropogenic disturbance. Our research will evaluate responses at the assemblage, population, and organismal levels, as well as the concomitant effects of temporal and spatial heterogeneity. Results from this integrated set of sedimentation studies will provide a key input to our **Initiative 3** forecasting efforts. Our general hypothesis is that changes in land use produce predictable changes in sedimentation that then drive biotic processes in watersheds where the change is occurring. We will test the following specific hypotheses:

1. Process-based, spatially-explicit soil erosion and transport models can accurately predict changes in suspended sediment yield caused by changes in land use.
2. Incorporating historic land use will improve our ability to explain current suspended sediment yields in southern Appalachian streams.
3. Changing land use patterns cause altered in-stream habitat (particularly sediment amount and distribution), which leads to altered fish assemblages resulting in part from upstream invasion by widespread generalists.
4. Increases in suspended sediments produced by changes in land use will reduce foraging success, energy accumulation, and population size of native water-column fishes.

II.C.2.a. Sediment Erosion and Yield Through Time. Although sedimentation is the primary source of anthropogenic changes in stream ecosystem structure and function (Harding et al. 1998), our ability to quantitatively predict sediment erosion, transport, and deposition is poor. Swift [, 1988] found that soil erosion from roads introduced significant amounts of sediment to streams, and Swank et al. (2001) attributed large increases in soil erosion and stream sedimentation to human land uses, particularly agriculture. Bolstad and Swank (1997) found that as streams progressed through increasingly developed watersheds, stream turbidity also increased leading to important reductions in water quality during stormflow (**Figure 5**). However, we know of no attempts at process-based predictions of the cumulative temporal and spatial effects of multiple land uses and land-use change on sedimentation for the southern Appalachian region.

A century of theoretical and empirical studies have identified the mechanisms by which sediments are eroded and transported to streams: Soil particles are dislodged by raindrop impacts and fluvial shear, then incorporated to surface runoff and transported down slope. Sedimentation processes are well understood in three-dimensional (two spatial + time) and four-dimensional (three spatial + time) systems, but these processes have rarely been incorporated into sediment generation and transport models due to complexity, computational limitations, and ill-conditioning (Flanagan and Nearing 1995).

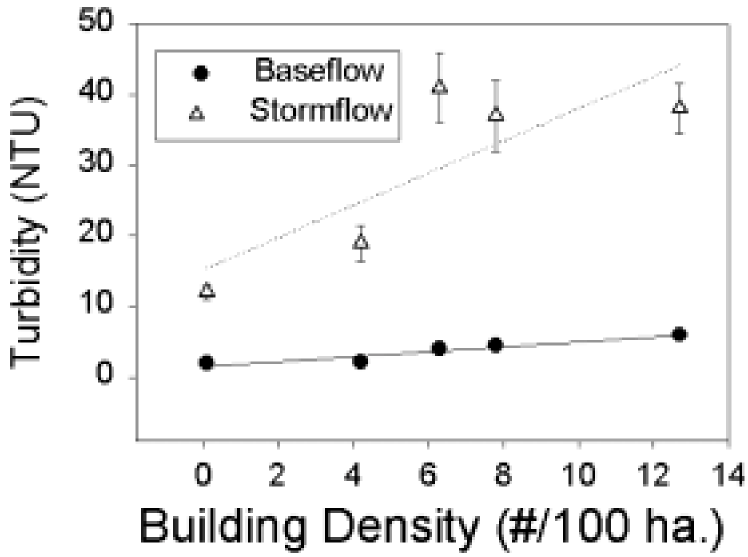

Figure 5. Sediment inputs are higher with increased building densities and result in more turbid waters, especially during stormflow conditions (Bolstad and Swank 1997, Figure 3).

Standard sediment models use explicit estimation of shear stress and resistance to generate erosion and transport rates. However, this requires spatially-detailed information for variables that are typically sparsely sampled at inappropriate spatial resolutions. Land use, soil characteristics, climate, and slope drive sedimentation, but are currently only known at coarse resolutions over broad scales, e.g., 30-meter horizontal sampling interval. Such constraints lead to the use of lumped parameter models (e.g., the Universal Soil Loss Equation, USLE) and its derivatives (the revised and the modified USLE). However, the numerous limitations of lumped parameter approaches restrict our ability to predict past and current sediment inputs at the accuracy and spatial detail needed for robust characterizations of past, current, and future sediment impacts on stream ecosystems.

We will quantify the impacts of human land use on sediment generation and input in decadal time steps from 1910 to the present through a series of field-measurement and fine-grained, process-based sediment models. We hypothesize that process-based erosion, and transport models will provide accurate estimates of sediment delivery to streams, and correlate with observed sedimentation rates. By quantifying the effects of historic and contemporary land use on sediment inputs to southern Appalachian watersheds we can investigate the consequences of these changes for stream communities as well as the bioenergetics and behavior of individual species.

We will generate data for eight watersheds spanning the range of current and past land-use conditions (e.g., from minimal to substantial agricultural and urban land uses). Sites will be co-located in the Little Tennessee and French Broad Rivers with other proposed studies; the selection of study sites will be guided by the historic land use coverages developed in II.B.1 and additional factors (e.g., current land use, stream size, gradient, elevation, and geology). We will measure surface transported sediment using sediment traps and other standard methods, and in-stream turbidity using stage, flow, and frequency samplers. We will also work with cross-sectional and other stream morphometry measurements as outlined in II.B.3.c.

The cartographic base for the study watersheds produced in II.B.1 will be augmented with fine-resolution terrain data (1-2 m) so we can represent near-stream depositional zones. Process-based models will be adapted to distributed network and grid approaches (Cochrane and Flanagan 1999), and applied to our study watersheds. Spatially-explicit land use data from each time period will be used to condition a landscape sediment model, and the resulting predictions will be compared to the sediment generation chronologies developed in II.B.3.c. Sedimentation chronosequences will be collected in each modeled watershed and use as independent checks on predicted sediment inputs.

II.C.2.b. Homogenization of Stream Fish Assemblages. We will examine the effects of land-use change on the characteristics of stream fish assemblages in the southern Appalachians. The continuum of land conversion in the upland areas of the region corresponds to fish assemblages dominated alternatively by native specialists or introduced generalists. From an initial assemblage characterized by species specialized for life in relatively cool, clear, shallow, low-nutrient, rocky and diverse habitats (e.g., darters, benthic minnows, sculpin, and brook trout), land conversion eventually leads to a mixed assemblage of introduced species tolerant of warmer, slower, nutrient-rich habitats with increased sediment loads (e.g., sunfishes, some suckers, some minnows, and perhaps some catfishes). The end-point of the shift in fish assemblage composition is regional and national homogenization (e.g. Rahel 2000).

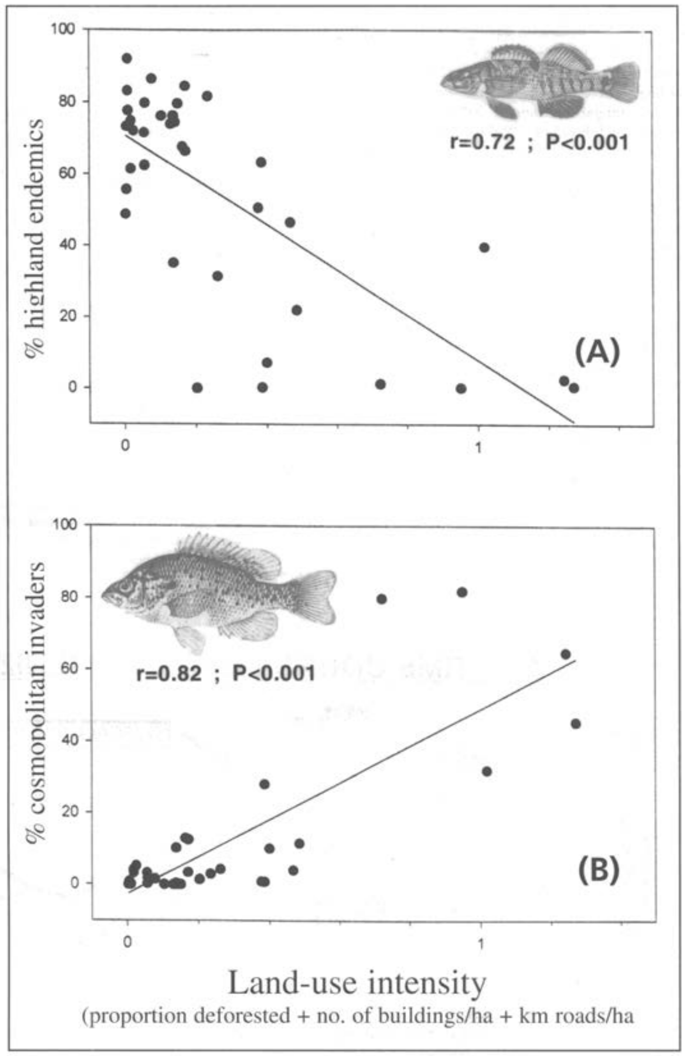

Figure 6. Relative abundance of (A) highland endemic versus (B) cosmopolitan fish species as a function of land use intensity at 36 sites in the Little Tennessee and French Broad river basins (Scott and Helfman 2001, Figure 2).

In 1997 and 1998 we sampled fish assemblage structure at sites in the Little

Tennessee and French Broad drainages, and found no significant correlation between overall fish diversity and land-use intensity. However, a significant relationship was revealed by dividing the fish fauna into regional, highland endemics and widespread, generalist species (**Figure 6** Scott and Helfman 2001, Scott et al. in review). The results indicate that upland areas of high

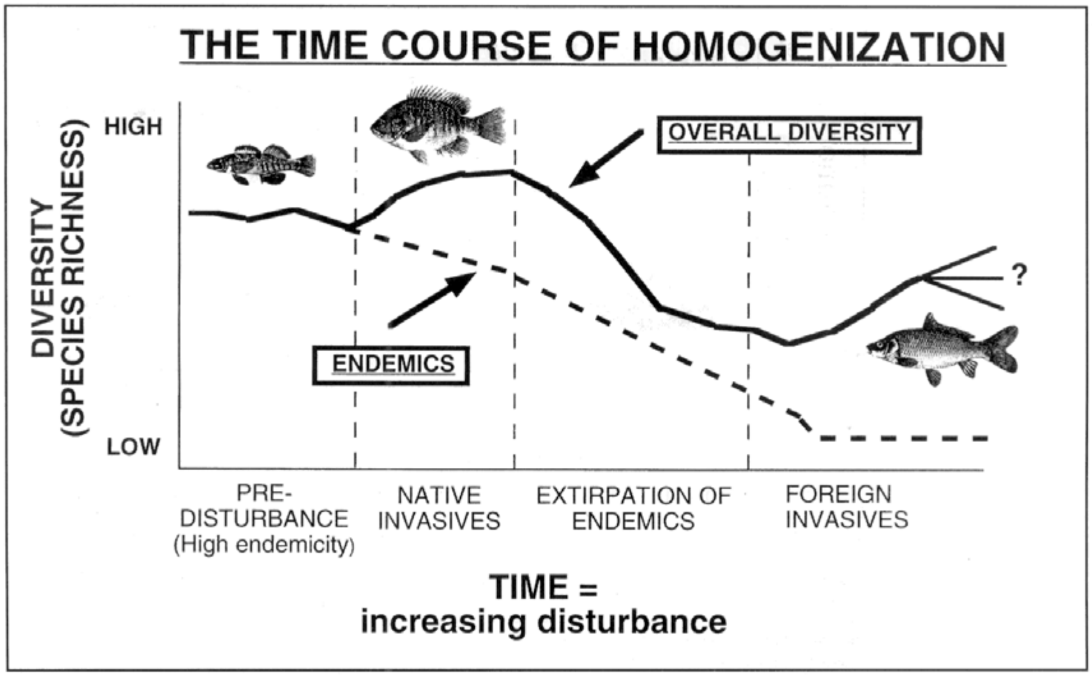

Figure 7. Postulated time course over which homogenization occurs in highland streams with increasing watershed disturbance (Scott and Helfman 2001, Figure 3).

endemism are being invaded, displaced, and homogenized by native species capitalizing on habitat degradation.We hypothesize that intermediate habitat conditions result from conversion of forestland to agricultural and suburban uses, and lead to progressive homogenization of the fish fauna (**Figure 7**). Large-scale homogenization is therefore dependent on summed events at smaller geographic scales so that our objective is to identify the intermediate steps facilitating the process of regional homogenization. We will test our hypothesis of homogenization-via-invasion in streams in the Little Tennessee and French Broad drainages across a gradient of land-use types that will include sites used in developing and validating the sediment generation model described in II.C.2.a. Assemblage characteristics, stream geomorphology, water quality and sediment distribution will be measured and our findings combined with results from the sediment generation model to determine how anthropogenic factors influence biotic responses that diminish the integrity of southern Appalachian stream communities.

II.C.2.c. Effects of Suspended Sediments on Fish Foraging Success and Habitat Use. Perhaps the most common impacts on streams of deleterious land-use change are increases in suspended and settled fine sediments (Waters 1995). Descriptive studies of stream fishes have detected an inverse correlation between fish diversity and siltation (Waters 1995). However, the mechanisms for these declines are unknown. The necessity for a mechanistic explanation for the relationship derives from the fact that increased siltation is certain to be a by-product of future land-use change in western North Carolina (e.g., increased urban and suburban development, and agriculture). Consequently, we will examine whether increases in suspended sediments deleteriously affect the prey-capture success and ultimately habitat selection and population size of several common water-column species in the Coweeta, Little Tennessee, and French Broad Drainages.

Siltation can negatively affect fishes in a variety of ways including reductions in spawning habitat, decreased prey abundance, and decreased foraging success (**Figure 8**). We have previously shown that turbidity levels associated with frequent storm events in the Coweeta drainage can significantly decrease the foraging success of rainbow trout (*Oncorhynchus mykiss*) (Barrett et al. 1992). The long-term consequences of these decreases are unknown, but they are certain to result in decreases in individual fitness, which ultimately may result in decreased population size.

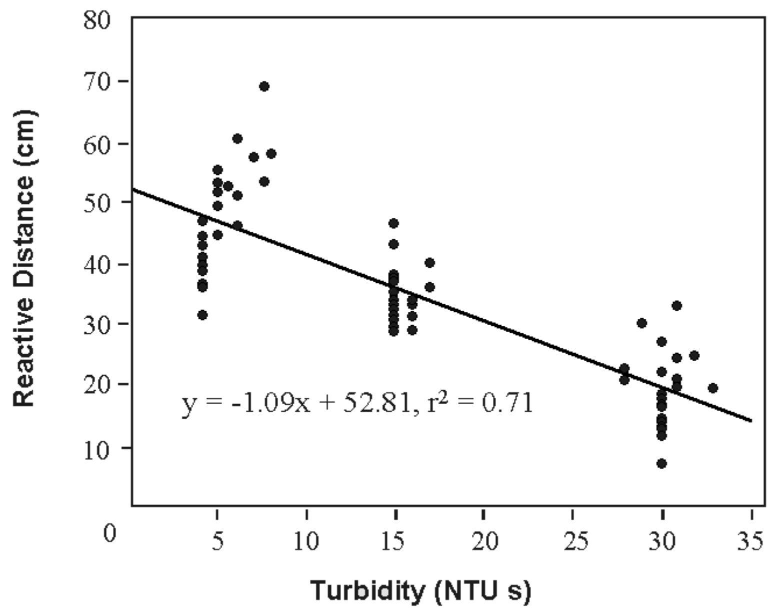

Figure 8. Increased turbidity significantly reduces the distance at which foraging rainbow trout are able to detect prey (Barrett et al. 1992, Figure 1).

We will use the methodology of Barrett et al. (1992) to determine whether increased turbidity significantly decreases the foraging success of several species of abundant drift-feeding fishes. We will probably select members of the Cyprinidae for which there is little extant data even though most southern Appalachian fishes belong to the order. We will choose 2-5 species that occur in sites to be used in validating the sediment generation model, and relate our results to a new optimal-foraging habitat selection model developed for Coweeta fishes (Grossman et al. 2002). Time-permitting, we will construct a bioenergetically-driven Individual-Based Model (Jaeger et al. 1997) to link decreases in foraging success to shifts in habitat selection and population persistence.

II.C.3. Understanding The Role of Organic Matter. Organic matter inputs to terrestrial and aquatic systems (senesced leaves, roots, and stems) represent significant additions of energy and nutrients into systems as diverse as primary and disturbed forests, suburban parklands, agricultural fields, and the managed plantings around shopping malls. Energy transfer and material recycling through litter inputs to soils and streams are among the most fundamental of ecological processes (Webster et al. 1995, Wallace et al. 1997). Understanding short- and long-term impacts of land use change on organic matter dynamics are critical to forecasting future impacts on ecosystem processes. The two studies in this section examine the recovery of streams from significant changes in organic matter inputs from logging, and the interaction of litter quality, microclimate, and biota in soils and streams.

II.C.3.a. Recovery of Headwater Streams from Logging. Watershed 7 (WS 7) was clearcut-logged in 1975-76 and we have extensively studied the effect of logging on Big Hurricane

Branch, which drains WS 7. The recovery of Big Hurricane Branch subsequently became a core research activity of the Coweeta LTER Program, and after 15 y of study we made long-term (100+ y) forecasts of the trends in stream processes following forest disturbance (Webster et al. 1992). These forecasts were based on the strong connectivity of forest streams and their riparian vegetation, largely related to the importance of large wood. We propose continuing a series of measurements in Big Hurricane Branch and Hugh White Creek (the reference stream) using the same methods we have used at monthly, annual, 5-year, and 10-year intervals since 1974 (Stone and Wallace 1998, Webster et al. 1999, Benfield et al. 2001, Webster et al. 2001). The measurements will be used to validate and refine our previous forecasts. The specific re-measurement studies we proposed for Big Hurricane Branch and Hugh White Creek are:

1. Leaf breakdown in 2004-5. Leaf breakdown rates in Big Hurricane Branch are faster than pre-clearcut rates and reference site rates after 23 years post-clearcut (**Figure 9**).
2. Benthic macroinvertebrate production in 2003-4.
3. Particulate transport in 2004-5. Particulate transport was measured intensely in both streams in the 1970s (Gurtz et al. 1980) and the 1980s (Webster et al. 1990), but has not been measured since.
4. Allochthonous inputs and benthic organic matter standing crop, including wood, in 2005-6.
5. Continuous DOC export in 2002-2008. We have measured DOC concentrations monthly since 1977.
6. Stream cross sections in 2006. Shortly after WS 7 was logged, we established permanent cross-sections on both streams to measure long-term changes in streambed morphology at approximately 10-year intervals.

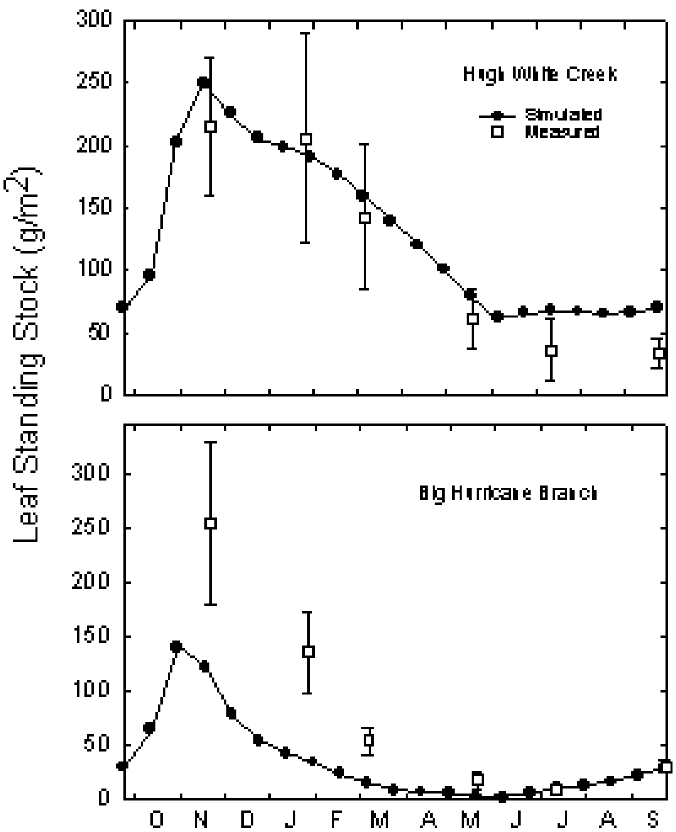

Figure 9. Predicted and measured standing crops of leaves in Big Hurricane Branch and Hugh White Creek in 1994-95, showing that both measured and simulated values are significantly lower in Big Hurricane Branch (Upper panel from Webster et al. 2001).

We also propose continuing a study of Cunningham Creek where we initiated in 1986 a long-term experiment of logs in streams (Wallace et al. 1995). We propose to make during the current funding cycle annual measurements of benthic communities at three sites upstream and downstream of where logs were added in 1988, and one re-measurement of the decay status of these logs.

II.C.3.b. Links Among Land-Use Change, Litter Inputs and Litter Processing. Changes in land-use result in changes in litter inputs and litter processing. The most obvious are gross changes in the quantities of litter entering soils and streams as natural plant communities are replaced by such structures as homes, businesses, and parking lots. There are also subtle changes resulting from shifts in the quality of litter entering soils and streams, the microclimate in which litter is processed, and the communities of fauna and flora participating in decomposition processes. Models of nutrient and energy flux in developed landscapes based solely on quantities of litter input are likely to be misleading since they do not incorporate the interactive effects of litter quality, microclimate, and biota.

We propose to combine monitoring and experimental procedures to explore the interactive effects of litter quality, microclimate, and biota on the decomposition of plant litter along gradients of land-use in southern Appalachia. Our primary questions are:

1. Do the relative roles of litter quality, microclimate, and biota on rates of litter processing vary along land-use gradients?
2. How do interactions among these key variables change along land-use gradients?

With previous funding from an LTER Supplement and other sources we explored the effects of macroinvertebrates on decomposition processes in upland, riparian, and stream habitats at the Coweeta and the Luquillo LTER sites. We tested the general hypothesis that the exclusion of macroinvertebrates would have increasing effects on the decomposition process as the quality of leaf-litter increased. We developed the hypothesis from studies of insect folivores on green leaf tissue, and it appears to hold true for senesced leaves. For example, the reduction in decomposition rates of leaf material in streams at Coweeta and Luquillo following the exclusion of macroinvertebrates is most pronounced on high quality litter (Powell 2001). We have also shown that the effects of fauna on decomposition are habitat-dependent; for example, macroinvertebrates have a greater impact on the decomposition of oak litter in riparian zones than in upland forest (Hunter et al., unpublished data, **Figure 10**). Simply put, litter quality, fauna, and habitat-type matter to the decomposition process and interact in complex ways.

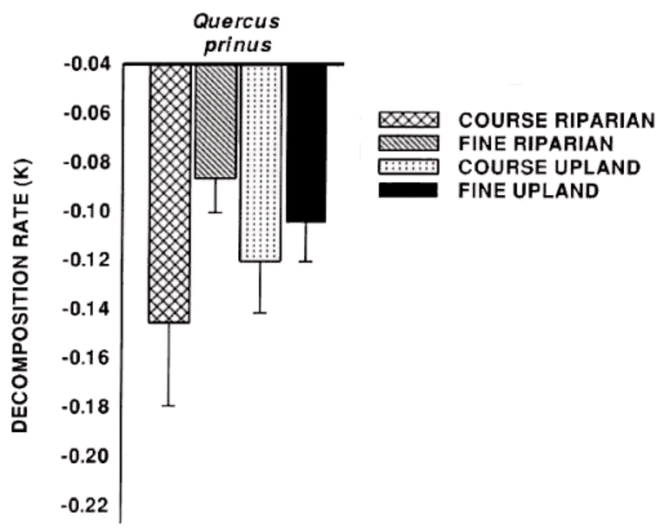

Figure 10. Reduction in decomposition rates of leaf material in streams at Coweeta and Luquillo following the exclusion of macroinvertebrates is most pronounced on high quality litter.

We will select sites within and beyond the Coweeta basin that reflect current variation in land-use across the southern Appalachian region and include the following habitat types: (a) oak hardwood, (b) production agriculture, (c) suburban parkland, and (d) urban housing development. We anticipate selecting three replicates of each habitat-type for a total of 12 sites to examine decomposition patterns in soils and streams using established procedures. Natural variation in the quality of litter, C inputs, N, phenolics and lignin will be measured and key abiotic variables including temperature, moisture, pH, stream flow and sedimentation will be estimated. Macroconsumer access to litter will be manipulated by mesh size (terrestrial) and electric exclosures (streams). For our control, we will transfer a standard reference litter to each field site, and a natural litter from each site to both a “common garden” and a “common stream” site.

II.C.4. Climatic and Site Controls of Forest Form and Function. Predicting forest response to global and regional change requires a mechanistic understanding of environmental controls on plant productivity, demography, diversity, and ecosystem function. Environmental factors such as available moisture, light, and soil nutrients influence plant growth and productivity. These factors vary geographically with regional climate and are modified locally by elevation and topographic position. Natural and anthropogenic disturbances may further alter local conditions, and the effects of past land use on soils and vegetation may persist for decades. Enhanced understanding of population- and ecosystem-level responses to environmental variability is needed to anticipate responses of southern Appalachian ecosystems to climate and land-use change.

We propose an integrated set of experimental and observational studies to understand how variation in climatic and site characteristics controls productivity, overstory tree demography, understory herbaceous diversity, microarthropod diversity, and ultimately forest form and function. Studies will be conducted in three landscapes that span a regional climate/elevation gradient (**Table II.3**): Nancytown, GA (~350 m, 34^{o}30' N), and the Coweeta Basin (~1000 m, N35^{o}03' N), and Mars Hill, NC (~730 m, 35^{o}45' N). The landscapes are located along north/south climatic and biogeographic gradients in the Southern Blue Ridge. Variation in temperature and precipitation among these three landscapes will permit us to conduct research under different climatic regimes. However, climatic effects may be mitigated by site-level edaphic factors such as light availability, soil moisture, and/or nutrient levels. Moreover, these edaphic factors are correlated with topographic position and land use history. By selecting study plots within landscapes to vary edaphic factors and by experimental manipulations, we will measure the interaction between broad-scale climatic gradients and fine-scale, local edaphic variation.

Within each landscape, replicated measurement plots will be selected and used in the research activities described below to analyze above- and belowground interactions. Each plot will vary in topographic position (i.e., ridge or cove). To address land use history, paired study plots differing in land-use history will be located in cove sites representing previously-farmed forested sites and non-farmed forested sites. Since ridge sites have typically never been farmed they represent a non-farmed forested site. The questions that organize our research are:

1) What underlying mechanisms cause primary production to change with moisture and temperature?
2) Are differences in net productivity driven by changes in gross production, respiration, phenology, allocation, or water use?
3) How do changes described above affect the primary limits on tree growth and demography including gross production, net production, allocation, defense, and dispersal?
4) How do tree and understory herbaceous species respond to variation in climate and land-use history, and how do these factors influence species composition?
5) How do soil microarthropod communities respond to climate gradients, and how are population size, density and/or diversity affected by land-use history?

Table II.3. Terrestrial sampling framework.

Sampling Location (elevation - m)	Topographic Position	Past Land-use Impact*	Research Projects**
Mars Hill, NC (800 m)	Ridge	Low	B, Hs, Hd, TSs, Pa, Pb
	Cove	Low	B, Hs, Hd, TSs, Pa, Pb, SM, Tg
	Cove	High	B, Hs, Hd, TSs, Pa, Pb, SM
Coweeta, NC (1350 m)	Ridge	Low	B, Hs, Hd, TSs, Pa, Pb
	Cove	Low	B, Hs, Hd, TSs, Pa, Pb, SM, Tg
	Cove	High	B, Hs, Hd, TSs, Pa, Pb, SM
Nancytown, GA (500 m)	Ridge	Low	B, Hs, Hd, TSs, Pa, Pb
	Cove	Low	B, Hs, Hd, TSs, Pa, Pb, SM, Tg
	Cove	High	B, Hs, Hd, TSs, Pa, Pb, SM

Replication: 9 sites above x 2 reps each = 18 plots; plot size = minimum 1 ha
Plots will be established at or near stream "hazard" sites where possible.

*Past Land-Use Impact:
Low = past low impact land use (logging)
High = past high impact land use (agricultural)

**Research Projects (sample area needed):
B = baseline measurements (all plots): air temperature, soil temperature, soil moisture, above-canopy light
Hs = herb surveys (20 - 5 x 5 m^2 subpots)
Hd = herb demography (10 - 5 x 5 m^2)
TSs = tree seedling survey (20 - 5 x 5 m^2)
Pa = aboveground net primary productivity productivity (36 – 5 x 5 m^2): plots will be used for validation sites for productivity models
Pb = belowground net primary productivity (36 - 5 x 5 m^2)
SM = soil microarthropods (10 - 1 x 1 m^2)
Tg = tree gap dynamics (10 - 5 x 5 m^2)

II.C.4.a. Controls on Productivity. Productivity influences individual plant demography by determining the energetic resources allocated to growth, reproduction, storage, and defense. Potential differences among species in energy allocation are the basis for the hypothesis that tradeoffs involving trophic interactions (e.g., competition for limiting resources and selective predation) and life history (e.g., longevity vs. colonization ability) are responsible for coexistence of similar species (e.g., Rees et al. 2001).

Total production in southern Appalachian forests is similar to other eastern deciduous forests, but relatively low given the exceptionally high precipitation and temperature relative to other temperate forests (Day and Monk 1977). Fine-scale analyses have shown strong trends in aboveground productivity related to both elevation and topographic position (Bolstad et al. 2001), and although the specific mechanisms have not been conclusively established, productivity decreases from low to high elevation (**Figure 11**). While a portion of productivity decrease is due to the length of the growing season, it also changes as a function of species composition and their physiological acclimation across the gradient (Bolstad et al. 1999, Mitchell et al. 1999).

We propose quantifying the effects of present climate variations on productivity and allocation in the dominant forest tree species of the southern Appalachian Mountains, and hypothesize that:

1. Higher net productivity at low elevation is primarily due to lower respiration, longer growing seasons, and higher rates of net photosynthesis.
2. Total production will be low on ridge sites (irrespective of elevation) in direct relation to where summer water deficits prevail. Belowground allocation will increase on ridges in response to low moisture availability, and relative reproductive allocation will be low.

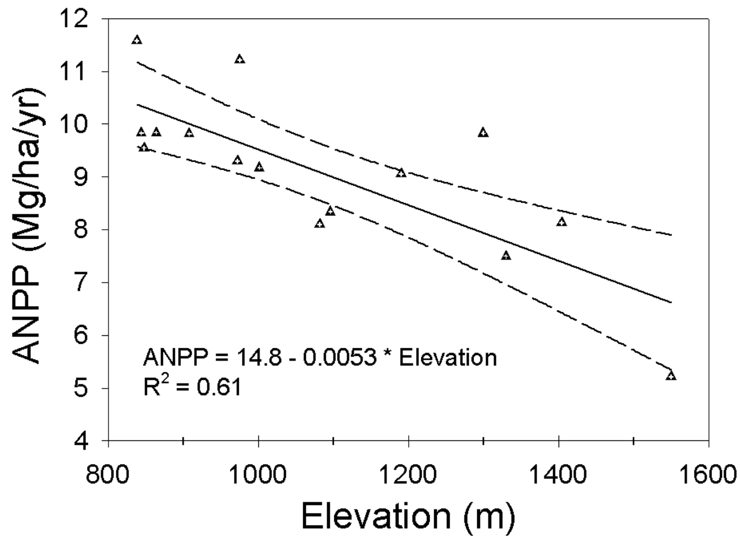

Figure 11. ANPP is significantly related to elevation in southern Appalachian forests, and productivity decreases from cove to ridge and from low to high elevations.

Two 30 x 30 m plots will be established in both ridge and cove positions in each of the three study landscapes (n=12 plots). Stems of all trees >1.5 m tall will be mapped, and productivity and demographic parameters measured using standard mensuration procedures. Forest structural measurements will include: height, diameter, leaf area and mass, leaf nitrogen, root mass by depth, understory composition and structure, soil N and C, N mineralization rates, and litterfall by species and tissue type. The physical environment will similarly be measured at each site by way of soil and air temperatures, relative humidity, soil moisture, and below-canopy radiation. One site on each landscape (n=3) will be designated an intensive measurement plot, on which above-canopy radiation, windspeed, and stem temperatures will be recorded.

We will link individual tree responses to stand dynamics by comparing productivity differences among species and crown classes with growth, mortality, and reproductive effort. Reproductive effort will by estimated from seed trap and census data (Clark et al. 1999b, LaDeau and Clark 2001). Our objective in this funding cycle is to parameterize the full fecundity schedules as a function of tree size. Mortality and its relation to growth rate will build on the initial census and modeling efforts of Wyckoff and Clark (2001) and incorporate the diameter censuses to be carried out in 2002 and 2004. For fecundity and growth, we will relate demographic and physiological responses from annual rates.

Variation in net primary productivity will be evaluated with simulation modeling. Our objective in this funding cycle is to parameterize a spatially-explicit and species-specific productivity model using detailed physiology data collected over the past 10 years (Sullivan et al. 1996, Bolstad et al. 1999, Mitchell et al. 1999, Vose et al. 1999). Sensitivity analyses will be used to evaluate the relative importance of tissue-specific respiration, growing season length, and net photosynthesis in regulating productivity across the landscape. Model results will be validated with data collected from the three study landscapes.

Belowground allocation will be measured intensively at the cove and ridge sites at Coweeta and Nancytown using a combination of minirhizotron images collected monthly and soil cores (Hendrick and Pregitzer 1993, Shan et al. 2001). Eight soil cores from each plot will be collected at the beginning of the study to establish a quantitative relationship between minirhizotron data and root mass. Additional cores will be collected throughout the study to check our ability at predicting changes in standing crop from minirhizotron production and mortality rates. We will establish a relationship between root length and numbers at the beginning of the study by digitizing images and estimating total root length. Thereafter, the dynamics of root numbers will be used to calculate length production and mortality. We have tested this technique using existing datasets and found numbers to be accurate ($r^2 > 0.90$) predictors of length; the technique also yields a 75% savings in time (Crocker et al. in review).

Less intensive measures of belowground allocation will be made across the gradient using the total belowground carbon allocation (TCBA) approach of Raich and Nadelhoffer (1989). We will measure soil respiration monthly, and when possible, bi-weekly during the growing season using a Li-Cor 6400 unit. Annual soil CO_2 efflux will be estimated using soil temperature data. Gravimetric soil moisture will be measured on three cores for each sampling period to correct for the effect of summer droughts (common along the gradient) on respiration rates (McDowell et al. 2001). Litterfall will be measured annually from the standard litter traps long-used on the Coweeta gradient sites. We will estimate fine root production for sites where it was not measured with cores and minirhizotrons using fine root production/TCBA relationships from the Coweeta and Nancytown sites.

II.C.4.b. Controls on Overstory Demography. Ecological theory predicts and empirical evidence supports the idea that the maintenance of diversity depends on tradeoffs. Trophic tradeoffs result from patterns of consumption while life history tradeoffs are generally expressed as variation in the timing of reproductive effort. In plants, life history and trophic tradeoffs are linked through patterns of allocation that affect growth, seed size, fecundity, dispersal, and survivorship (Connell and Slatyer 1977, Loehle 1988, Tilman 1988, Clark 1991, Rees et al. 2001). Tradeoffs are most important in forests at recruitment stages when they likely reflect resistance and tolerance to herbivores (Janzen 1970, Connell 1978, Harms et al. 2000, HilleRisLambers et al. 2002), and canopy gaps (Clark et al. 1998, Hubbell 2001).

In forests, the trophic tradeoff hypothesis predicts that species coexist as a consequence of tradeoffs in competitive ability for resources and/or susceptibility to herbivores. In effect, species in optimal sites are abundant because they realize maximum growth rates, experience low mortality, and/or allocate more resources to defense and consequently have low herbivore losses. The life history tradeoff hypothesis predicts that some species escape competitive exclusion by episodically reaching sites missed by their more dispersal-limited competitors. In effect, they may be poorer competitors yet persist by virtue of obtaining sites that poor dispersers fail to reach or by release from frequency and/or density dependent regulation where populations are dense. We therefore hypothesize that:

1. Tradeoffs in life history and resource acquisition mediate patterns of coexistence and diversity of trees in southern Appalachian forests;

2. Variation in conditions between gap and non-gap sites, and along gradients in elevation, provide the environmental heterogeneity on which life history and trophic tradeoffs are expressed;

3. Tradeoffs change the relative ranking of species in their recruitment success at seed and seedling stages along gradients in climate and light availability.

We propose experimental recruitment studies on seed and seedling plantings that include selective exposure to vertebrate and invertebrate seed and seedling predators across moisture and elevation gradients, in gap and non-gap settings. We will include the dominant canopy species (n=10) in the region, and carry out experiments at (a) the non-farmed cove sites in each study landscape, (b) the natural gaps in the three study landscapes, and (c) the established experimental gaps in the Coweeta Basin (independent funding to Clark). At each site we will establish four 2-m x 1-m exclosures against vertebrate and invertebrate herbivores consisting of sunken barriers (for small mammals) topped with agricultural cloth (for deer and invertebrates) (Beckage et al. 2000). Previous studies show that fine grade agricultural cloth does not significantly reduce light levels reaching plants. Each exclosure will be associated with a control plot to which herbivores have free access. Our overall design will consist of 3 landscapes x 8 sites (4 gap, 4 non-gap) x 2 exclosure levels x 4 replicates, or a total of 192 sampling units.

In each replicate we will plant 10 seeds and 6 seedlings of each species, and record the following response variables: germination, growth, mortality, allocation to defensive compounds, and herbivore losses. Allocation to defense will be estimated monthly from phenolic microanalyses based on 2mm disks removed from foliage and analyzed for hydrolysable tannins, condensed tannins, total phenolics, and astringency (modified from Hunter and Forkner 1999, Klaper et al. 2001). Losses will be monitored with biweekly censuses of seed and seedling damage, beginning with damage to newly fallen seed (pre-dispersal loss rate). We will quantify for each species the effects of recruitment limitations in each setting and determine the extent to which differences may support the notion that tradeoffs contribute to potential persistence.

II.C.4.c. Controls on Understory Diversity. Forest understory plants are small, have relatively short life spans, mature sooner, and are therefore easier to manipulate experimentally than trees. As such, they provide an excellent model experimental system for how plants may respond to climatic variation and land-use change (**Figure 12**). We hypothesize that:

1. The demographic performance and geographical limits of many forest understory herbs are determined by soil moisture, in particular the length and severity of the summer drought and available light levels (PAR) during the growing season;
2. Past land-use history has altered the size and spatial variability of soil carbon and nutrient pools, and therefore influences present-day habitat quality for these species;
3. Species with specialized habitat needs and limited dispersal ability will be more vulnerable to both climatic variation and landscape change.

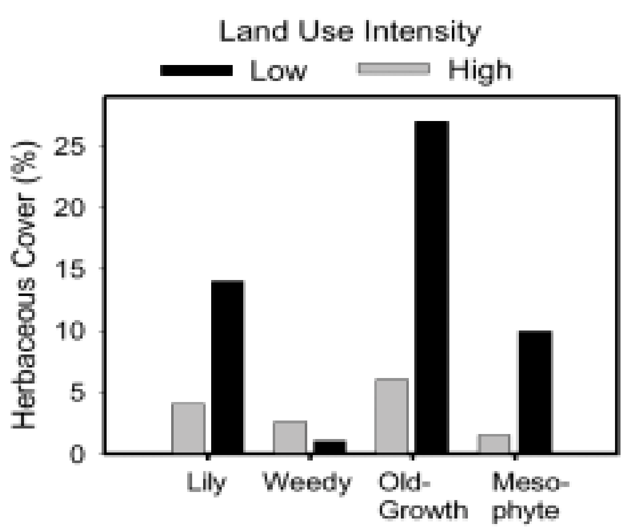

Figure 12. Herbaceous species diversity shifts to weedy species when patches are smaller, or when the past disturbance regime in the forest has been more intense.

Our goals in this study are to discover how abiotic factors (i.e., nutrients, moisture, or light) limit the local and regional distributions of a set of representative species, and how land-use history interacts with these factors to affect the suitability of specific sites. Species under consideration for detailed studies include *Anemone quinquefolia, Arasaema triphyllum, Botrychium virginianum, Hepatica acutiloba, H. nobilis, Viola canadensis, Polygonatum biflorum, Smilacena racemosa*, and *Goodyera pubescens*. We already have extensive distributional data on all of these species, and we have preliminary demographic data (independent funding to Pulliam) on several of them.

The hypotheses concerning the impacts of local environment and land use history on plant demography and distribution will be tested both by measuring demography across the full range of conditions where the species normally occur and introducing them into microhabitats where they do not normally occur.

Six study sites will be (or have already been) established on each of the three study landscapes in closed-canopy, mixed deciduous forest. Two study sites on each cove position will be located on previously-farmed mesic locations and four sites will be placed on non-farmed locations that include two mesic and two xeric positions (i.e., coves or ridges). A 24m x 20m demography plot will be located on each site and divided into 120, 2m x 2m cells. All individuals (ramets) of selected forb species and tree seedlings will be marked and monitored for survival, growth, and reproduction. During the growing season, light levels, soil moisture, soil temperature and nitrogen, and phosphorous mineralization will be monitored on 16 or more points within each plot. Rates and spatial dependency of potential nitrogen mineralization will be assessed as a function of land-use history.

We will also establish small (5m x 5m) experimental plots on each site in the immediate vicinity (50-100m) of each demography plot (a total of 48 small plots). Preliminary identification of light gaps and light level measurements (PAR) will be used to stratify the small experimental plots so that on each site half the plots are in low-light and half in high-light patches. On each landscape there will be 2 to 4 replicates of 6 treatment conditions (mesic, high light, previously-farmed; mesic, low light previously-farmed; mesic, high light, non-farmed; mesic, low light, non-farmed; xeric, high light, non-farmed; and xeric, low light, non-farmed). Each treatment condition is further divided into four subplots.

Twelve of the small experimental plots on the non-farmed locations will be used as "common garden" experiments to focus on 4 forb species (*Polygonatum biflorum*, *Goodyera pubescens* and two others to be determined) selected to represent a range of life history and dispersal strategies. Seeds, seedlings, and adults of each species will be collected at each of the four study landscapes and grown under the same conditions in all twelve gardens. This will test the degree of local adaptation as determined by growth and survivorship. We will also include plants from other locations even if they do not grow naturally at the experiment location as part of our test of factors limiting the geographic range of species.

The remaining 36 small plots (2 replicates x 6 treatment conditions x 3 landscapes) will be used for local (within landscape) transplants and ecophysiological measurements. The transplant experiments will be used to test the range of local conditions that plants from one locale can tolerate. Within the constraints of plant material available for transplanting, seeds, seedlings and adults of all four species will be grown across the full range of moisture, light, and land-use history, however, we will vary one factor at a time focusing on moisture first, followed by light, and concluding with land-use history. We will measure physiological response of individual plants to light, nutrients, and moisture on each small plot with a LiCor 6400 photosynthesis machine equipped with a built in light source.

II.C.4.d. Controls on Microarthropod Diversity. Much of forest diversity is underground and consists of bacteria, protists, fungi, and many animal groups. We will compare soil microarthropod populations between sites with different land-use histories to help us predict the effects of future land-use change on soil biota critical to the decomposition process (Swift et al. 1979, Reynolds et al. 2000, Reynolds and Hunter 2001). We hypothesize that:

1. Increases in the size of canopy openings, and the consequent decrease in canopy inputs such as frass, litter, and throughfall, will lead to changes in soil microarthropod communities, and particularly decreases in collembola and oribatid mites.
2. Rates of decomposition will decrease as canopy inputs are reduced.

We have already established 5 transects at Coweeta containing 10, 1m-square plots that encompass gap and adjacent control areas. We will establish additional transects in the cover locations at the Nancytown and Mars Hill landscapes in matched non-farmed and previously-farmed sites. Microarthropods will be sampled seasonally from soil cores on each plot with additional samples collected immediately prior and subsequent to the gap creation at Coweeta (n=50). Microarthropods extracted from soil cores will be sorted into the following categories: collembola, three suborders of mites, and “other.” Collembola and oribatid mites will be identified to species (oribatids) or morpho-species (collembola) for testing our diversity hypothesis.

Measures of decomposition will only be carried out at the Coweeta gap plots. We will use 15cm x 15cm litter bags containing 2.5 g of red oak/red maple leaves (Reynolds et al. 2002). Twelve bags will be set out adjacent to 6 of the soil microarthropod plots after gap establishment at Coweeta (n=360). The study will be conducted for 2 years, with bags brought in for weighing and microarthropod extraction every other month.

II.D. Initiative 3 - Forecasting Ecosystem Responses to Variation in the Socio-Natural Template

Research in the Coweeta LTER program has linked land-use changes and legacies to their ecological consequences for the distribution of habitats and species from plot- to landscape-scales (Turner et al. 1996, Bolstad et al. 1998, Clark et al. 1998, Pearson et al. 1998, Wear and Bolstad 1998, Grossman et al. 2002). In the proposed research we will construct explicit forecast scenarios drawing from our observational data networks and experimental research to move from hypothesis testing to real-world applications that could include conservation planning (Baker 1989, Bender et al. 1998); landscape management and design (Baskent 1997); and the assessment of potential changes from land development or climate change (Baker et al. 1991, Nielson et al. 1992, He et al. 1999). Basic research at fine scales, which is a critical step in generating the scientific knowledge for building scenarios and modeling, seldom provides the requisite knowledge on interactions and processes required for planning and decision-making (Carpenter 1996, Clark et al. 2000).

Several useful attempts have been made to link social factors to deforestation and forest cover change (Wilkie and Finn 1988, Baker 1992, Dale 1994, Gilruth et al. 1995, Gaston et al. 1998). However, land-cover change is typically used as a surrogate for land use so that the result is more properly a landscape–transition model (Dale and Rauscher 1994). Research by Coweeta investigators integrating ecological and socioeconomic factors within a probabilistic framework (Turner et al. 1996, Wear and Bolstad 1998) have already taken the first step toward incorporating decision-making to forecast models to make them more realistic of the process of change. We will take the next step in the proposed research by focusing on the development of forecasts that incorporate feedbacks between ecological and socioeconomic modules (Lee et al. 1992, Riebsame and Parton 1994).

Our proposed efforts will focus on the conceptual and technical integration of research results from **Initiatives 1** and **2**, since the current trend in forecasting is clearly toward multi-scale, multi-process models. Our goal in forecasting is to incorporate the complex interactions between socioeconomic and biogeophysical components of southern Appalachian ecosystems, and reflect the temporally and spatially explicit linkages between land-use legacies and watershed processes. Research activities in this initiative will concentrate on the Little Tennessee and French Broad drainages where we have the greatest control (and information) over temporal, spatial, and decision-making processes. This will provide us with the greatest assurance that our forecast scenarios incorporate our best scientific understanding. Since important questions remain unresolved about the necessary content or validation of forecasts, we will carry out limited empirical validation of the model through studies of the response-trajectory of streams to changing land-use, how stream systems respond to contrasting rates of suburbanization, and the social valuation of specific land management goals.

<u>II.D.1. Conceptual and Technical Development of the Forecasting Framework</u>. Ecological systems have intrinsic temporal rhythms and patterns on characteristic spatial scales, but also bear the signature of human institutions that act directly or indirectly to alter the dominant spatial and temporal modes or introduce new ones (Pyne 1997, Carpenter and Gunderson 2001, Scheffer et al. 2001, Turner et al. 2002). The human institutions in turn are shaped and influenced by the environmental rhythms and ecological arrangements of the biogeographic region in which they emerged (Cronon 1983, Dove and Kammen 1997, Berkes and Folke 1998, Ostrom et al. 1999) leading to reciprocal imprinting of scales so that it becomes impossible to parse landscapes into "natural" and "human" components. Rather, they must be studied as integrated wholes (NRC 1999, Kinzig et al. 2000, Mitchener et al. 2001).

Forecasting is the formation of expectations about future states or processes of specific historical entities (Duncan 1969, Henschel 1976, Land and Schneider 1987). Forecasts can be used for their explanatory value in a scientific sense to the fulfillment of statutory policy requirements. Our objective is to isolate through our research the patterns that allow us to predict how the cycle of land-use change, ecological change, and human response will vary over space and time (Veldkamp and Lambin 2001). We drawn on the common and comprehensive datasets we will build over the course of the research that includes: 1) characteristics and change over time in land use and land cover, 2) ecological processes associated with diversity, water quality, sedimentation, climate and organic flux, and 3) social processes associated with the formation of choice, development, agricultural practices, and political institutions. Landscape trajectories will be based on scenario analysis under different suites of assumptions (i.e., business as usual, major conservation efforts, planned development with some land-protection measures, massive population growth and economic development). The future is uncertain, but scenario planning can help anticipate a variety of contingencies (Bunn and Salo 1993, Schoemaker 1995).

This work builds on our current research (Clark et al. 1998, Clark et al. 1999a, Clark et al. 1999b, LaDeau and Clark 2001, Pearson et al. in review) directed at understanding how changes in habitat abundance or quality affect population persistence by altering schedules of survival and reproduction. It also incorporates novel elements from our proposed decadal choice-based analysis (II.B.2) and disturbance regimes (II.B.4) in order to define a standard discrete choice model with variables that incorporate land-use alternatives as well as characteristics of the unit of observation. We anticipate specifying land-use choice according to McFadden's Discrete Choice model (Maddala 1983), and using logistic cumulative distribution functions based on relative rents, per capita income, and other social and economic factors.

We will hold a workshop in year 4 in which all Coweeta investigators will participate in developing the final parameterization and design of the scenarios to forecast land-use probabilities for the Little Tennessee and French Broad drainages in 2010, 2020, and 2030. At this point we will also determine the means by which we will evaluate the relative importance of particular spatial predictions (Gardner et al. 1981, Costanza 1989, Turner et al. 1989, Caswell and Trevisan 1994). We will eventually develop a stochastic simulator for generating future land use maps to assess the relative impacts and uncertainty of distinct inputs, e.g., how commodity prices, transportation costs, or relative land values lead to particular land uses. Our stochastic simulator will also provide land-use forecasts by decade in order to evaluate the potential impacts of future land uses, e.g., how forest structure and sediment erosion suggest future policy alternatives. The previously noted pending collaborations with the UVT Gund Institute for Ecological Economics and the ASU Center for Environmental Studies will be complementary to our forecasting initiative activities. In all three cases, beyond the intrinsic interest our approach to forecasting may have in the scientific literature, our efforts are directed toward having an impact on the planning and management of real landscapes of the future (e.g., Hobbs 1997).

<u>II.D.2. Partial Validation of Land-Use Forecasts</u>. There is no uniform procedure for validation, and ultimately no forecast can ever be thoroughly validated (Levins 1966, Greenberger et al. 1976). Validation is simply an indication of the level of confidence in a model's behavior given its purpose, its desired performance, and the context for its use (Rykiel 1996, Ford 1999, Turner et al. 2001). Data does provide, however, a tangible link between a model and its reference system thus providing a central means for gaining confidence in the results of the model (Greenberger et al. 1976). The final test of a model's usefulness is whether a forecast, for example, leads to implementation of policies that produce the results predicted by the model (Wear et al. 1998). The following three research activities address some of the issues of operational and conceptual validation (Sargents 1988, Rykiel 1996) that derive from the purpose, desired performance, and context of use for our forecasting.

<u>II.D.2.a. Stream Hazard Site Project</u>. We are documenting in the Stream Hazard Site Project the response-trajectory of streams to changing land-use patterns in multiple watersheds. Aquatic ecosystems in the southern Blue Ridge tend to have low productivity due to low light, low temperature, high gradient, and low nutrient levels. Human activities are rapidly transforming the landscape and altering these important drivers of ecosystem structure and function. Our sampling design consists of collecting data in streams draining watersheds identified as "high risk" for development in the near future (**Figure 13**). We predict that disturbance will affect sites differently depending on the starting point of each site.

Eight medium-sized watersheds (10-40 sq. km) were selected in 1998 in the Little Tennessee and French Broad drainages in three categories: (1) forested "reference", (2) forested, but changing land use, and (3) agricultural, but changing land use. Land use in categories (2) and (3) is anticipated to move respectively toward second home development and suburban land use based on projections from 1993-2000 land use data. Site-selection was based on the work of Wear and Bolstad (1998), and the regression models of Gardiner (in prep). Abiotic and biotic parameters will be measured at each Hazard Site on a five-year interval over the next 30 years.

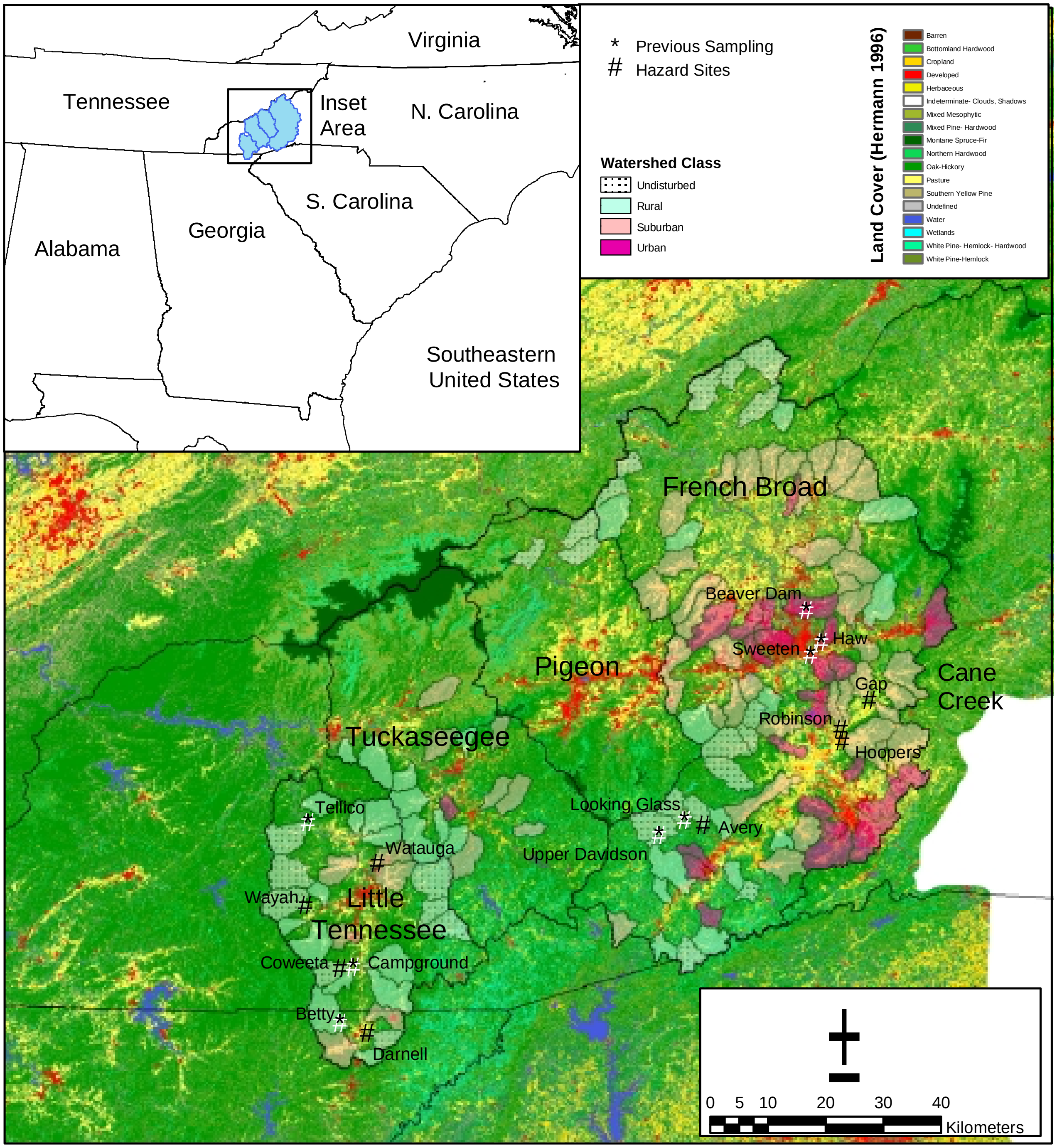

Figure 14. Land use data were used to classify watersheds into four land use categories corresponding to the groups identified with biological and physical ecosystem assessments (Gardiner et al. in prep).

We completed our first sampling of algae, insects, and fishes in 2000 and propose re-sampling in 2005 with renewal funds. Coinciding with the 2005 stream sampling we will map land use, building location, road location and type, and impervious surface from geometrically corrected aerial photographs and/or high-resolution satellite imagery. The recently completed ordination of data on fish relative abundance collected in 2000 from the Hazard Sites and other sites (Scott 2001) suggest study sites form two distinct clusters related to land use in 1970 and in 1993. In effect, stream assemblages are starting from different points as a result of differences in land use in each watershed. Sampling over time at the Hazard Sites will allow us to determine if the trajectory of ecosystem response to disturbance will similarly differ, and as such help validate our integrated forecasts of ecosystem response to variation in the socio-natural template.

II.D.2.b. Effects of Development on Stream Ecology. Our objective is to determine how streams respond to contrasting rates of suburbanization. Many parts of the southern Appalachian region are experiencing rapid population growth tied to suburbanization of formally agricultural lands and leading to negative impacts on stream structure (Sponseller et al. 2001) and function (Sponseller and Benfield 2001). Suburbanization of sub-basins in the Little Tennessee and French Broad watersheds is proceeding at varying rates (e.g., slow vs. fast) that we hypothesize are a function of factors such as elevation, road density, market access, land-use history, and others.

In earlier work, we identified the end-members of a continuum of private land holdings in agricultural use distinguished by their suburbanization rate (Wear et al. 1998). We propose to distinguish among local effects of particular land-use practices in order to explore the cumulative effects of these practices on steam structure and function over the longitudinal axis of the study basins from headwater to mouth. We will attempt to replicate stream types at the level of stream order within sub-basins. An example stream type would be a 2nd order stream with a 500 m lateral buffer zone from mouth-to-headwater that was approximately 90% in agricultural use and had 10 houses in 1950, that by 2000 was approximately 40% in agricultural use and had 100 houses. While we realize there will be difficulties in identifying replicate streams, we are experienced in dealing with the problem. We are currently studying 30 streams (6 classes of 5 replicates each) recovering from agriculture that were selected using the method described below.

Streams will represent a land-use continuum over space and time selected by interpreting chrono-sequenced (oldest available to most recently available in 10 y increments), high-resolution aerial photographs or ortho-images at spatial scales from m to km. Using GIS, we will quantify land-use variables in the sub-basins into zones reaching laterally from the stream channels and longitudinally to the headwaters. Buffer zones will then be defined (Harding et al. 1998) by: % land cover type (forest, agricultural row crop/pasture/fallow, recreational, industrial, suburban, urban); miles of improved and unimproved roads; bridge crossings; building density; impervious surface area, and others.

We will assess stream responses in land-use categories through structural (macroinvertebrate and fish biodiversity), functional (decomposition and stream metabloism) and geomorphic (cross-section and sedimentation) measurements obtained using standard methods (e.g., Benfield et al. 2000, Benfield et al. 2001, Sponseller and Benfield 2001, Sponseller et al. 2001, McTammany et al. in prep).

II.D.2.c. Ecosystem Valuation and Social Dynamics. Valuation is the measurement of the contributions of natural services to human objectives and well-being. In the psychological literature, the determinants of well-being are most often linked to the satisfaction of basic human needs (Max-Neef 1992), but it should be more broadly linked to the satisfaction of particular sets of goals. Some goals are shared among all individuals (e.g., basic human needs) while others are specific to different ethnic, socioeconomic, and regional populations. We propose assessing the degree to which our research results and forecast scenarios contribute to the achievement of specific management goals.

We will use a procedure developed by Gregory and Wellman (2001) to determine perceptions and relative importance of management options, acceptable trade-offs in management, and implied valuations of ecosystem services. The procedure relies on a variety of value-structuring tools. After determining the fundamental objectives of stakeholders, means-ends analyses will be used to specify and evaluate alternatives, e.g., limiting livestock access to streams relative to upgrading forest management roads. Participants assess trade-offs using a workbook to (a) rank management options irrespective of formally presented information on their costs and benefits, and (b) detail choice tasks (i.e., "plans") for each management option individually.

Costs are varied for each individual until they switch their preference for given plans, thus providing information on acceptable trade-offs for a given objective. The notable feature of the Gregory and Wellman (2001) procedure is that it does not rely on individual valuations as might be derived from willingness-to-pay measures, but on the public costs implied by federal or state activities. The individual is thereby induced to consider the valuation as a public citizen (Sagoff 1998). The basis for the procedure is multi-attribute utility theory (Keeney and Raiffa 1993), which is a variation of conjoint analysis (Farber and Griner 2000).

Understanding valuation and the links between social dynamic and value formation will provide independent tests of key assumptions behind the choice-based modeling framework. In addition, this study will provide insights into the potential long run structural change in individuals' perspectives on and uses of land and natural resources in southern Appalachia. This understanding is critical to building our scenarios and validating our forecasts.

II.E. Synthesis

During the next six years we will continue to build on 21 years of Coweeta LTER research to advance scientific understanding of the spatial, temporal and decision-making components of land use and land-use change in the southern Appalachian Mountains. Our spatial coverage extends from experimental plots to the southern Appalachian region, while our temporal coverage ranges from hours through centuries. Our studies will increase our understanding of controls on the spatial and temporal variation in ecosystem structure and function. Through our work with historical disturbance regimes, we anticipate substantial increases in our understanding of the role of historical disturbances in determining contemporary and future ecosystem structure and function. In our forecasting efforts we will link short-term temporal and small-scale spatial dynamics to develop decadal forecasts of future land use patterns and their ecological consequences. While emphasizing the core LTER ecological goals, we also anticipate a new integrative understanding of the long-term processes of temperate forest systems through research that bridges different scales and levels of organization (Levin 1992, Pickett et al. 1994).

In the proposed research we will also forge new links between the natural and the social sciences, both locally and through our collaborations with other sites. Adding the social dimension to long-term ecological research is increasingly recognize as critical for facing the current challenges of understanding and managing ecological systems (Pickett et al. 1994). The southern Appalachian region is an ideal natural laboratory to evaluate the synergism between the socio-natural template and the resulting patterns and processes in ecological and socioeconomic systems. Our contributions to long-term research will derive from our empirical studies, mechanistic experiments, and sampling programs along with the methods and analyses that assure the quality of our investigations. However, we also bring ecological and social scientists together as equal partners in the development of our integrative approach to the study of ecosystems.

Certainly our capacity for success rests fundamentally on a high-quality and balanced team of researchers, however, it also depends on our site management plan (**Section III**). The knowledge we will gain and the techniques we will develop for integrating ecological and social scientific understanding will be available through our information management and outreach activities (**Section IV**), which are furthermore central to fostering strong links to the human communities in proximity to our research sites through outreach and service (**Section V**).

III. PROJECT MANAGEMENT

The signatory PIs of the Coweeta LTER 2002-2008 are Ted Gragson, Jim Vose, and Brian Kloeppel. They will be jointly responsible for project management and administration although for practical reasons each will carry out certain activities. Ted Gragson is based on the University of Georgia campus and will coordinate campus activities including communication with all program associates and administrative relations with the UGA Research Office. Jim Vose is Project Leader at the Coweeta Hydrologic Laboratory and serves as the USDA Forest Service liaison in the Cooperative Agreement with the University of Georgia by which there is shared-use of on-site facilities. Brian Kloeppel is the LTER Site Director and he supervises the on-site technical staff, and oversees the management of the analytical lab, visiting scientist dormitory, field vehicles, and shared field equipment. The vitality of the Coweeta LTER program and the communication necessary to achieve our research goals are ensured by a Science Advisory Committee, research theme leaders, a meeting calendar, and regular external assessments.

III.A. Science Advisory Committee

Decisions about overall research direction are made by the seven member Coweeta LTER Science Advisory Committee by consulting formally and informally with all senior scientists on the project, and by taking into consideration the opinions of affiliated scientists (undergraduate, graduate, and post doctoral scientists) as well as collaborators on other projects and peers within the broader scientific community. The current members are selected to represent the disciplinary and institutional breadth of the program and include: Ted Gragson (University of Georgia), Jim Vose (USDA Forest Service), Brian Kloeppel (University of Georgia), Jack Webster (Virginia Tech University), Jim Clark (Duke University), Dave Coleman (University of Georgia), and Paul Bolstad (University of Minnesota). Committee members communicate on a regular basis by telephone and email, and meet as a group at least twice each year during the winter and summer science meetings. The Committee is directly responsible in the current proposal for the organization of the research into three initiatives.

III.B. Research Theme Leaders

In the 2002-2008 renewal in addition to the three lead PIs, there are 25 Co-PIs affiliated with seven institutions. Each of the three research initiatives is divided into multiple projects on which typically several scientists collaborate (as noted in **Table II.1**). These projects are nevertheless organized into research themes according to how they complement each other with respect to achieving our overall objective of understanding the spatial, temporal, and decision-making components of land use and land-use change in the southern Appalachian Mountains. Each theme is led by a senior scientist Co-PI (see **Table III.1**) who ensures coordination between the various collaborating scientists and complementary projects, as well as the crosscutting experiments and/or collaborations between themes and initiatives.

Table III.1. Research theme leaders by initiative.

INITIATIVES AND RESEARCH THEMES	LEADER
Initiative 1: Charaterization of the Socio-Natural Template	
Theme 1: Mapping Long-Term Land-Use Trajectories	Paul Bolstad
Theme 2: Environmental Gradients	Brian Kloeppel
Theme 3: Disturbance Regimes	Ted Gragson
Initiative 2: Ecosystem Reponses to Variation in the Socio-Natural Template	
Theme 1: Sedimentation as an Athropogenic Driver	Jim Vose
Theme 2: Organic Matter as an Athropogenic Driver	Jack Webster
Theme 3: Climatic and Site Controls of Forest Form and Function	Jim Clark
Initiative 3: Forecasting Ecosystem Responses to Variation in the Socio-Natural Template	
Theme 1: Conceptual and Technical Development of the Forecasting Framework	Dave Wear
Theme 2: Partial Validation of Land-Use Forecasts	Cathy Pringle

While the number of scientists participating in the Coweeta LTER is large, our philosophy is that LTER funding and infrastructure provide a stable research platform from which individuals are expected to leverage additional resources. It is also true that the science required in the Coweeta LTER with its regional focus on both ecological and socioeconomic patterns and processes requires a greater disciplinary breadth and an organization that ensures the proper balance between institutional memory, productivity, technical/disciplinary approach, and scientific vitality.

III.C. Meeting Calendar

Interaction between PIs, Co-PIs, technical support staff, graduate and undergraduate student associates and other collaborators is maintained by the distribution of programmatic information and regular opportunities for the personal exchange of information. LTER Network and NSF LTER Program office communications are routinely forwarded to all Coweeta LTER personnel. All scientists and associates on or near the University of Georgia campus meet monthly for discussion and brief science updates, and minutes are forwarded to the entire group via email. The Coweeta LTER program also hosts two, two-day meetings each year that are attended by all scientists and associates. One meeting held in January is used to plan and coordinate research activities during the calendar year, using breakout groups arranged by research themes. A second meeting in June gives scientists the opportunity to present their research results-to-date to the entire group. The agendas, abstracts, and results from both meetings are posted to the Coweeta website (http://coweeta.ecology.uga.edu).

III.D. External Assessment

The periodic assessment of our research by independent scientists convened by the Coweeta LTER Science Advisory Committee and the NSF are important for maintaining our focus and direction. In the renewal we have scheduled visits in years 2, 4, and 6 of external advisory committees consisting of three to four scientists representing the range of disciplines appropriate to evaluate the breadth of the Coweeta LTER research program. As we have done in previous funding cycles, we will charge them to review our progress and provide us with scientific and organizational guidance. In year 3 at the mid-point of our renewal funding cycle we anticipate that NSF will convene a committee to independently review our progress and direction. In addition to these formal reviews, we request informal commentary of the many scientific visitors to the Appalachian region and to the University of Georgia campus on specific aspects of the Coweeta LTER research program.

IV. INFORMATION MANAGEMENT & TECHNOLOGY

The information management system of the Coweeta Long-term Ecological Research Program is designed to support the scientific efforts of all associated investigators as well as our obligations to the wider research and educational communities.

The Coweeta LTER Program is an interdisciplinary research effort that builds from studies and data on environmental gradients and natural disturbance toward a comprehensive understanding of the spatial, temporal, and decision-making components of land use and land-use change in the southern Appalachian Mountains. Our collaborative, multidisciplinary research teams depend on a scientific information system that not only archives data and information, but also fosters its use. Our website (http://coweeta.ecology.uga.edu) is the access portal to data, metadata, and information on long-term research in the Southern Appalachian Mountains, and the central node in our communication network between Co-PIs distributed from Georgia to Minnesota. Our information management and technology activities during the proposed renewal depend critically on our approach to information management, personnel, information technology systems, physical storage facilities, collaborations, and data policy.

IV.A. Approach to Information Management

Our recent information management efforts have focused on building a solid infrastructure that supports our current and proposed research program. From the premise that information management should make data readily available to those who seek it, Coweeta has invested heavily in personnel and equipment. This is because web technologies, GIS, and advanced database systems are potentially the most effective way to both organize and serve data, and maintain the level of communication necessary between Coweeta researchers, LTER network researchers, and fellow researchers across a wide span of disciplines.

IV.B. Personnel

In the fourth quarter of 2001 we hired Barrie Collins as the Coweeta LTER Information/GIS manager. He brings over a decade of senior-level experience working with ESRI and ERDAS softwares, integrating spatial and attribute databases, and designing web interfaces to access information in ways that are maximally responsive to users. Barrie Collins was hired when we reorganized the objective of the Coweeta Informatics Center (CIC) to meet our emerging information needs as a region-based research project, and the anticipated demands of our proposed 2002-2008 research. He will be assisted on a part-time basis in the renewal by Ron Rouhani who served as the Coweeta LTER Data Manager for several years. Ron has extensive programming skills in building structured SQL databases and scripting, thus ensuring efficient and effective management and retrieval of our highly diverse information sources.

As part of his responsibility in reorganizing the Coweeta LTER CIC, Barrie Collins is coordinating the effort of several assistants who are: a) documenting and locating historical and ongoing research sites in both the Coweeta Basin and the region; b) metatagging information to facilitate and expedite search and retrieval operations; and c) developing web-accessible products that respond to the varied levels of need and expertise of our site users (researcher and visitor alike). The reorganization will directly facilitate the exchange of information specific to our renewal research activities, and link our empirical models with voucher information in a spatial display format. Our website already includes a dynamic scheduling calendar for dorm rooms at Coweeta, and making reservations on project equipment and vehicles. We also provide online versions of previous proposals, annual research summaries, a searchable bibliography, and diverse other information that will soon include full-text research articles cross-linked to projects and data.

IV.C. Information Technology Systems

Our information technology platform is a network of Sun SPARC (UNIX) and NT workstations, that serve as the backbone to communicating data, information and knowledge across spatial, temporal, and disciplinary boundaries. Eighty-one Type I datasets and their corresponding metadata are available for download (**Table S.2** lists all Type I and II datasets). We will also provide a wide array of online spatial datasets through a highly customized Internet Mapping Tool developed by Barrie Collins to be officially launched January 31, 2002 (access at http://coweeta.ecology.uga.edu). Beyond providing tangible evidence of the Coweeta LTER project's commitment to making data publicly available, the Internet Mapping Tool gives site visitors access to maps and supporting attribute information through Internet Explorer or Netscape, without any additional software or GIS experience. (The schema and rationale for the system can be found at http://www.lternet.edu/documents/Newsletters/DataBits/00fall.)

Most data management tasks are accomplished with the SAS data-warehousing engine, while the SAS/ASSIST module allows easy creation and updating of data sets, generating QA/QC procedures, and interactive analysis of data sets. Our GIS (geographic information system) is built around software standards in the field: ESRI's ARC/INFO and ArcView, and the ERDAS Imagine package for digital image analysis. Spatial information is provided as fully projected GIS files (ERDAS IMAGINE and ESRI ARC/Info), mid-level GIS (ArcView), and exportable files for transfer to other software packages.

IV.E. Collaborative Efforts

We strive for an informatics platform that not only builds from our necessities as an independent research project, but from the needs of the larger community of LTER researchers and public users. We have benefited in solving technical issues and building information capital from our collaborations with the H.J. Andrews LTER (Theresa Valentine; Don Henshaw), the San Diego Supercomputer Center (Tony Fountain; Chaitan Baru; Peter Arzberger), and the Central Arizona-Phoenix LTER (Peter McCartney). More recently we began a close collaboration with the information management and GIS centers of the Georgia Coastal LTER (Wade Sheldon and Alice Chalmers) that like the Coweeta LTER is based on the University of Georgia Athens campus. This collaboration will allow both sites to pool knowledge resources toward developing a mature information management system, and through our common approach to information management make it possible for researchers to carry out plot-to-regional science in tangible ways from the Blue Ridge peaks of North Carolina to the Atlantic coast of Georgia.

IV.F. Physical Storage Facilities

Physical samples including voucher specimens of plants and animals along with soil samples are an invaluable resource for future researchers. A total of 17,354 plant vouchers and soil samples are archived in a storm- and fire-proof vault at the Coweeta Hydrologic Laboratory. Item lists are available on our website (http://coweeta.ecology.uga.edu/ronarchive.html). Animal vouchers from the Coweeta Basin and surrounding areas (11,312 herps; 9,630 small mammals; 610 fish; and 50 birds) are archived at the Georgia Museum of Natural History in Athens were they are available to all researchers through standard GMNH policies.

IV.G. Data Policy

Scientists participating in the Coweeta LTER project are required to submit metadata documenting the characteristics of their data prior to data collection, and submitting their data to the Coweeta LTER database once data collection is complete. We strongly encourage investigators that are not conducting NSF-funded research, but who are collecting data relevant to the Coweeta LTER program to also archive their data and metadata on the Coweeta website. This ensures data redundancy and maximizes the utility of the information to present and future Coweeta investigators as well as the larger scientific community.

The Coweeta LTER data policy conforms to the LTER Guidelines for Site Data Management. While it gives researchers first opportunity to use the data they contribute to the Coweeta dataset, it also recognizes that data are timely. Individual researchers are responsible for quality assurance, quality control, data entry, validation, and analysis. However, all research funded entirely by the NSF-LTER program must be described in a metadata file and comply with Type 1 and Type 2 data requirements:

> **TYPE 1**: includes data routinely collected by staff, Co-PIs or associated investigators supported financially or in-kind by NSF-LTER funds and crucial to multiple research projects. This includes climatological, hydrological and similar data. These data sets are available to all interested parties with few or no restrictions other than those stipulated in the DATA USERS AGREEMENT (http://flynne.ecology.uga.edu/ronpolicies.html). Such data must be uploaded to the Coweeta website and made available within three (3) years of finishing the data collection.

> **TYPE 2**: includes original data collected by staff, Co-PIs or associated investigators supported financially or in-kind by NSF-LTER funds. Type 2 data are available only with written permission from the Co-PI(s) directing the research. This ensures that the data being requested are appropriate for the purposes stated and that the Co-PI, particularly in the case of graduate students, has sufficient time to process, analyze, synthesize and publish results. Type 2 datasets will be maintained for a maximum of

three years after completion of a project at which time they are automatically migrated to Type 1 status.

V. OUTREACH, EDUCATION AND COLLABORATION

The Coweeta LTER Program has a long history of formal and informal outreach and education to user groups in local, national, and international communities. Our future outreach and education activities will comprise guided scientific tours, training of future scientists, information distribution, and making research results relevant to society.

V.A. Guided Scientific Tours

Scientists and staff at the Coweeta Hydrologic Laboratory will provide guided scientific tours on topics that include ecosystem function, stream biology, vegetation management, water quality and yield, and forest road design and construction. Tours are scheduled on demand, and we anticipate in 2002-2008 a volume comparable to what we received in 1996-2002 when we guided a mean of 59 groups and 952 people each year. Sixty eight percent of the groups and 47% of all visitors were students from university classes, or scientists and land managers. (Complete information at http://128.192.18.26/tours.html, and educational program information can be found at http://128.192.18.26/School%20Yard%20LTER.htm.) We also anticipate meeting the needs of drop-in visitors ranging from scientists to the general public. In 1996-2002 we averaged 300 drop-in visitors each year. The receptionist at the Coweeta Hydrologic Laboratory, Kathy Flowers, typically meets these visitors as she also maintains our Information Booth with maps, photos, and descriptions of individual research projects.

V.B. Scientist Training

The Coweeta LTER Program will continue its long-standing tradition of training undergraduate, graduate, and post-doctoral scientists. From 1980 until August 2001, 138 graduate students carried out their research entirely or in part at Coweeta (the list is available at http://coweeta.ecology.uga.edu/cgi-bin/gradlist/grad_msql.cgi?action=query_t). Eighty-three graduates were from the University of Georgia, 16 from Virginia Tech University, 12 from Clemson University, 5 from Duke University, and 22 from other educational institutions. We currently have 11 undergraduate, 48 graduate, and 6 post-doctoral scientists working on Coweeta LTER Projects, and many will continue into the 2002-2008 renewal. Financial support for these scientists comes directly from the Coweeta LTER grant, from REU and other grants leveraged as a result of the Coweeta LTER grant, or in the form of access to project study sites and use project equipment and facilities.

V.C. Information Distribution

We will continue to distribute electronic data and information through our website (http://coweeta.ecology.uga.edu), the use of which has more than doubled each year since going on line in 1996 (see **Table V.1**). The number of computers accessing our website between 1997 and 2002 increased on average 157% each year while the number of “hits” increased 170% each year. We anticipate the use-trend of our website to continue upward as we make available an increasingly diverse array of information as described in **Section 4**.

Table V.1. Coweeta website use.

Year	# Computers	# Hits
1997	5,756	51,761
1998	8,413	100,546
1999	15,708	190,022
2000	27,340	294,026
2001	33,225	417,761

In addition to digital information, we will continue distributing publication reprints on demand, which is a Forest Service cost-share to the Coweeta LTER project (includes staff time, and copying and postage expenses). We anticipate requests similar to those received in 1996-2002 when we sent out each year: 900 publication reprints, 1000 Coweeta LTER brochures, 200 site maps, and reprints of our popular magazine articles (e.g., Koppes 1998).

V.D. Making Research Relevant to Society

All previously described outreach and education activities as well as our Schoolyard LTER are carried out by project scientists and staff in addition to their primary responsibilities. As a direct outgrowth of the research we propose in **Initiative 3** of developing explicit forecast scenarios, we have taken the first step toward obtaining full-time support for an outreach and education coordinator. This person would ensure the Coweeta LTER program could achieve the goal of **Initiative 3** of moving from hypothesis testing to real-world applications including conservation planning, landscape management and design, and the assessment of future potential changes. The coordinator would take over responsibility of our Schoolyard LTER program and increase its impact through teacher training programs, public research and education presentations, and land manager workshops. They would also carry forward our emerging collaborations with the University of Georgia Museum of Natural History and the Macon County (North Carolina) Historical Society. We are finalizing creation of a "Coweeta Foundation" account through the University of Georgia that would allow us to receive grant money as well as private donations (the account is governed by a joint UGA and USFS committee). This is the necessary mechanism at our institution to support a full-time outreach and education coordinator, and once this step is taken we will begin to actively seek funding for the position. Initial contacts have already been made with several regional funding organizations.

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Supplementary Document

Table S.1. Publications resulting from 1996-2002 Coweeta LTER funding (DEB-9632854).

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Supplementary Document
Table S.2. Coweeta LTER Online Data Listing.

Data Description	Records	Funding Source*	Investigator(s)	Availability**
Coweeta Climate	Feb 1935 - Present	USDAFS	L.W. Swift, Jr.	Type I
Streamflow for Watershed 8	Oct 1934 - Present	USDAFS	L.W. Swift, Jr.	Type I
Streamflow for Watershed 18	Jul 1936 - Present	USDAFS	W.T. Swank	Type I
Streamflow for Watershed 27	Nov 1946 - Present	USDAFS	W.T. Swank	Type I
Precipitation Chemistry	Feb 1972 - Present	USDAFS, LTER	W.T. Swank	Type I
Salamander Population Estimates	Sep 1976 - Present	UNC	H. Wiley et al.	Type I
Dissolved C in WS7, 14, and 27 Streams	Jul 1979 - Present	NSF, LTER	J.L. Meyer	Type I
Atmospheric Deposition	Apr 1981 - Present	NADP	NADP	Type I
Elevational Gradient Microclimate	Aug 1991 - Present	LTER	L.W. Swift, Jr.	Type I
Franklin, NC Climate	Feb 2000 - Present	LTER	B.D. Kloeppel	Type I
Tree Allometry	Jun 1997 - Aug 1997	LTER	B.D. Kloeppel	Type I
Forest Patch Size	Apr 1995 - Dec 1996	LTER	S.M. Pearson	Type I
Litterfall on the Elevational Gradient (6)	Dec 1995 - Apr 1996	LTER	D.A. Crossley Jr. et al.	Type I
Litterfall on the Elevational Gradient (5)	Nov 1995	LTER	D.A. Crossley Jr. et al.	Type I
Litterfall on the Elevational Gradient (4)	Oct 1995	LTER	D.A. Crossley Jr. et al.	Type I
Litterfall on the Elevational Gradient (3)	Aug 1995 - Sep 1995	LTER	D.A. Crossley Jr. et al.	Type I
Litterfall on the Elevational Gradient (2)	Aug 1994 - May 1995	LTER	D.A. Crossley Jr. et al.	Type I
Litterfall on the Elevational Gradient (1)	Oct 1992 - Feb 1993	LTER	D.A. Crossley Jr. et al.	Type I
Seasonal Dynamics of Fine Root Length	Jul 1994 - Jul 1995	LTER	B.L. Haines	Type I
Fine Root Length	Jul 1994 - Jul 1995	LTER	B.L. Haines	Type I
Litter Decomposition	Dec 1993 - Sep 1995	LTER	D.C. Coleman	Type I
Nitrogen Transformation	May 1991 - Jan 1995	LTER	J.D. Knoepp	Type I
Root Mass	Jul 1993 - Jul 1994	LTER	B.L. Haines	Type I
Annual Rates of Fine Root Dynamics	Jul 1993 - Jul 1994	LTER	B.L. Haines	Type I
Microbial Biomass	1994	LTER	D.C. Coleman	Type I
Microhabitat Stream Fishes	Jun 1983 - Dec 1989	LTER	G.D. Grossman	Type I
Gap Regeneration Characteristics	Jul 1988 - Oct 1988	USDAFS, LTER	B.D. Clinton	Type I
Gap Regeneration Seedling	Jul 1988 - Oct 1988	USDAFS, LTER	B.D. Clinton	Type I
Remeasurement of 25 Selected Plots	Jul 1988 - Oct 1988	USDAFS, LTER	B.D. Clinton	Type I

Tree Diameters for Dead and Live Stems	Jul 1988 - Oct 1988	USDAFS, LTER	B.D. Clinton	Type I
Pre-Cut Lysimeter and Throughfall Data	Feb 1975 - Oct 1986	LTER	B.L. Haines	Type I
Post-Cut Lysimeter and Throughfall Data	Feb 1975 - Oct 1986	LTER	B.L. Haines	Type I
Nitrification with Forest Floor Extracts	Oct 1985 - Oct 1985	LTER	B.L. Haines	Type I
Nitrification and Leaching	Apr 1984 - Jul 1984	LTER	B.L. Haines	Type I
Nitrification in WS6 and WS14	Apr 1984 - Apr 1984	LTER	B.L. Haines	Type I
Nitrification: Glucose and NH4 Additions	Jun 1984	LTER	B.L. Haines	Type I
Nitrification WS6 and WS12 Soil Density	Jul 1984	LTER	B.L. Haines	Type I
In Situ Incubations (Buried Bags)	Apr 1984 - May 1984	LTER	B.L. Haines	Type I
Clearcut Renegeration Study	Jul 1977 - Apr 1984	LTER	B.L. Haines	Type I
Soil Solution Nitrogen in Watershed 7	Jul 1983 - Sep 1984	LTER	B.L. Haines	Type I
Nitrification with Black Locust Leachate	Oct 1984	LTER	B.L. Haines	Type I
Nitrification WS6 and WS14 Forest Floor	Oct 1984	LTER	B.L. Haines	Type I
Nitrification Ammendments in WS14	Oct 1984	LTER	B.L. Haines	Type I
Nitrification WS6 and WS14 NH4 Control	Oct 1984	LTER	B.L. Haines	Type I
Nitrification Potential in Watershed 7	May 1983 - Nov 1983	LTER	B.L. Haines	Type I
Nitrification: WS2 and WS7 Comparison	Nov 1979 - Jun 1983	LTER	B.L. Haines	Type I
Nitrification Potentials in Forest Stands	Oct 1983 - Nov 1983	LTER	B.L. Haines	Type I
Woody Vegetation Survey	Jun 1982	LTER	B.L. Haines	Type I
Woody Litter: C. Oak Study (0-3 cm)	Jan 1977 - Jan 1978	LTER	D.A. Crossley Jr.	Type I
Woody Litter: C. Oak Study (3-5 cm)	Jan 1977 - Jan 1978	LTER	D.A. Crossley Jr.	Type I
Arthropods Dynamics in Clearcut Forests	May 1977 - Oct 1978	LTER	D.A. Crossley Jr.	Type I
Ecology of Stream Invertebrates	Jan 1977 - Sep 1978	LTER	J.B. Wallace	Type I
Defoliation Estimates of Chestnut Oak	Jan 1975 - Jan 1976	LTER	B.L. Haines	Type I
Tree Survey of WS7 Pre-Clearcutting	Jan 1975 - Dec 1975	LTER	W.T. Swank	Type I
Hydrologic Transport Of Elements	Jan 1969 - Jan 1974	LTER	R. Best	Type I
Litterfall	Aug 1972 - Jan 1974	LTER	J.R. Webster	Type I
Drift Detritus, 24 Hour Samples	May 1973 - Jan 1974	LTER	J.R. Webster	Type I
Insect Drift, 24 Hour Samples	Sep 1972 - Jan 1974	LTER	J.R. Webster	Type I
Surber Stream Water Samples	Sep 1972 - Jan 1974	LTER	J.R. Webster	Type I
Nutrient Concentrations in Vegetation	Mar 1972 - Jun 1974	LTER	F. Day	Type I
Insect Emergence	Jun 1972 - Aug 1973	LTER	J.R. Webster	Type I
Stream Detritus	Oct 1972 - Aug 1973	LTER	J.R. Webster	Type I

Population Density of Small Mammals	Sep 1970 - Sep 1973	LTER	D.A. Crossley Jr.	Type I
Small Mammal Physical Data	Sep 1970 - Sep 1973	LTER	D.A. Crossley Jr.	Type I
Tree Dendrometer Bands	Nov 1973 - Mar 1973	LTER	F. Day	Type I
Kalmia and Rhododendron Gas Exchange	Mar 1973 - Aug 1973	LTER	E.L. Dunn	Type I
Forest Floor Dyamics: Lab Soil Data	Aug 1972 - Jul 1973	LTER	J.D. Yount	Type I
Tree Population Age Structure	Jun 1972 - Aug 1972	LTER	E. Franz	Type I
Litter Dynamics in Pine and Hardwood	Sep 1969 - Sep 1972	LTER	C.D. Monk	Type I
Population Var.of Litter Macroarthropods	Sep 1971 - Sep 1972	LTER	D.A. Crossley Jr.	Type I
Population Par. of Litter Microarthropods	Sep 1971 - Sep 1972	LTER	D.A. Crossley Jr.	Type I
Tree Increment Cores	Oct 1972 - Oct 1972	LTER	F. Day	Type I
Leaf Surface Area	Apr 1972 - Oct 1972	LTER	F. Day	Type I
Nutrient Concentrations of Stream Fauna	Nov 1970 - Jul 1971	LTER, UGA	J.B. Wallace	Type I
Forest Floor Dynamics: Comp. Soil Data	May 1970 - May 1971	LTER	J.D. Yount	Type I
Forest Floor Dynamics: Lab Litter Data	May 1970 - Sep 1971	LTER	J.D. Yount	Type I
Forest Floor Dynamics: Comp. Litter Data	May 1970 - Sep 1971	LTER	J.D. Yount	Type I
Hydrology Transport of Elements	Oct 1969 - Nov 1970	LTER	R. Best	Type I
Tree Stems < 1 inch DBH	Jun 1970 - Sep 1970	LTER	F. Day	Type I
Tree Stems >= 1 inch DBH	Jun 1970 - Sep 1970	LTER	F. Day	Type I
Stems of Plants < 1 foot Tall	Jun 1970 - Sep 1970	LTER	F. Day	Type I
Litter Dynamics on Watershed 18	Jun 1970 - Aug 1970	LTER	C.D. Monk	Type I
Litter Dynamics on Hardwood Litter	Jun 1970 - Aug 1970	LTER	C.D. Monk	Type I
Population Densities of Stream Fauna	Aug 1968 - Jun 1969	LTER, UGA	J.B. Wallace	Type I
Seedling Recruitment in Artificial Gaps	Jun 1993 - Present	NSF, LTER	B. Beckage et al.	Type II
Tree Growth-Mortality Relationships	Jun 1995 - Present	NSF, LTER	P. Wyckoff et al.	Type II
Tree Seedling Densities across Gradient	Jun 1996 - Present	NSF, LTER	J. HilleRisLambers et al.	Type II
Seed Bank Densities across Gradient	Jun 1995 - Present	NSF, LTER	J. HilleRisLambers et al.	Type II
Joyce Kilmer Forest Microclimate	May 1996 - Present	LTER	B.D. Kloeppel	Type II
Coweeta WS02 Tree Stem Temperature	Oct 1996 - Present	LTER	B.D. Kloeppel et al.	Type II
Coweeta WS18 Tree Stem Temperature	May 1996 - Present	LTER	B.D. Kloeppel	Type II
Coweeta WS27 Tree Stem Temperature	Oct 1996 - Present	LTER	B.D. Kloeppel et al.	Type II
Gradient Dendrometer Bands	Jul 1992 - Present	LTER	J.M. Vose	Type II
Gradient Soil Moisture	Aug 1991 - Present	LTER	J.M. Vose	Type II
Terrestrial Gradient Tree Growth	1991 - Present	LTER	J.S. Clark et al.	Type II

Forest Gap Microclimate	May 1993 - Present	LTER	J.M. Vose et al.	Type II
Forest Gap Dendrometer Band	Apr 1992 - Present	LTER	J.M. Vose et al.	Type II
Forest Soil Moisture at Coweeta Sites	Jan 2000 - Present	NSF	B.D. Kloeppel et al.	Type II
Riparian Microclimate	Jun 1992 - Present	LTER	J.A. Yeakley	Type II
Fish Collections at Coweeta 100m Sites	Sep 1991 - Present	LTER	R.E. Ratajczak et al.	Type II
Habitat Availability of LTER Streams	Aug 1991 - Present	LTER	R.E. Ratajczak et al.	Type II
Riparian Soil Moisture	Jun 1992 - Present	LTER	J.A. Yeakley	Type II
Riparian Litter Decomposition	Jun 1992 - Present	LTER	D.C. Coleman et al.	Type II
Riparian Soil Water Chemistry	Mar 1993 - Present	LTER	J.A. Yeakley	Type II
Acclimation Common Garden Microclim.	Jan 1999 - Present	NSF, LTER	B.D. Kloeppel et al.	Type II
Watersheds 1 and 17 White Pine Survey	May 2001 - Jul 2001	LTER	A.R. Cooper et al.	Type II
Land Snail Diversity at Forested Sites	Jul 1997 - Dec 2000	LTER	S.M. Pearson et al.	Type II
Crayfish Breakdown of R. max. Litter	Jul 1999 - Nov 1999	LTER	K.A. Schofield et al.	Type II
Algal and Detrital-Based Food Webs	Aug 1997, Nov 1999	LTER	K.A. Schofield et al.	Type II
R. Maximum Cover across Gradient	Jun 1997 - Jun 1999	NSF, LTER	J. HilleRisLambers et al.	Type II
Riparian Stream Dissolved Organic C	Jun 1992 - Oct 1999	LTER	J.A. Yeakley	Type II
Forest Gap Soil Moisture	May 1993 - May 1998	LTER	B.D. Clinton	Type II
Soil Respiration on Gradient Sites	Jun 1997 - Dec 1998	LTER	B.C. Reynolds et al.	Type II
Soil Respiration (Resin Bags) on Gradient	Apr 1998 - Nov 1998	LTER	B.C. Reynolds et al.	Type II
Nematodes in Canopy Gradient Sites	Feb 1997 - Aug 1998	LTER	B.C. Reynolds et al.	Type II
Nematode Functional Groups on Gradient	May 1998 - Sep 1998	LTER	B.C. Reynolds et al.	Type II
Litter Decomposition in Gradient Plots	Dec 1996 - Dec 1998	LTER	B.C. Reynolds et al.	Type II
Nematode Litterfall on Canopy Plots	May 1998 - Sep 1998	LTER	B.C. Reynolds et al.	Type II
Flood Organic Matter Dynamics	Sep 1997 - Sep 1998	LTER	M. Neatrour et al.	Type II
Top-Down Interactions in Streams	Aug 1997, Jul 1998	LTER	K.A. Schofield et al.	Type II
Litterfall on the Elevational Gradient	May 1996 - May 1998	LTER	D.A. Crossley, Jr. et al.	Type II
Litterfall on the Elevational Gradient	Dec 1995 - Apr 1996	LTER	D.A. Crossley, Jr. et al.	Type II
Litterfall on the Elevational Gradient	Nov 1995	LTER	D.A. Crossley, Jr. et al.	Type II
Litterfall on the Elevational Gradient	Oct 1995	LTER	D.A. Crossley, Jr. et al.	Type II
Litterfall on the Elevational Gradient	Aug 1995 - Sep 1995	LTER	D.A. Crossley, Jr. et al.	Type II
Litterfall on the Elevational Gradient	Aug 1994 - May 1995	LTER	D.A. Crossley, Jr. et al.	Type II
Gradient Throughfall Collection	Jul 1992 - Nov 1997	LTER	W.T. Swank	Type II
Forest Gap PAR	May 1993 - Aug 1996	LTER	B.D. Clinton	Type II

N Transformation along Gradient	May 1991 - Jan 1995	LTER	J.D. Knoepp	Type II
Fine Root Dynamics along Gradient	Jul 1993 - Jul 1995	LTER	J.P. Davis et al.	Type II
Riparian Microbial Biomass	Mar 1994 - Dec 1994	LTER	D.C. Coleman et al.	Type II
Litterfall on the Elevational Gradient	Oct 1992 - Feb 1993	LTER	D.A. Crossley, Jr. et al.	Type II
Leaf Decomposition in Ball Creek	Nov 1991 - Jul 1992	LTER	E.F. Benfield et al.	Type II
Benthic Organic Matter in Ball Creek	Apr 1991 - Jul 1992	LTER	E.F. Benfield et al.	Type II
Geomorphology of Ball, Coweeta Creek	Jul 1989 - Jul 1989	LTER	J.R Webster et al.	Type II

* Funding Source Codes: LTER = Coweeta LTER Program, USDAFS = United States Department of Agriculture Forest Service, UNC = University of North Carolina, NADP = National Atmospheric Deposition Program, UGA = University of Georgia, NSF = National Science Foundation (Non-LTER)

** Online Availability Codes: Type I = Data Publicly Accessible, Type II = Data Password Accessible to Project Personnel